Brain Waves, A Cultural History: Oscillations of Neuroscience, Technology, Telepathy, and Transcendence

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ABSTRACT

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This project proceeds from a narrow question: What, if anything, is a *brain wave?* Beguiling in its simplicity, this question prompts a cultural-historical investigation that spans over 150 years of science, technology, and society. Proposed in 1869, the original theory of brain waves cites etheric undulations to explain reports of apparent thought transference. Though most modern thinkers no longer believe in outright telepathy, I argue that dreams of thought transmission and other mental miracles subtly persist—not in obscure and occult circles, but at the forefront of technoscience.

A hybrid of science and fiction, brain waves represent an ideal subject through which to explore the ways in which technical language shrouds spiritual dreams. Today, the phrase "brain waves" often function as shorthand for electrical changes in the brain, particularly in the context of technologies that purport to "read" some aspect of mental function, or to transmit neural data to a digital device. While such technologies appear uniquely modern, the history of brain waves reveals that they are merely the millennial incarnation of a much older hope—a hope for transmission and transcendence via the brain's emanations.

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I wrote most of this dissertation in my pajamas. Well, pajamas and sweatpants. If I added up all the hours that I worked on this piece in "real" clothes, I think it would account for about 10% of the process, tops. For though I had to leave my apartment every so often to gather bits of research, the bulk of the effort was an at-home deal. In some respects, this was a great luxury: though technically hard at work, I have been sitting on my couch for months. Yet, this sort of secluded, sedentary life complicates the task of being a person—a happy-ish, sane, sociable, showered person. If it were up to me, I imagine that I would have spent the entire process by myself, straining my brain and my laptop until one of them crashed irreparably. Thus, insofar as I have finished the dissertation and maintained a shred of sanity, I must thank the incredible people who accompanied me on this journey.

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Chapter 1. Introduction: Wave Hello

The human skull is remarkably durable. Among body parts, only tooth enamel rivals the cranium in terms of sheer hardness. More than a secondary surface off which to bounce soccer balls, the skull confers obvious biological benefits. Chiefly, it keeps the brain safe. For good measure, crania also contain cerebrospinal fluid, which, among other things, serves as a sort of shock absorber, ensuring that the brain doesn't smash into its hard casing when things get rough. Doubly insulated, brain matter makes physical contact with the outside world under only the most extreme circumstances.

Though cortical tissue doesn't regularly touch the space beyond the skull, the brain seems well aware its surroundings. Indeed, the organ warrants extreme protection *because* of its ability to intelligently perceive and respond to its environment. Responsible for cognition, emotion, memory, and so forth, the brain must remain intact for the rest of the body to be of any use. Given as much, one might presume: the more protection, the better. Yet, to call a person *thick-skulled* hardly resonates as a statement of admiration. Rather, the term—which dates back to the seventeenth century—denotes stupidity.[1]

In the course of a frustrating conversation, one may yell, "Get it through your thick skull"—the implication being that the brain casing of a second party is so darn thick that knowledge cannot penetrate her cortical tissue and her consciousness. Yet, the charge is as unfair as it is figurative. Even the smartest brain can neither deliver nor receive information directly through the scalp. Brains don't communicate, *people* communicate.

Using our gestures and clumsy language, we relay coarse approximations of our intent and hope that these messages spark some understanding in a conversational counterpart.

Communication does not guarantee that brain number two will experience anything close to the subjective state of brain number one. If the skull contains the brain, and the brain contains the mind, then our psyches are fated to isolation—and ultimately, termination. For even when the mind imagines distant worlds, the brain remains locked in place, tethered to a body with a looming expiration date. In the end, the skull turns out to be a hardy piece of armor, but an imperfect protector. Brain tissue begins to decay almost immediately following death; and, in a morbid joke, the skull stays intact for tens to thousands of years, guarding sacred matter that no longer exists.

The grim fate of brains doesn't bode well for the longevity of minds—that is, presuming one holds a monist stance on the whole mind-brain situation. Folks inclined to believe in an immaterial spirit, however, may contend that the mind needn't perish with the body—that a skull no more confines consciousness than a laptop confines the internet. This type of dualism has its perks. Unbound to brain matter, a soul can perform all manner of fancy tricks, perhaps making contact with other souls and surviving for eternity. In this way, religion tends to eschew the permanence of death and the finite bounds of bodies. Science, however, typically doesn't trade in immateriality and eternity. Science demands meticulous measurement of material phenomena. Belief in a mind beyond body thus appears incongruous with any properly empirical account of the self. Yet, science has its loopholes.

To the empirically inclined, *reality* comprises not just those events to which our senses can attest, but also those recorded by machines. Telescopes, for example, bring into view impossibly distant stars—a glimpse of the heavens via technological intervention. Scientific tools also make knowable more local phenomena, such as the electromagnetic (EM) waves that apparently flow around and through our bodies. In this sense, there exists a gap between common experience and experimental artifacts. Put another way: scientific enlightenment requires an element of faith.

EM fields, like god, do not present visibly; yet, we trust that they underlie the cohesion of the universe. And, like scripture, the arc of technological innovation offers hope for salvation. One day, scientists may figure out how to sustain life on distant planets; doctors may develop techniques that render death obsolete; and technologists may learn to read minds by reading brains. The future, like the afterlife, is not falsifiable.

In what follows, I interrogate the ways in which spirituality subtly manifests in technologic and scientific discourse. Specifically, I explore how the mind has been thought to escape the harsh imprisonment of the skull via the power of something called *brain waves.* Proposed in 1869, the original theory of brain waves cites etheric undulations to explain reports of apparent thought transference. Though few modern thinkers any longer believe in spontaneous telepathy, dreams of mind reading and other mental miracles persist—not in obscure and occult circles, but at the forefront of technoscience. Part experimental artifact, part fantasy, brain waves offer insight into the ways in which spiritual desires penetrate our understanding of—and hopes for—scientific progress.

So. What *Is* a Brain Wave?

brain wave, *n.*

1. A (supposed) telepathic wave emanating from the brain…

2. A fluctuation of electrical potential in the brain, as measured by electroencephalography.

—Oxford English Dictionary[2]

Officially, the term *brain wave* has two definitions. The first amounts to fantasy—an imagined medium that carries thoughts from brain to brain, skulls be damned. The second definition refers to the practice of electroencephalography (EEG), which is to say, boring old technoscience.

Plenty of words possess dual meanings. However, detangling the above definitions proves more difficult than clarifying, "No no, I meant squash the *gourd,* not the sport." For the history of brain wave discourse reveals not two distinct referents, but a spectrum of conceptually related phenomena. On one end of the spectrum lies EEG (pure technoscience); on the other end lies telepathy (pure fiction). Usage of the term tends to fall somewhere between these extremes: modern brain wave discourse often relates to empirical research, while also accommodating a hint of hooey. The intrigue of "brain waves," I will argue, depends on this strange confluence of reality and fantasy. EEG research grants the term authority and legitimacy; and an implicit association with mental magic imbues such research with an appeal beyond standard studies in electrophysiology.

Invented by psychiatrist Hans Berger in the 1920s, EEG refers to the process by which electrodes placed along the scalp monitor changing electrical potentials within the brain. At rest, a neuron is said to be polarized—the inside of the cell has a negative charge as compared to the outside of the cell. When a neuron "fires," charged particles (ions) move across its membrane, resulting in a net *de*polarization. When many cells depolarize simultaneously, electrodes on the skull can detect this change; and when many cells fire in a rhythmic pattern, EEG charts reveal rising and falling voltages—scribbles that, indeed, warrant the name waves (though contemporary researchers tend to prefer "neural oscillations").

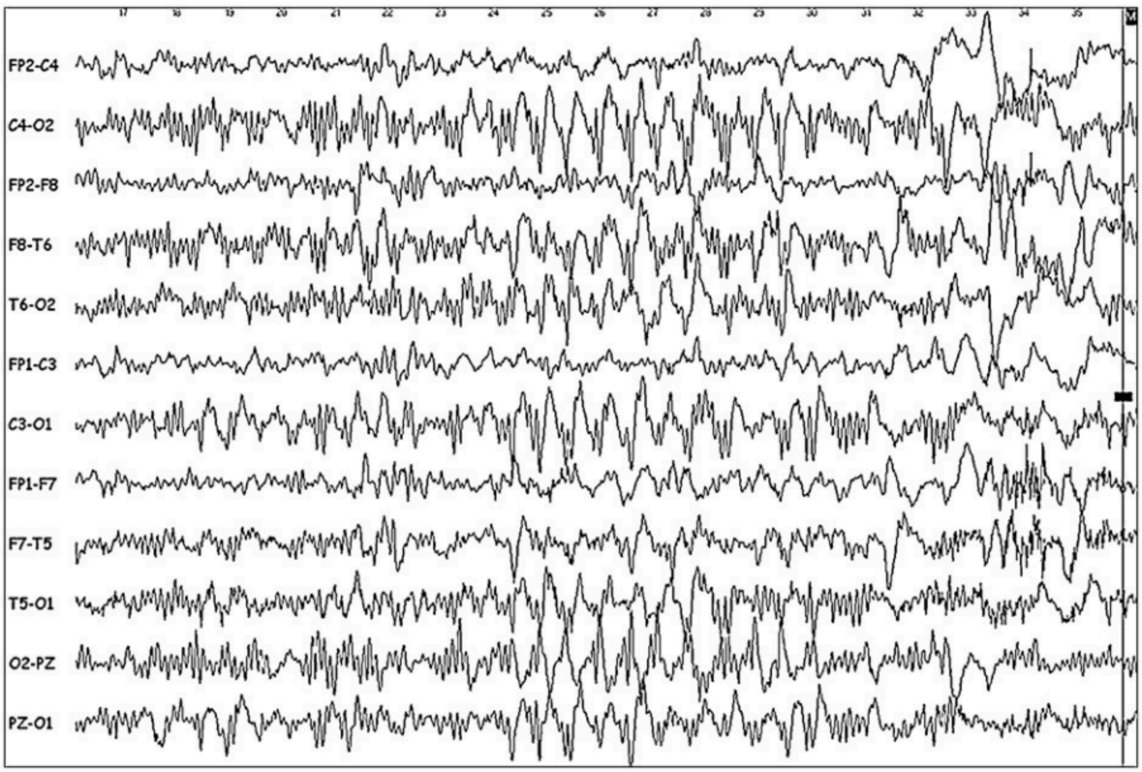

Figure 1. Sample EEG record. "Nine-year-old child. Awake state. Intermixed bilateral occipital slow waves preceded by a sharp wave." Each line of oscillations corresponds to electrical changes detected by a distinct electrode. Reprinted from Monika Eisermann et al., "Normal EEG in Childhood: From Neonates to Adolescents," *Neurophysiologie Clinique/Clinical Neurophysiology* 43, no. 1 (2013): 61.

EEG studies contribute to the understanding of a range of psychiatric conditions and cognitive functions, though sleep and epilepsy studies form the bread and butter of the field. The bulk of this research—like most research—is limited in scope and, pro forma, attracts only the attention of scientists in relevant fields. I state as much not to minimize the importance of EEG, but to stress that its graphs do *not* amount to transcripts of conscious thought. EEG, like electrocardiography (EKG), provides clinicians and scientists with sometimes-useful physiological data. It does not entail mind reading.

Still, the brain wave science that penetrates popular news has a distinct, sometimes telepathic, pizazz. Consider the following headlines (all run between 2016 and 2018):

> "Did You Know That The Military Wants To Read Your Brain Waves?"[3]
>
> "Controlling Electronic Devices with Brain Waves"[4]
>
> "Nissan Car Technology Will Read Drivers' Brain Waves"[5]
>
> "Study Finds Hackers Could Use Brainwaves to Steal Passwords"[6]
>
> "How Companies Will Use VR and Read Your Brainwaves to Sell You More Stuff"[7]

The target audience for such headlines, no doubt, extends beyond sleep and epilepsy researchers, or their subjects. Indeed, EEG news receives a sensationalist treatment not present among most accounts of E*K*G research. After all, no one ever talks about reading "heart waves," as adorable as they sound. For even when the heart murmurs, it doesn't have much to say. The brain, however, uniquely evokes the mind and its effusive stream of consciousness. And waves denote movement—a rippling outward. Together, these words seem to suggest the mobilization of mental content. Thus, technologies that purportedly track or read brain waves make headlines because they appear to imply the transmission of *thought.*

I am not suggesting that twenty-first century readers interpret brain wave news according to definition one, "telepathic wave[s] emanating from the brain." Rather, I contend that modern usage of the term conflates its realistic and fantastic definitions, resulting in a fuzzy understanding that falls somewhere in the middle of the spectrum outlined above. Though journalists seem to exploit the intrigue of "brain waves," I do not blame writers for confusing the term's two definitions; nor do I blame readers for misunderstanding what or where brain waves are. As I will show, the nebulousness of the term derives not simply from modern definitional conflation, but from the historic interplay of brain wave science and fiction.

A telepathic reading of brain wave news does not pervert the term's true connotation, but rather reflects the intent of its originator. In 1869 James Thomas Knowles coined the term in a letter, published by *The Spectator,* in which he describes the brain as "a centre of undulations transmitted from it in all directions through space." He asks, "Why might not such undulations, when meeting with and falling upon duly sensitive substances… produce impressions, dim portraits of thoughts, as undulations of light produce portraits of objects?"[8] Importantly, Knowles's letter preceded the development of EEG by half a century, giving the term's telepathic connotation a healthy head start. When news of Berger's invention garnered press coverage during the 1930s, many journalists referred to the machine's undulations as "brain waves;" but as the term absorbed a new scientific authority, it did not shed its fanciful flavor.

Knowles and Berger at first appear to represent two distinct traditions, corresponding to the two definitions above. Yet, these seemingly separate breeds of brain wave share more than a name—again, this isn't squash. First, the theories of Berger and Knowles rely on similar assumptions about neurophysiology. When Knowles proposed his brain waves, he posited that "whensoever any action takes place in the brain, a chemical change of its substance takes place also…An electric manifestation is the likeliest outcome of any such chemical change, whatever other manifestations may also occur."[9] Sixty years later, Berger detected such an electrical manifestation and found the dynamics thereof to be quite oscillatory. In this sense, Berger produced empirical evidence for at least part of Knowles's theory.

Second, though Berger eventually rejected telepathic interpretations of EEG, his work was initially motivated by a telepathic experience of his own (see Chapter 4). Moreover, the popularization of Berger's research depended, in part, on whimsical speculations about brain waves—thus instigating a symbiosis of brain wave fact and fantasy. EEG aided the survival of the term "brain wave," elevating its status from psychical lore to demonstrable science; and, in turn, the term's seduction imbued EEG research with a distinct allure.

Third, EEG research functions on two provocative premises that also underlie Knowlesian waves. Namely, EEG proceeds from an assumption that (1) traces of brain activity escape the skull; and (2) these traces reveal something meaningful about the goings-on of the brain. Changing potentials within the brain affect the movement of electrons (within electrodes) on the other side of the skull. Thus, though EEG studies do not corroborate the view that brains emit thought undulations, traces of brain activity do indeed transcend the cortex. And EEG charts are *meaningful* insofar as physicians and researchers find them useful (which they do).

That is not to say that Knowles's views and Berger's views are equivalent. Crucially, whereas Knowles imagined his waves to exist *out there* in a "universal, impalpable, elastic 'Ether,'" Berger's waves amount to marks on a graph.[10] Yet, again, this distinction is less stark than it appears. Though the neuroscientist understands EEG to measure local (intra-brain) changes, the physicist may note, "Ah, but cell depolarization is an electrical phenomenon! This process therefore entails the radiation of *electromagnetic* waves from the brain outward! Waves *do* exist out there!" The physicist, in her physicist's way, has a point: electrical changes in the brain do make a miniscule EM dent on the universe. Thus, while modern science does not support Knowles's telepathic claims, modern science *does* support the notion that chemical activity in the brain yields an "an electric manifestation" that ripples through space.

Finally, though Knowles's 1869 letter does not appear in many (any?) histories of neuroscience, his vision of brain waves may guide the future of the field. For the term's telepathic connotation represents a longing—a wish for thought transference, and transcendence from biological matter. And, as neurotechnology advances, researchers are beginning to *build* technologies that satisfy this wish. Consider, for example, a Bluetooth-enabled EEG headset capable of transmitting brain data from skull to smartphone.[11] Such devices exist; and such devices do, in a sense, read and relay brain waves. Indeed, with the development of novel neurogadgets, the dream of mobile mental impressions obtains new plausibility. In this way, the interaction between Knowlesian and Bergerian brain waves surpasses semantic muddling.

Our brains can't broadcast their tremors with the precision that Knowles had hoped. Yet, the skull does *not* fully insulate the activity of the brain—a scientific detail that opens up a world of real and imagined possibilities.

Within a Larger Wave of Brains

In the twenty-first century, neuroscience offers a sexy, scientific framework through which to understand oneself and one's fellow humans. A subscriber to pop-neuroscientific creed may come to believe, for example, that nasty mood swings arise from an unfavorable balance of brain chemicals, and that psychopathic tendencies result from maladaptive wiring or firing in key brain regions. This genre of neuroscience satisfyingly codifies people according to material features of the brain, and thus makes for punchy headlines. However, such codification holds nontrivial social implications, and thus becomes an easy target for accusations of neuroreductionism and neurocentrism—accusations implying that people are more complex than their brain matter and that neuroscience fails to acknowledge as much.

Colorful neuroimages garner particularly loud critiques from anti-reductionist camps, which have been vocal since the early 2000s. Joseph Dumit's *Picturing Personhood* (2004), for example, challenges the assumption that one can infer mental illness from pictures yielded by positron emission tomography (a type of brain scan).[12] Dumit's ethnography interrogates the production and reception of these "extreme images," considering their sway in perceptions of disease and identity. Currently, popular derision and cultural analysis of neuroimaging largely targets functional magnetic resonance imaging (fMRI)—another brain scanning technique. Though critics often acknowledge that fMRI holds some empirical value, they stress that neuroimaging studies can oversimplify social and psychological phenomena, particularly when their findings are diluted or exaggerated by popular news outlets.

For example, in *Brainwashed: The Seductive Appeal of Mindless Neuroscience* (2013) authors Sally Satel and Scott Lilienfeld write:

> Naïve media, slick neuroentrepreneurs, and even an occasional overzealous neuroscientist exaggerate the capacity of scans to reveal the contents of our minds, exalt brain physiology as inherently the most valuable level of explanation for understanding behavior, and rush to apply underdeveloped, if dazzling, science for commercial and forensic use.[13]

As the discipline of neuroscience grows and matures, critical engagement with its methods and discourses matures in kind. Analyses of this variety now qualify as "Critical Neuroscience," a field formalized via a 2012 handbook by that name. Editors Suparna Choudhury and Jan Slaby state that Critical Neuroscience seeks to "respond to the impressive and at times troublesome surge of the neurosciences, without either celebrating it uncritically or condemning it wholesale."[14] They continue:

> Situated between neuroscience and the human sciences, our notion of critical neuroscience uses a historical sensibility to analyze the claim that we are in the throes of a "neurorevolution" since the beginning of the Decade of the Brain in 1990. It investigates sociologically the motivations and the implications of the turn to the *neuro* in disciplines and practices ranging from psychiatry and anthropology to educational policy, and it examines ethnographically the operationalization of various categories in the laboratory. Investigating the historical and cultural contingencies of these neuroscientific categories, critical neuroscience analyzes the ways in which, and conditions through which, behaviors and categories of people are naturalized.[15]

The present project similarly situates brain science with respect to the cultural conditions of its production-reception and, in that respect, finds precedent in the Critical Neuroscience literature. Yet with its gaze directed towards shiny images and potent brain chemicals, said literature tends to miss the waves featured herein. Indeed, the historical analysis I offer addresses a facet of brain research and discourse largely neglected among cultural critiques of the field.

This neglect is, to a certain extent, understandable. Pushback against brain scans tends to involve resistance to reducing the complexity of personhood to a three-pound blob of fat. Given that brain *waves* don't resonate as fatty matter, they seem an awkward target for accusations of reductionism. Yet, I will argue, the uncertain materiality of brain waves in fact contributes to their cultural appeal—and thus warrants close critical attention.

Though the tactics of Critical Neuroscience feature in what follows, the present discussion somewhat strays from the mandate of the discipline, as defined by Choudhury and Slaby—in part, because the history of brain waves begins long before the Decade of the Brain. Though I do not contest the notion of a "neurorevolution," I argue that the analysis of modern neuromania benefits from a broader historical frame. After all, the brain's charisma long precedes technologies that depict the organ in flamboyant portraiture.

During the mid-nineteenth century, when the story of brain waves begins, there existed neither a field of Neuroscience nor a theory of neurons. Yet scholars and laypersons with questions about the mind nonetheless consulted (pseudo)sciences of the brain. Practitioners of phrenology, for example, purported to determine the character of their subjects by surveying their scalps for telling bumps. This approach assumes that each patch of cortical landscape yields unique intellectual fruits, and thus has a certain agrarian charm. Yet, in the same way that the telegraph sparked globalization and growing estrangement from the land, so too did it inspire neural metaphors that traded geography for connectivity. The telegraph offered a model for thinking of the brain not simply in terms of its *matter*, but in terms of its *messages*. The etymological proximity of telegraphy and telepathy, of course, is no coincidence.

Brain waves and telepathy do not tend to play prominent roles in cultural critiques of neuroscience. Superficially, the "science" of thought transmission has no bearing on modern brain research because, well, telepathy is bogus. Yet, phrenology is equally bogus, and still, this antiquated endeavor often receives a strategic nod in Critical Neuroscience literature: the folly of scalp readers serves handily as a cautionary tale for modern brain scan enthusiasts. Bao and Pöppel, for example, warn: "An uncritical use of new imaging technology may open the door to a new kind of old fashioned phrenology, i.e. looking at specific areas only and neglecting the interconnectivity of a neuronal network."[16] Similarly, Rose refers to "a localization problem that has dogged neuroscience ever since the days of phrenology."[17]

In recent years, a number of scholars have revived phrenology, not due to an interest in the past, but to address a "localization problem" in the present. This exercise makes good sense: historic missteps in research, as in politics, should inform practitioners as to how to avoid analogous missteps in the future, or how to interpret contemporary phenomena. Yet, just as fMRI does not exhaust the whole of modern neuro-culture, neither should excavation of neuro-history end with head bumps. In this spirit, I propose that past beliefs about telepathy and brain waves can provide critical context for analyzing current trends in neurotechnology and popular interpretations thereof. Indeed, just as brain scan skeptics call forth phrenology as a response to modern fMRI hype, my interest in the origins of brain waves initially grew from annoyance with wavily misleading claims in contemporary pop-science literature.

Whereas fMRI may be phrenology under a different name, the name of brain waves remains intact; and the longevity of the term renders the brain wave a fruitful, if quirky, protagonist around which to form a narrative about the intersection of science, technology, and culture. My goal in tracing brain waves is not to mock the ridiculousness of bogus beliefs. Rather, I aim to illuminate why and how wavy theories become attractive in the first place. By looking at the connotations and uses of brain waves since the nineteenth century, I hope to identify the cultural desires to which such theories speak. Brain waves, I contend, satisfy a desire to distill mind from matter and message from medium, thus preserving dreams of intimate mental union and corporeal transcendence.

Waves Out of Water

The realms of science and fiction, technology and theology, do not occupy distinct planes. Imagination informs invention. Rigorous research commands religious reverence. Though science and spirituality commingle in a variety of contexts, the history of brain waves serves as a particularly effective prism through which to view this sort of interplay. By virtue of their association with minds, brains tend to excite the imagination: the cultural intrigue of neuroscience exceeds that of, say, kidney science. Still, in the equation *brain + waves,* the latter term plays a nontrivial role. In fact, the mystique of brain waves depends, in large part, on the surprisingly slippery ontology of waves at large.

Indeed, the definitional conflation discussed above can be understood in terms of an ontological haziness that characterizes waves more broadly. Knowles framed his waves as undulations in ether—physical vibrations through a material medium. Berger's brain waves, on the other hand, refer to curves on a chart. In the latter case, real waves exist to the same extent that a pie chart denotes a "real" pie. That is, though EEG graphs summarize a genuine material phenomenon, their waves do not necessarily denote oscillations in or through a medium. Just as "pie" can refer to a scientific representation or to a real, delicious pastry, so too can a wave refer to an abstract dynamic or a tangible physical undulation. Unlike the case of pies, however, the diversity and complexity of waves in the universe confuses distinctions between scientific measurement and material reality.[18]

To begin with a (relatively) simple example, consider common ocean waves. One may treat such waves as distinct, agential objects, in the manner of, "*Get out the way, goofball! You're about to be hit by a wave!*" Yet, in the event of such a collision, the goofball finds herself covered in water—not waves. Here, waves do not amount to matter in their own right, but rather denote the dynamic movement *of* matter. Thus, even in the case of the ocean, wave ontology is less than straightforward.

Without qualification "a wave" tends to suggest the aquatic variety. And this familiar usage serves as a reference point for conceptualizing other sorts of waves. Such imagery, for example, allows one to visualize the transmission of sound: though one does not *see* sound, one can imagine sound waves rippling away from their source, in the manner of water moving in concentric circles after devouring a stone.

Sound waves, like ocean waves, involve vibrations in a material medium (such as air). In some cases, however, waves needn't refer to any particular medium at all. Sine waves, for example, possess defined mathematical properties, but are medium agnostic—they can exist in abstract space. Elsewhere, abstract waves are more poetic than mathematic. For instance, when one refers to a wave of sadness, no one assumes the presence of a despondent, oscillating liquid. This phrase, however, efficiently communicates a certain sentiment; it gets at some deep emotional reality.

Wavy graphs, like effective poetry, invent a relatable character (the wave) to convey a point. And just as the reader of poetic allegory does not mistake invented characters for real people, the scientist who keeps in mind the fictional aspects of models should not arrive at false conclusions. The electrophysiologist, for instance, understands that brain matter does not undulate in the manner of the ocean.

Yet, our pesky physicist friend will maintain that brain waves *do* produce genuine oscillations, albeit of the EM variety. Far from presenting a more conceptually concrete sort of brain wave, the introduction of EM science further complicates wave ontology. Sound and water both qualify as *mechanical* waves, meaning that they require a material substrate through which to travel. EM waves, however, can travel through a vacuum—*i.e. a space void of matter*. What, then, are these waves made of? Beyond materially elusive, EM waves may, in fact, amount to nothing more than poetry.

When James Clerk Maxwell first used the language of waves to describe electromagnetism in the mid-nineteenth century, he readily admitted the analogic nature of this work. He summarized his tactic as "a method to enable the mind to grasp some conception or law in one branch of science, by placing before it a conception or law in a different branch, and directing the mind to lay hold of that mathematical form which is common to the corresponding ideas."[19] Specifically, Maxwell applied to electromagnetism the rules of fluid dynamics—with much success. Still, for Maxwell, EM waves did not refer to a literal fluid any more than does the poet's wave of sadness. He writes:

> The substance here treated of must not be assumed to possess any of the properties of ordinary fluids except those of freedom of motion and resistance to compression. It is not even a hypothetical fluid…It is merely a collection of imaginary properties... The use of the word "Fluid" will not lead us into error, if we remember that it denotes a purely imaginary substance.

According to Maxwell, EM waves do not truly amount to *things*, but rather denote "a collection of imaginary properties." However, unlike purely abstract oscillations, EM waves appear to be agential phenomena *out there:* they carry radio signals, microwave food, and render bones visible via X-ray. Thus, on the one hand, EM waves possess an ontological hardiness beyond that of the graph; yet, on the other hand, they denote "a purely imaginary substance."

Röhl treats the baffling ontology of EM waves and fields extensively, and points to a somewhat simple means by which to resolve the matter (or lack of matter). He writes: "One rather obvious ontological option for waves would be to understand waves as a special process."[20] That is, considered with respect to *process* ontology, waves become less mysterious and possess precisely definable features. EM field waves, Röhl states, are "(1) time-varying with a special periodic pattern" and "can (2) be characterized by amplitude, frequency and wavelength (or wave number) and wave velocity."[21]

According to a process ontology, the character of a wave becomes a question of its shape in time, rather than its material constitution. And, indeed, the EM spectrum comprises diverse waves whose particular effects depend not on their chemical features, but on their temporal features: the difference between the waves that make my food (microwaves) and those that make my music (radio waves) lies in their disparate frequencies. Within the EM spectrum waves thus adhere to a proper scientific hierarchy, without any sort of *material* differentiation. The prioritization of process over substance, I will argue, plays a key role in the acceptance of brain waves as "real," even where they lack defined materiality.

Like Knowles, modern thinkers have an intuition that waves surround us, often carrying information. Though we no longer believe that ether occupies all the universe's crevices, we unflinchingly accept that an invisible ocean of undulations—ranging from radio to Wi-Fi—flows through the air. Given the perplexing materiality of such waves, we may come to think of them as pure *signals*—messages unbound to media. And if waves of rich internet content flow seamlessly from device to device, why shouldn't our brains trade rich mental content in an analogous manner?

Cortical Communications

Skulls serve as a (literally) firm reminder of existential loneliness. My brain matter will never make contact with a second brain; and my psyche, it seems, will never truly grasp that of a second person. Yet, just as cell phone signals ably penetrate solid walls to deliver mobile messages, brain waves appear to release mental content from overprotective crania—and, perhaps, to ameliorate phenomenal solitude.

In his original letter, Knowles wrote that brain waves "may convey sympathies of feeling beyond all words to tell,—groanings of the spirit which cannot be uttered, visions of influences and impressions not elsehow communicable, may carry one's living human presence to another by a more subtle and excellent way of sympathy."[22] In short, Knowles believed that etheric entanglement entails more than just another way to trade words. Brain waves, he thought, underlie a profound sort of psychological connection.

Knowles's view hardly represents modern scientific consensus around brain waves; however, as I will show, contemporary brain wave discourse reflects a convergence of science, fiction, past, present and future. As such, the history of brain waves helpfully illuminates how and why we currently use the term. In the following chapters, I refer to Knowles's "groanings of the spirit" several times. For this phrase implies not just a revolution in how we communicate, but a redefinition of human intimacy. Spiritual "groanings" summarize a hope that words do not exhaust our ability to relate to one another—that, by delivering some trace of the brain, waves may convey "one's living human presence." This sort of exchange at once represents a pragmatic tool—more rapid, direct communication—and a spiritual desire. It reflects hope for a more pure connection to, and understanding of, other souls.

In his history of communication, John Durham Peters discusses this kind of hope at length. He writes: "'Communication' is a registry of modern longings. The term evokes a utopia where nothing is misunderstood, hearts are open, and expression is uninhibited."[23] Peters attributes the emergence of such longings to the culture and technology of the late nineteenth century, highlighting two telling words coined at that time: "solipsism" and "telepathy." Both words, Peters writes, "reflect an individualist culture in which the walls surrounding the mind were a problem, whether blissfully thin (telepathy) or terrifyingly impermeable (solipsism). Since then, 'communication' has simultaneously called up the dream of instantaneous access and the nightmare labyrinth of solitude."[24]

The original theory of brain waves corresponds—chronologically and conceptually—to the techno-spiritualist culture that Peters explores. Knowles's theory, like the coinage of "telepathy," grew from the invention of telegraphy, and exemplifies how technological innovation can inspire the cultural imagination. Following the development of early electrical communications tools, Peters writes,

> Interpersonal relations gradually became redescribed in the technical terms of transmission at a distance—making contact, tuning in or out, being on the same wavelength, getting good or bad vibes. Communication in this sense makes problems of relationships into problems of proper tuning or noise reduction.[25]

The following pages certainly attend vibes, good and bad, as well as tuning problems that hinder understanding of the human psyche. However, whereas Peters describes the *metaphorical* potency of communications technologies, a study of brain waves exposes compelling and confusing biotechnological loci where the line between metaphor and equivalence dissolves. For example, early electrophysiologists relied on instruments developed by telegraph and radio engineers. The ability to know another individual, in this case, *literally* became a matter of "proper tuning or noise reduction." Indeed, the history of brain waves reveals a series of instances in which humans become sources of signals, not merely via discursive diffusion, but also via technological diffusion—from engineering to biology and vice versa.

The present study thus fuses two traditionally distinct research traditions: the histories of (1) brain science and (2) communication. Joint attention to these histories sheds new light on the ways in which technology changes perceptions of the human subject. A brain scan, like a cell phone call, captures a person's essence with eerie intimacy; and both tools may alter cultural attitudes towards corporeality and individuality. Yet cell phones and brain scans rarely appear juxtaposed in a single investigation (save the annual article purporting to identify a link between mobile devices and brain cancer).

This analysis capitalizes on the shared history of EEG technology and communications technology to elucidate broader connections between brain science and telecommunications. Given the chronological scope of this investigation, I necessarily miss some significant developments in the relevant fields, and rush through others. Often, I focus on actors or anecdotes that, I hope, illuminate larger empirical and cultural trends.

Where I offer extended discussion of the discoveries of particular researchers (*e.g.,* Grey Walter, Joe Kamiya), I do not mean to suggest that these individuals are the greatest or only figures contributing brain wave discourse during the era in question. Rather, I have highlighted players and moments that, I believe, effectively encapsulate key components of brain wave discourse, and the progression of that discourse over time.

To be clear, my focus on brain waves should not be taken as an argument that these oscillations represent the most important facet of brain science throughout history. If they did, certainly their story would already be written. In fact, the analytical value of brain wave science, I contend, depends on its sometimes-marginal status. Brain wave discourse often exists in a liminal space between research and reverie; as such, its history uncovers curious intersections of science and society.

Importantly, I hope to avoid imposing contrived relations on distinct historical arenas. Instead, I aim to highlight real material and discursive exchange among those building communications tools and those studying the body. This effort finds precedent in Laura Otis's *Networking: Communicating with Bodies and Machines in the Nineteenth Century*. Therein, Otis explores the physical and metaphoric interactions between humans and machines during the early days of the telegraph. "Like our own comparisons of brains to computers," she writes, "these early alignments of bodies and technologies altered people's sense of identity. The tendency to see a communications device as continuation of one's own nervous system developed in the nineteenth century, not the twentieth."[26]

Building on Otis's work, this study attends to the evolution of technological metaphors we deploy to describe the brain and the mind, with particular attention to communications technologies. That we look to complex machines to understand the brain is, of course, not a novel observation: both historic and modern projects in cybernetics emphasize the functional similarity of organic and synthetic systems; and computer-brain analogies now appear regularly in popular and esoteric publications. However, I argue, the apparent austerity of technological language elides the spirituality embedded in accounts of the brain qua machine. Thus, beyond documenting material-discursive crossover, I hope to reveal the ways in which bio/technological confusion lends itself to mystical, even religious thinking.

First, I show that models of communication, like models of brain waves, prioritize *signals* over substance. In both cases, this prioritization diverts attention from mushy materiality to immaterial processes.[27] As I suggest above, process ontologies manage to exude scientific precision, while rendering individuals according to decorporealized dynamics.

Second, I discuss the mutual electrification of brains and communications tools, delineating the strange kinship of electric bodies and electric machines. For example, researchers assert that neurons communicate with one another via electrical action potentials that fire in an "all-or-none" manner—a process that conspicuously mirrors the discrete 0/1 language of digital devices. Additionally, scientists often discuss the brain in terms of its wires and circuits, reflecting deeply entrenched bio/technological analogy. Of course, skulls do not actually house wires; yet, electrically charged copper (actually) interacts with the nervous system. In the case of EEG, electrical signals seem to flow from an organism into a machine, challenging distinctions between mind and matter, signal and substance, biology and technology. With these boundaries rendered porous, it becomes possible to think of the self in terms of immaterial waves and abstract data—a mind without body.

Third, I examine cases in which biotechnological comparisons become not just descriptive but aspirational. Persisting brain-machine parallels can result in an assumption or hope that the former will possess qualities of the latter. In some cases, aspirational thought involves the misattribution of technological features to the brain—such as Knowles's conviction that the brain, like the telegraph, transmits messages across vast distances. In other cases, however, aspirational thinking leads to genuine innovation: perhaps our brains cannot, on their own, broadcast waves, but technologists can *build* devices that detect and transmit details about brain activity.

I argue that the entanglement of neurological and technological discourse seems to imbue the future of brains with the promise of future machines. For example, current techno-optimists in the field brain computer interfaces believe that our cortices will soon regularly relay their waves to computers using wireless gadgets and snazzy algorithms. Proposed applications of modern neurotechnology include brain-controlled TVs, brain-to-brain communication, and even "mind uploading"—which is to say, telekinesis, telepathy, and transcendence.

According to stereotype, a scientific orientation towards the world precludes a hope for life after death and belief in miracles or souls. The perks of overtly religious dualism are not available to materialists committed to a mind-brain identity. However, this identity can offer its own path to salvation. Via a reduction of mind to brain, and soul to cerebrum, existential crises become mere scientific challenges. From this perspective, technologies that somehow release the brain's waves from their hard casing also serve to liberate the mind—from solipsism, from embodiment, and from other chronic deficiencies of the human condition. Hard as skulls are to crack, these casings appear to insulate only the brain's matter—not its messages.

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[18] I do not mean to suggest that pies lack diversity and complexity. I acknowledge that the planning and baking of, say, a crisp apple pie is no simple matter. Further, the apple pie differs drastically from a chocolate cream pie—which, some argue, does not technically qualify as a pie. Both desserts, however, are delicious.

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Chapter 2. Early Ripples

James Thomas Knowles coined the term “brain-waves” in 1869. However, to assess that Knowles invented the notion of nervous vibrations gives the Victorian architect a bit too much credit. Knowles was hardly the first thinker to propose some kind of wave within brain matter; and, in fact, when he published his ideas in *The Spectator,* the magazine’s editors effectively called the work derivative.

In a printed comment preceding Knowles’s piece, the editors observe that this “new” theory seemed “very like [David] Hartley's theory of the undulations in the whitey-brown matter of the brain, as the key to the phenomena of sensation.” They further note that Hartley himself merely expanded on a concept earlier articulated by Isaac Newton.[1]

Not primarily known for his theory of brain waves, Newton initially raised the topic in the context of a larger discussion about the movement of energy through the universe. Newton, it turns out, held a highly vibrational view of the physical world—a view that depended on an assumption that there exists an “ethereal medium…which fills all Space adequately without leaving any Pores.”[2] In his 1704 *Opticks* Newton asks:

> [D]o not hot bodies communicate their heat to contiguous cold ones, by the vibrations of this medium propagated from them into the cold ones ? And is not this Medium exceedingly more rare and subtile than the Air, and exceedingly more elastick and active? And doth it not readily pervade all Bodies? And is it not (by its elastick force) expanded through all the Heavens?”[3]

In the same way that Newton believed vibrations of an etheric medium might propagate heat, he also believed they might propagate signals in the nervous system. He continues:

"Is not Animal Motion perform'd by the Vibrations of this Medium, excited in the Brain by the power of the Will[?]"

Newton returns to this premise in his in his "General Scholium," appended to the *Principia* in 1713. Therein, he discusses a "most subtle Spirit which pervades and lies hid in all gross bodies." He hypothesizes that "the members of animal bodies move at the command of the will, namely by the vibrations of this Spirit, mutually propagated along the solid filaments of the nerves, from the outward organs of sense to the brain, and from the brain into the muscles."[4] Here, Newton preserves an element of human agency ("command of the will"), but provocatively suggests that this agency somehow manifests as vibrations along nerves: will within waves.

In the mid-eighteenth century philosopher David Hartley expanded on this idea. Whereas Newton describes his vibrations as a mechanism for sensorimotor transmission, Hartley adapts this framework to develop a vibrational model of mental connections—something closer to a theory of thinking. In his 1749 *Observations on Man* (OM) Hartley uses the term "vibratiuncles" in reference to slight vibrations in the brain that, he believed, underlie cognitive associations.[5] Glassman and Buckingham write: "The vibratory medium was hypothesized to process associative linkings for motor-sensory information, as well as for the ultimate scaffolding of an architecture of moral thought. The seeds of a Pavlovian model of behavior were being sown in OM."[6]

Indeed, Hartley appears to have articulated components of associationist psychology before psychology became proper scientific field. He also created a kind of brain wave theory over a century prior to Knowles's publication. Yet, neither Hartley nor Newton pointed to brain vibrations as a mechanism for transferring thoughts from one psyche to another. In their comment, the *Spectator* editors call attention to this distinction. They write:

> [Knowles] is inclined to accept what was in fact Hartley's theory of brain-waves, but uses it, not for the purpose of explaining as Hartley did the phenomena of association of ideas and so forth, but for the purpose of explaining those few remarkable cases of mysterious sympathy between persons who have held no communication in words, which we may call thought-reading, by which it now and then occurs that one person, even though a stranger, deciphers the secret thought lurking in the mind of another, and, still more rarely, that persons who are not strangers, but who are separated perhaps by the whole earth, become dimly sensible of events vitally affecting each other at the very moment they occur.[7]

Brain waves, as described by Knowles, went (literally) much further than Hartley's vibratiuncles. Rather than merely account for psychological connections within a single brain, Knowles described mysterious mental connections between two physically isolated brains. This distinction effectively encapsulates the spiritual-scientific mood cultivated between the time of Hartley's writing and the publication of Knowles's wavy hypothesis.

Namely, nineteenth century advances in EM science provided a new empirical language in which to discuss the movement of invisible waves throughout the universe; and the commercialization of telegraphy provided a precedent for contemplating the rapid transmission of messages. These developments, I argue, rendered the notion of thought transmission plausible, and even rational. No, Knowles alone does not deserve credit for imagining an electric, oscillating telepathic medium. Rather, his theory of brain waves can be read as a crystallization of scientific and spiritual ideas floating in the conceptual ether.

Magnetic Musings

From the get-go, the nineteenth century was a good time for waves. In 1801 English polymath Thomas Young proposed that light does not take the form of corpuscles (particles), as was argued by Newton, but rather that it moves in *waves*, or, as

Young put it, "Undulations of the luminiferous ether."[8] Through his famous 1807 double-slit experiment, Young offered strong evidence for these undulations, leading to a (temporary) closure of the contentious waves-corpuscles debate.

Though Young's stance on light contradicted that of Newton, he similarly assumed the presence of ubiquitous ether—a common assumption at the time. Since antiquity, scholars employed the concept of (a)ether to describe some imponderable—meaning, weightless—medium that fills air and solid bodies alike.[9] Nature, or perhaps culture, abhors a vacuum; and ether promises that no space is truly empty. Further, ether suggests a kind of interconnectedness among objects and people: via etheric undulations, the actions of the body extend across space and time.

Practically speaking, ether came in handy for scholars formulating theories on the transmission of electricity, heat, or other apparently imponderable energies. Since ether pervades all space, so goes the reasoning, it can account for the movement of energy between physically disconnected bodies (biological or otherwise). Etheric theories long predate Young's research; however, they obtained new relevance in the context of nineteenth century science and technology. Schaffner writes: "Though aether theories had been proposed in previous centuries, it was primarily through the development and acceptance of a powerful wave theory of light that more and more attention became focused on the nature of the optical medium."[10]

That is, Young's apparent verification of undulations in ether newly invigorated interest in the medium, and in other sorts of waves that might flow through it. As the nineteenth century progressed, the quantity and quality of wavy theories increased. More than a luminiferous medium, ether would come to explain a variety of natural (and sometimes supernatural) phenomena.

In 1820 Hans Christian Ørsted famously observed that the presence of a battery compromised the direction of his compass needle. In its surprising movement, the needle in fact pointed to a relationship between electricity and magnetism.[11] Starting in the 1820s (and continuing until his death in 1864), Michael Faraday conducted a series of experiments that confirmed Ørsted's observation and laid the groundwork for EM science and technology.[12] In addition to providing experimental evidence for the link between magnetic and electric forces, Faraday would posit (though he could not prove) that the rest of the material universe is similarly entangled. In 1845 he stated: "I have long held an opinion…that the various forms under which the forces of matter are made manifest have one common origin."[13]

In the following decades, James Clerk Maxwell built on Faraday's work and applied a mathematical finesse to EM theory. Borrowing the framework of fluid dynamics, Maxwell developed a series of equations that described EM phenomena in terms of waves. He published "A Dynamical Theory of the Electromagnetic Field" in 1865.[14] Therein, Maxwell observes that the velocity of EM waves "is so nearly that of light, that it seems we have strong reason to conclude that light itself (including radiant heat, and other radiations if any) is an electromagnetic disturbance in the form of waves propagated through the electromagnetic field according to electromagnetic laws."[15]

Without getting into the particulars of Maxwell's mathematics, one can appreciate two broad implications of his work. First, he suggested that seemingly distinct phenomena (light, magnetism, electricity) are, in some deep sense, related, thus reiterating Faraday's suspicion that "that the various forms under which the forces of matter are made manifest have one common origin." Second, Maxwell's equations indicated that such forces move in waves. And this emphasis on waves ensured, for the time being, an important role for ether. Schaffner writes: "As the medium of optical, and then electromagnetic activity, the aether was assumed by many to constitute the absolute frame of reference in which the equations of the optical aether and Maxwell's equations would have their simplest form."[16]

As I have previously described, the ontology of EM waves can prove perplexing. However, the nineteenth century assumption of ether rendered these vibrations more conceptually tangible. As etheric undulations, EM waves can be understood as something like ocean waves—relatable ripples.

Still, scientists never treated ether quite like your typical material medium. Ether was thought to be like air, but *special*—"more rare and subtile," in Newton's words. Further, new evidence suggesting that light, magnetism, and electricity travel via waves in ether imbued the medium with a sort of magic that boring air lacks. Within ether, it seemed, hid versatile and transmissive forces. Throughout the nineteenth century, scientists and spiritualists would venture to uncover the full potential of these forces, and to channel their dynamism.

Od(d) Experimentation

Burgeoning alongside the field of electromagnetism was a magnetic theory of a distinct—but not wholly unrelated—variety. Namely, EM science breathed new life into the theory and practice of mesmerism (or animal magnetism). Subscribers viewed animal magnetism as a shape-shifting force that manifests alternately as electricity, heat, or light;

in this respect, mesmerism closely resembled EM theories of the day.[17] However, physician Franz Mesmer (the school's popularizer) also framed his magnetism as a kind of vital force or energy that governs psychophysical processes—a view that Faraday and Maxwell did not espouse.[18] Natale summarizes: "Mesmer claimed to be able to influence the balance of powers that regulates the health of every individual, stimulating a vital fluid which, according to his theories, pervaded the entire universe."[19]

When Mesmer introduced his school in the late eighteenth century, he faced significant skepticism from men of science and medicine. However, animal magnetism was by no means out of style among the laity when Faraday began his work; and emerging revelations about EM forces may have lent new rationality to the practice. Fuller argues that the tenets of mesmerism would have been particularly attractive to thinkers attempting to consolidate scientific and religious views. Discussing the appeal of the practice in the United States, he writes:

> Since its doctrines were ostensibly those of empirical investigation, mesmerism lent an aura of legitimacy to those seeking reassurance about their spiritual well-being; at the same time, it reflected the progressivist spirit of a dawning modernity…To the popular reading public, the mesmerists' description of the structure of human consciousness straddled a fine line between religious myth and scientific psychology.[20]

Mesmerism can be understood as part of a broader intellectual culture that held spiritual inclinations, but that increasingly sought scientific explanations of the world. At the time, the qualifications of "scientific" remained imprecise; thus, many schools of thought ably satisfied both of these needs. From a modern perspective one can easily distinguish the pseudo of Mesmer from the science of Faraday; however, such demarcations come from inherited distinctions as to what constitutes science—distinctions negotiated during the period in question.

Throughout the nineteenth century, debate surrounding the legitimacy of certain pseudosciences catalyzed a larger discussion of science's role in society: What counts as science? Who should be allowed to participate in it? And to what practical matters can its findings be applied? Scottish lawyer-phrenologist George Combe saw science—including his field of phrenology—as applicable to all of life's quandaries. Gieryn writes: "Combe presented an image of science as essentially limitless: phrenological science could provide a sound foundation for deciding religious or political questions."[21] Combe also believed that public consensus played a vital role in scientific debate, and favored this type of discourse over experts-only exchange.[22] Perhaps predictably, many experts disagreed. Yet public spectacles—including mesmeric healing displays and phrenological readings—remained a common way for individuals to interact with science and "science."[23]

Though many scientific showmen traded in bogus goods, they nonetheless exposed spectators to elements of contemporary technoscientific culture. For example, electrotherapists claimed to cure aches or hysteria via the application of electrodes to various parts of the body—a process sometimes referred to as "faradization."[24] Though a fair amount of quackery featured in this sort of treatment, electrotherapy communicated the spirit of ongoing physiological research—it (vaguely) reflected contemporary studies of the electrical properties of the nervous system. Put another way: even as pseudoscientists bastardized more rigorous research, they captured and conveyed the technoscientific ambience of the day. The revival of mesmerism, for instance, corresponded to genuine advances in magnetic research.

Mesmerism appropriated the language of ether and magnetism to frame spirituality in empirical terms. This framework offered adherents a kind of religious guidance, while also permitting them to identify as rational, scientific thinkers. Fuller writes:

> [M]esmerism drew its most enthusiastic support from the ranks of those who were intellectually disenfranchised from religious orthodoxy. Sensitive to the culture lag besetting contemporary religious thought, these individuals had the courage to step outside Christian sources in an effort to reconceptualize the essence of moral and religious thought.
>
> …To the mesmerists' way of thinking, psychological self-adjustment was the ontological equivalent of reconciling oneself with immanent spiritual forces.[25]

Mesmerism implicitly located the soul within a magnetic force, thus offering religious comfort in a style congruent with the era's cutting edge science.

Though this sort of scientific extrapolation often transpired in the context of public spectacles, mystical thinking also penetrated experimental research. For example, the German geologist and metallurgist Karl von Reichenbach seriously studied animal magnetism; and in the 1840s he conducted a series of experiments that investigated the relationship between psychophysical states and the action of celestial bodies.

This research culminated in the 1846 text, *Researches on Magnetism and on Certain Allied Subjects, including a Supposed New Imponderable.*[26] The "new imponderable" in question was what Reichenbach referred to as the "odic force"—a force that, he believed, governed connections among light, electricity, magnetism, and mental states. Reichenbach cites, among other things, experiments apparently showing that the positions of stars influence both magnets and human spines. These investigations, he concludes,

> …furnish a beautiful proof…of the action of the whole material world, even the heavenly bodies, on us, with the same force which we find in terrestrial

> matter…they prove that there actually does exist a mutual influence between us and the universe, an influence hitherto unsuspected ; so that possibly the stars may not be altogether without some influence on our sublunary world, even in practical matters, or on the working of the human brain…
>
> [T]his force exist in all, even amorphous, bodies, including the heavenly bodies, and takes its place as a universally diffused natural force.[27]

Reichenbach's work was inspired by mesmerism and largely reiterates its tenets, replacing a vital magnetic fluid with the odic force.[28] Reichenbach asserts that this force, "is conducted and carries its efficiency with it through matter of every kind, even through living human beings;" yet, he leaves open-ended the mechanism and medium of transference. That is, he does not explicitly endorse or negate a view that waves play an important role in the dynamics of the natural world. Later citations of Reichenbach's work, however, map the odic force onto a wave-based framework in which mind and matter interact via etheric undulations. Specifically, Reichenbach's research influenced the thinking of geologist Edward Hitchcock (discussed below) who, in turn, features in Knowles's theory.

Thus, in addition to exemplifying the application of scientific vocabulary to spiritual desires, animal magnetism falls within the intellectual lineage of brain waves. Even today, popular discourse regarding neural oscillations, at times, recalls mesmeric theory. Brain waves often implicitly obtain the status of an electrical soul; and biofeedback techniques aimed at altering oscillatory patterns ring of efforts to restore magnetic stasis (see Chapter 6). Indeed, though the modern materialist may presume that science has exorcised all of its "pseudo," brain wave discourse continues to offer spiritual reassurance via electrifying, empirical language.

A "Telegraphic Universe"

While pseudoscientists claimed to harness EM forces for the purpose of spectacular healing, inventors and engineers harnessed these forces to develop spectacular new technologies. Commercialized in the 1840s, photography and telegraphy underscored the wavy connectivity of the universe, and also enhanced it. Cameras, for example, seemed to capture undulations of the luminiferous ether; and the resultant photographs depicted faraway scenes, thereby connecting otherwise distant people and places. Further, the very real miracles achieved by new technologies often bred belief in less real, more fantastic feats. By the 1860s "spirit photography"—a method of double exposure that purportedly made ghosts visible—became a common attraction at séances.[29]

The telegraph, of course, radically altered the ways in which individuals understood and enacted interpersonal relationships. The cultural influence of this technology cannot be overstated—and it has been stated quite a bit. James Carey, for example, writes: "Before the telegraph, 'communication' was used to describe transportation as well as message transmitted for the simple reason that the movement of messages was dependent on their being carried on foot or horseback or by rail... [T]he telegraph freed communication from the constraints of geography."[30]

A reference to the telegraph is hardly complete without mention of the "annihilation of time and space" that its invention entailed. But, in addition to altering human spacetime orientation, telegraphy also altered the relationship between communication and corporeality. That is, telegraphy enabled messages to move faster than—and independent of—people, thus detangling human interaction and human bodies.

Or, to borrow Carey's phrasing: *the telegraph freed communication from the constraints of biology.*

This real liberation served as a conceptual model for envisioning a more profound sort of liberation—namely, the liberation of mental messages from brain matter (*i.e.* telepathy). In the case of telegraphy, messages leapt into the sky and moved with lightning speed to distant destinations. The application of these principles to mental content did not require much labor on behalf of the imagination—particularly because contemporary research in electrophysiology revealed striking similarities between telegraphic and nervous communication.

Following the development of improved recording instruments in the late 1840s, researchers Emil du Bois-Reymond and Hermann von Helmholtz (among others) obtained increasingly precise measurements of nervous impulses.[31] The field of electrophysiology flourished in the second half of the century, coinciding with the construction of telegraph lines across the developed world. Accordingly, early accounts of the telegraph often likened country-spanning wires to the innervation of the nervous system.

Otis writes: "the telegraph and the nervous system appeared to be doing the same things and for the same reasons. Their common purpose was the transmission of information, and they both conveyed this information as alterations in electrical signals."[32] The likeness of technological and biological communication, Otis contends, swayed not only public perspectives on nervous electricity, but also esoteric practices. She continues: "Throughout the nineteenth century scientists' electrophysiological understanding of the nervous system closely paralleled technological knowledge that allowed for the construction of telegraph networks."[33]

The apparent similarities between nerves and wires seemed to suggest that a single force (electricity) coursed through organisms and machines alike. Furthermore, the success of the telegraph demonstrated that electric currents can carry meaningful messages. Finally, EM science elucidated etheric connections between electricity, magnetism and light. Together, these advances made fathomable the notion that electrical changes in the nervous system might somehow ripple out into the ether, distributing mental messages in their wake.

In his midcentury lecture, "The Telegraphic System of the Universe," Geologist Edward Hitchcock verbalized such a notion.[34] He states:

> It seems to us a marvellous discovery, which enables man to convey and register his thoughts at the distance of thousands of miles by the electric wires. Should it excite any higher wonder to be told, that, by means of this same power, all our thoughts are transmitted to every part of the universe, and can be read there by the neuter perceptions of other beings as easily as we can read the types or hieroglyphics of the electric telegraph? Yet what a startling thought is it, that the most secret workings of our minds and hearts are momentarily spread out in legible characters over the whole material universe! nay, that they are so woven into the texture of the universe, that they will constitute a part of its web and woof forever! [35]

An overtly religious scholar, Hitchcock imbues the material world with a god-like omniscience, imagining that both physical and mental actions make a legible, electric dent on nature. He explicitly invokes waves to describe how our thoughts might permeate space, writing, "whenever we change the electrical condition of bodies around us, we start a movement to whose onward march we can assign no limits but the material universe. These waves of influence consist of a series of attractions and repulsions."[36]

Hitchcock falls short of positing a widespread ability to intercept thought waves, as he suspects that "so subtile a power" likely goes undetected by standard sensory organs. Still, he imagines that "in a future spiritual state," men will, like angels, ably perceive all etheric impressions. And in fact, Hitchcock argues, our failure to perceive such impressions at present likely reflects our sins and mortal imperfections. For Hitchcock, a telegraphic universe does not take the place of religion, but rather should "serve to stimulate us to our duty, if a sense of the divine omniscience is not sufficient."[37]

In many respects, Hitchcock adheres to a Christian worldview, citing the bible numerous times throughout his lecture. Yet, simultaneously, he establishes a framework for spiritual thought that, in some ways, obviates conventional religion. Hitchcock imagines that the actions of all beings, living and dead, pulsate through the material world. He writes: "It is as if we were linked to every created being by a golden chain, and every pulsation of our heart or movement of our mind modified the pulsation of every other heart and the movements of every other intellect."[38] According to this view, the universe preserves beings for all eternity. Even without acknowledging a conventional deity, one might find spiritual comfort in such a view—a hope for immortality in the electric ether.

Perhaps as a result of his Christian leanings, Hitchcock notes that not every electric soul will enjoy a happy etheric afterlife. He writes: "if this principle be true, how annoying will it be, to the man who has not acted well his part in this world, to meet in eternity the ever-recurring mementoes of his evil deeds!"[39] Though later brain wave theories lack such intense moral overtones, they often treat electrical oscillations like a kind of spirit—a trace of the self that adheres to material laws, but that transcends bodily matter. And though modern discourse regarding "brain reading" technology does not threaten eternal damnation, it can instill an anxiety analogous to that produced by an omniscient being. For technologies that purport to read brain waves threaten to make public the most private, even sinful thoughts (see Chapters 8 and 9).

A Theory

Sir James Thomas Knowles was born the same year as Maxwell (1831) and similarly took an interest in electric waves, if via a much different course. A successful architect, Knowles kept elite company and often dabbled outside his profession into fields like literature and metaphysics.[40] Among his closest associates was the poet Alfred Lord Tennyson, for whom Knowles designed a house, and with whom he founded the Metaphysical Society of London (MSL) in 1869.[41] Other members of the society included the outspoken Darwinist Thomas Henry Huxley, physicist John Tyndall and other well-known representatives of both the scientific and religious establishments.[42]

The MSL met once a month to debate impossible subjects, such as, "The Personality of God," "What is Death?" and "Has a Frog a Soul?"[43] The group also hosted a discussion "On the Words *Nature*, *Natural*, and *Supernatural*"—a topic highlighting the uncertain purviews of such categories at the time.[44] The MSL's more theological conversations were particularly contentious in the context of a culture still reeling from Darwin's 1859 shock to anthropocentrism.[45] Consider, for example, that during the year the metaphysical society formed, Huxley coined the term "agnostic," and published "On the Physical Basis of Life," a widely read essay that called for the "banishment" of any kind of immaterial soul or spirit.[46] Now imagine Huxley discussing his views over dinner with fellow MSL member Henry Edward Manning, the Catholic Archbishop of

Westminster. The society lasted twelve furious years, with its members concluding that, despite their shared interests, they held hopelessly irreconcilable opinions.[47]

While it survived, however, the MSL addressed a range of odd psychological experiences, including thought transference. At the time, this topic was of interest to the public and to select scientists, though there existed no general theory of how such transference might transpire. During the year of the MSL's formation, Knowles thus took it upon himself to propose one.

In January of 1869 Knowles submitted to *The Spectator* a letter titled "Brain-Waves—A Theory."[48] In the piece, Knowles endeavors to provide an explanation for uncanny mental experiences—premonitions, intuitions, and knowledge about events to which the subject in question has no immediate access. Knowles believed that such experiences, though perhaps anomalous at the individual level, occurred with sufficient regularity to qualify as natural, if not normal.

As both impetus and validation for this theory, Knowles cites a list of practitioners who appear to channel the uncanny, including "mesmerists, spiritualists, [and] electro-biologists." He supplies several exemplifying anecdotes, including two from his friend Tennyson. The poet, Knowles reports, "was induced to try (successfully) the curative effect of mesmerism by passes of the hands upon a patient, who became so sensitive as to be aware on one occasion of his approach by railway two hours before he reached the house."[49] Knowles contends that the powers of mesmerists and spiritualists point to "a common action of force." He proposes that bizarre psychological phenomena—whether spontaneously experienced by a layman or induced by a professional—arise not from supernatural energies, but from electrochemical activity in the brain and associated "brain-waves." He writes:

> Let it be granted that whensoever any action takes place in the brain, a chemical change of its substance takes place also…[An electric manifestation is the likeliest outcome of any such chemical change, whatever other manifestations may also occur.] Let it be also granted that there is, diffused throughout all known space, and permeating the interspaces of all bodies, solid, fluid, or gaseous, a universal, impalpable, elastic "Ether," or material medium of surpassing and inconceivable tenuity.
>
> [The undulations of this imponderable ether, if not of substances submerged in it, may probably prove to be light, magnetism, heat, &c.]
>
> But if these two assumptions be granted, and the present condition of discovery seems to warrant them, should it not follow that no brain action can take place without creating a wave or undulation (whether electric or otherwise) in the ether ; for the movement of any solid particle submerged in any such medium must create a wave ?
>
> If so, we should have as one result of brain action an undulation or wave in the circumambient, all-embracing ether,—we should have what I will call Brain-Waves proceeding from every brain when in action.
>
> Each acting, thinking brain then would become a centre of undulations transmitted from it in all directions through space. Such undulations would vary in character and intensity in accordance with the varying nature and force of brain actions, e.g., the thoughts of love or hate, of life or death, of murder or rescue, of consent or refusal, would each have its corresponding tone or intensity of brain action, and consequently of brain-wave (just as each passion has its corresponding tone of voice).
>
> Why might not such undulations, when meeting with and falling upon duly sensitive substances, as if upon the sensitized paper of the photographer, produce impressions, dim portraits of thoughts, as undulations of light produce portraits of objects?
>
> …It will but be a vague, dim way, at the best, of communicating thought, or the sense of human presence, and proportionally so as the receiving brain is less and less highly sensitive. Yet, though it can never take the place of rudest articulation, it may have its own place and office other than and beyond speech. It may convey sympathies of feeling beyond all words to tell,—groanings of the spirit which cannot be uttered, visions of influences and impressions not elsehow communicable, may carry one's living human presence to another by a more subtle and excellent way of sympathy.

> …No doubt atomic movements, causing waves in space, must start from other parts of the body as well as from the brain, and, indeed, from the fluctuations of all material bodies (whence Hitchcock's ingenious fancy of the "Universal Telegraph").[50]

I quote Knowles at length because his letter represents the first recorded articulation of the term "brain waves," and because his theory neatly synthesizes the supernatural and scientific murmurs of the day. Incorporating electricity, magnetism, waves, ether, and thought-transference, Knowles's letter efficiently encapsulates both the intellectual influences of the MSL, and of the broader technoscientific ambience.

Indeed, Knowles was hardly alone in pursuing the topic of uncanny mental events. Contemporaneously, thought transference and other apparent miracles attracted attention from diverse thinkers, many of whom held credentials more relevant than "architect." Specifically, Alfred Wallace and William Crookes applied a scientific lens to phenomena that, today, would seem decidedly beyond science's purview.

Science Meets Séance

Alfred Wallace was a naturalist, an explorer, and a fellow of the Royal Society of London—though he is perhaps most famous for being less famous than Charles Darwin.[51] Also a fellow the Royal Society, William Crookes was a chemist, meteorologist and inventor who, among other things, discovered the element thallium.[52] Which is to say: Wallace and Crookes were neither crazies, nor outsiders to the scientific establishment. So when they independently ventured to study séances and spiritualism, they brought an air of scientificity to these subjects.

Still, the scholarly community did not universally endorse this brand of science. A healthy contingent of Victorian researchers openly derided séances, mediums, and any men of science who took them seriously. Crookes and Wallace thus made preemptive efforts to combat colleagues who deemed spiritualist talents impossible or supernatural. They did so by calling attention to the contemporary instability of categories like *natural* and *possible.*

For example, in the introduction to his 1875 essay collection, *On Miracles and Modern Spiritualism*, Wallace refers to David Hume's account of miracles, defined by Hume as "a violation of the laws of nature." This definition, Wallace writes, "assumes that we know all the laws of nature."[53] Wallace assumes the opposite, highlighting gaps in the scientific understanding of forces that govern the world. Given such gaps, he concludes, many so-called miracles may turn out to be perfectly natural phenomena. He adds: "the action of galvanism or electricity, when these agents were first discovered, and before they were ascertained to form part of the order of nature, would answer accurately to [Hume's] definition of a miracle."[54]

Wallace essentially argues that if the accepted laws of nature are in flux, then one cannot easily distinguish the natural from the supernatural; and, in light of this uncertainty, the strange movement of a séance table should warrant scholarly attention equal to that received by the strange movement of Ørsted's compass. This line of thought drives not only Wallace's opening argument, but also a broader contemporary tendency to question the parameters of the super/natural. A mid-century comment in the *Chicago Tribune,* for example, asks:

> Is there not a phenomenon stranger than table-turning in the fact of two magnets—insensate matter, minerals—moving of themselves and uniting? Here there is not even a human agency, and yet all the world accepts the fact that two pieces of matter can move by the agency of an unknown fluid, which is called magnetism, in order to give it a name.[55]

Between EM science, the telegraph, and a railway boom that I won't endeavor to summarize, the umbrella of the possible was rapidly expanding. Wallace embraced this mood of possibility and, in his writing, directs pointed attacks at close-minded contemporaries. *A priori* dismissal of the "so-called supernatural," he argues, does not reflect scientific rigor, but rather reflects a detrimentally dogmatic intellectual orientation.

In 1870, Crookes used similar logic to defend his own pursuit of the super/natural. Rather than cite Hume, Crookes targets a more contemporary figure—and one critical of spiritual research—to exemplify the tautology of *a priori* judgment. He writes:

> Faraday says, "Before we proceed to consider any question involving physical principles, we should set out with clear ideas of the naturally possible and impossible." But this appears like reasoning in a circle : we are to investigate nothing till we know it to be possible, whilst we cannot say what is impossible, outside pure mathematics, till we know everything.[56]

In their respective essays, Crookes and Wallace make persuasive cases for the legitimacy of their research. That these prominent researchers so adamantly advocated for investigations into spiritualism, again, evidences the ongoing negotiation of scientific boundaries. If these men viewed séances as worthy of defense, it should not be surprising that the broader public might find mesmerism or thought transference reasonable.

In *Miracles and Modern Spiritualism,* Wallace ventures to legitimize a number of so-called miracles that intrigued and enchanted the public during his time. His text includes, for example, discussion of mesmerism, the odic force, and "Evidence of the Reality of Apparitions."[57] Like others attempting to naturalize the supernatural, Wallace more or less aggregates bizarre stories. And, like Knowles, Wallace argues that the apparent volume of these occurrences reflects something more than coincidence or charlatanism. He views mediums as individuals "gifted with unusual powers of perception… sometimes in a manner which no abnormal power of the ordinary senses will account for, but which imply the existence of faculties in the human mind of a nature analogous to those which are generally termed supernatural."[58] Here, Wallace cites the mind itself as a "bridge over the great gulf between the so-called natural and supernatural."[59]

Crookes similarly invokes a kind of brainpower to explain apparent miracles; however, he arrives at this conclusion via more genuinely experimental techniques. During the early 1870s, Crookes studied the famed Scottish medium Daniel Dunglas Home, whose talents included the ability levitate and to play musical instruments ("generally an accordion, for convenience of portability") without directly touching them.[60] Over a series of visits, Crookes took careful measurements of Home and his props, transforming the séance table into a laboratory of sorts. To enhance the credibility of his research, Crookes invited other men of science to witness his investigations and controlled to their satisfaction any possible confounding variables or forms of deception.

In *Researches in the Phenomena of Spiritualism* (1874)*,* Crookes provides a detailed account of his observations and concludes: "These experiments appear conclusively to establish the existence of a new force, in some unknown manner connected with the human organisation, which for convenience may be called the Psychic Force."[61] Crookes suggests that "The force itself is probably possessed by all human beings," mediums simply being the most sensitive among us. Though Crookes does not elucidate exactly how this force might work, he observes that it seems to move in "successive waves."[62]

Both Crookes and Wallace viewed the mind as a source of amazing—yet *natural*—powers. They characterized so-called miracles as the products of yet another elusive etheric energy—a force that interacts with brains and bodies, but that also extends beyond biology. Though the men certainly faced pushback for their ideas, they also found many receptive ears, particularly among members of the Society for Psychical Research (SPR).

Founded in 1882, the SPR comprised a mix professional mediums, spiritualists, psychologists (*e.g.,* William James), and physicists (*e.g.,* Oliver Lodge). The group discussed hauntings, hallucinations, thought-transference, and anything else that might transpire at your typical séance—if any séance can, in fact, be deemed typical.[63] Like Crookes and Knowles, the SPR treated psychical energies as an extension of accepted natural forces.

In 1882, SPR founder and poet-psychologist Frederic W.H. Myers coined the term "telepathy." Myers introduced the word, he said, "to cover all cases of impression received at a distance without the normal operation of the recognised sense organs."[64] At the time, both laypersons and psychical researchers reported a variety of such cases; and Myers's broad definition offered a unifying vocabulary in which to discuss these experiences. Myers himself explored telepathy at length, theorizing on the topic in lectures and in print, particularly in the SPR text *Phantasms of The Living*.[65]

For Myers and the rest of the SPR, psychic and spiritual "sciences" of the day were not (when conducted in earnest) departures from physics, but rather represented a hope towards consilience in mental and physical theory. Luckhurst writes: "Telepathy was theorized at vanishing points—just where confident demarcations between truth and error, science and pseudo-science, could not at the time be determined."[66] Though outlandish from a modern perspective, the notion of a psychic or telepathic force cohered with motifs of nineteenth century technoscience.

EM research introduced new potent and invisible waves; telegraphy and photography facilitated spooky transmission of human messages and faces, respectively. Fusing these two ideas, proponents of telepathy posited that some invisible force moves mental impressions from one brain to another. For some thinkers with scientific training—and many without it—belief in telepathy did not require a substantial conceptual leap. Or, it required a relatively minor leap compared to the technoscientific bounds of the preceding decades.

In some ways, the appeal of telepathy or mesmerism seems uniquely of its time—a time in which scientific rationality held an attractive clout, but in which the margins of institutional science remained malleable. Yet, the desire to find spiritual comfort within empirical language extends far beyond nineteenth century pseudoscience. As I will show, the enduring allure of brain waves relies on such a desire. Just as telegraphy and electromagnetism enchanted previous generations, computers and neuroscience now enchant a new cohort of rational thinkers eager to pin transcendent dreams on scientific innovation.

"A Word Which Would Live"

Though a close relation to telepathy, my protagonist—the brain wave—is more versatile than its telepathic sister. Whereas *telepathy* describes a specific phenomenon (thought transference), brain waves connote a mechanism or medium that, through history, has been used to describe a range of spiritual and empirical events. Thus, while today the use of "telepathy" signals fanciful thinking, "brain waves" may very well refer to artifacts of legitimate experimentation. And, whereas spontaneous telepathy appears less tenable as research accumulates, brain waves seem to parasitically thrive on novel science and technology.

The final years of the nineteenth century brought a number of applications of the EM principles championed by Faraday and Maxwell. Notably, in 1895 Guglielmo Marconi and others introduced wireless telegraphy (see Chapter 3). If *wired* telegraphy made thought transference more vaguely imaginable, *wireless* telegraphy presented a wave-based mechanism for how the brain's emissions might travel through ether or EM fields. And this proof-of-concept was not lost on Knowles. In 1899, at the height of Marconi madness, Knowles republished his theory with an introductory pat on the back. He writes: "The wonderful discovery of wireless telegraphy tempts me to put forward again a theory which I ventured to publish thirty years ago, and to which Signor Marconi's new invention seems, in some ways, to lend additional 'plausibility.'"[67]

On this point, Knowles was correct. Though his theory did not gain many adherents following its 1869 publication, a number of thinkers found the notion of brain waves newly plausible in light of Marconi's early demonstrations of wireless telegraphy. Just prior to Knowles's republication, variations on his hypothesis began to surface in both esoteric and popular circles. For example, in 1897 inventor-entrepreneur Edwin J. Houston commented: "It is very improbable…that brain action is unaccompanied by wave disturbances in the ether. It is only a question as to their intensity and capability of awakening thought in a recipient brain."[68] Though initially published in The *Electrical Engineer,* Houston's comments subsequently appeared in *Current Opinion* and the *New York Daily Tribune*.[69]

In the following years, the popular press began to use the terms “brain waves” and “thought waves” with increasing frequency, often associating such waves with telepathy and EM technology. It was not until the 1920s that a scientific instrument actually detected electrical oscillations in the human brain. But when early electroencephalographs did produce undulatory scribbles, their moniker was ready made. Indeed, recounting a conversation with Tennyson, Knowles writes: “He said I had, at any rate, made a good word in ‘brain-waves,’ and a word which would live.”[70]

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[47] Brown, *Metaphysical Society*.

[48] Knowles, "Brain-Waves."

[49] Ibid.

[50] Ibid.; brackets are from the original text. That is, the text within bracket here does not represent additions from the present author, but from Knowles himself—or, possibly, from the editors of *The Spectator.*

[51] See M. Shermer, *In Darwin's Shadow: The Life and Science of Alfred Russel Wallace: A Biographical Study on the Psychology of History* (Oxford: Oxford University Press, 2002).

[52] William Hodson Brock, *William Crookes (1832–1919) and the Commercialization of Science* (Routledge: Abingdon, 2016).

[53] Alfred Russel Wallace, *On Miracles and Modern Spiritualism: Three Essays* (London: James Burns, 1875), 4.

[54] Ibid., 4.

[55] H. Le Hon, "Magnetism in the Nineteenth Century: The Connection Between Spiritualism and Electro-Biology," *Chicago Daily Tribune*, May 25, 1857, 3.

[56] William Crookes, "Spiritualism Viewed by the Light of Modern Science," ([Reprinted from *The Quarterly Journal of Science*] London: J. Burns, 1874), 4.

[57] Wallace, *On Miracles*, 69.

[58] Ibid., 52.

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[60] William Crookes, *Researches in the Phenomena of Spiritualism* (([Reprinted from *The Quarterly Journal of Science*] London: J. Burns, 1874), 10.

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[68] Edwin J. Houson, "Mental Action and the Ether," *Electrical Engineer* 23 (March 3, 1897): 265, https://books.google.com/books?id=CIg5AQAAMAAJ.

[69] "A New Form of Energy," *New-York Tribune*, March 14, 1897; and "Scientific Problems, Progress and Prophecy," *Current Opinion* 21 (1897): 499, https://books.google.com/books?id=SHo9AQAAMAAJ&dq.

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Chapter 3. Something's in the Air

Waves and related descriptive tools (*e.g.,* vibrations, undulations) have a long history in science, philosophy, and literature. At its barest level, a wave connotes the tendency to rise and fall, come and go, shift this way and that. Everything from feminist movements to sports stadium cheer seems to come in waves. That is to say, "wave" is a useful way to describe a dynamic state.

Yet some waves are treated as more than the state *of* a thing. Today, EM waves are discussed as things themselves. Functionally, one may point the independence of EM waves to explain why astronauts cannot hear in outer space, yet they can see: sound waves are mechanical and thus require a medium through which to travel; light waves are EM and move along just fine on their own. In the former case, we are to believe that the wave is a vibration *in or of something*; in the latter case, vibrations count as objects in their own right. Given this ontological discrepancy, can we correctly refer to both phenomena as waves? Well, we do. So better to ask: of what consequence is this conflation, if any? And how did it come to pass?

In this chapter, I discuss early twentieth century inventions that changed the face of modern technology and that, I argue, subtly liberated waves from a mandatory medium. Following the detection of Hertzian waves and the debut of wireless technologies, EM oscillations came to be understood as powerful, diverse *things*—agential energies that the eyes often do not see, but that the appropriate machinery might detect or transmit.

The invention of EM technologies that convey wavy messages also provided a new way to conceptualize thought transference. These tools offered a novel language in which to discuss cases of spontaneous telepathy and, additionally, inspired hope that technologists might devise methods to mechanically mobilize thoughts—just in case brains couldn't accomplish as much on their own. Indeed, as EM science and its applications matured, so too did theories of brain waves, which graduated from the realm of spiritual hypotheses to that of hypothetical technologies.

Of Wires and Waves

To contextualize the early twentieth century's wavy, wireless aesthetic, one must first consider the very wired years that preceded it. Though telegraphy liberated messages from conventional terrestrial travel, the technology did not completely dematerialize communication. For the telegraph established a new geography of transmission, dictated by the lines—the wires—that guided messages to their respective destinations.

Starting in the 1880s, commercial power lines thickened the mesh of wires accumulating in cities across the United States and Europe. Simultaneously, the telephone industry burgeoned, necessitating yet further wiring. Despite initial excitement surrounding telegraphy, telephony, and electrical power, the ubiquity of wires was not without its drawbacks. In addition to being an eyesore, the wires that carried messages and electricity were vulnerable to adversaries seeking to obstruct the communication of intelligence. Wires also fell victim to apolitical enemies, as highlighted by an 1887 news article reporting, "MEXICAN TELEGRAPHS: ATTACKED BY MONKEYS, ANTS, WOODPECKERS AND TIGERS."[1]

While cities remained mired in wires, German physicist Heinrich Hertz turned his attention to waves. Specifically, in the 1880s Hertz attempted to experimentally verify the EM waves described by James Clerk Maxwell some twenty years prior.[2] Between 1886 and 1889 Hertz conducted a series of trials using a spark gap transmitter that delivered "very rapid electrical oscillations" to a dipole antenna.[3] In subsequent experiments, Hertz placed his oscillator several meters from a zinc receiving plate, a setup that allowed him to measure the velocity and magnitude of emitted waves. Through these trials, Hertz demonstrated that his rapid oscillations behaved according to Maxwell's rules. That is, he seemed to confirm that EM waves indeed flow through the universe. The oscillations came to be known as Hertzian waves, and the spark gap transmitter later became a component of early radiotelegraphs.

Before addressing the industrial appropriations of Hertz's findings, it is worth briefly considering this moment in the historical ontology of waves. Again, waveforms were not novel to science: any alternating variable may be plotted in this manner. Yet, such a plot is not taken to imply that some sort of wave *thing* exists beyond the edges of its graph paper—it is a description of a physical phenomenon, but not a physical phenomenon itself. And, as I describe in Chapter 1, even Maxwell thought of waves as oscillations in an imaginary fluid—a fiction invented to make the laws of electromagnetism relatable. The apparent detection of EM waves *out there* thus represents a transition of EM waves from mathematical metaphor to detectable *things.*

Why was this transition not the subject of scientific controversy, or at least, scientific confusion? I contend that the persistence of ether among physical theories obscured the changing ontological status of EM waves. At the time, it was not uncommon for popular and scientific publications to refer to EM frequencies as "ether waves" or "etheric waves."[4] Given as much, one might understand Hertzian waves to function much like standard mechanical waves—as perturbations in a physical medium.

Ether, I propose, made EM waves cognitively fathomable—playing a role much like Maxwell's imaginary fluid, but to a much broader audience. Yet, unlike in previous decades, EM waves did not necessarily return the favor. Though ether initially smoothed the ontological transition of waves, discourse about EM frequencies slowly transferred the magic and explanatory potency of the all-pervading medium to waves alone.

Going Wireless

Hertz's research quickly bred public speculation about potential applications of EM technology. Yet, early conjectures about wireless innovation did not immediately emphasize telegraphy. Rather, initial coverage of Hertz's work often focused on the prospect of improving the transmission of light and power.

For example, an 1891 article in the *New York Tribune* laments: "The present methods of generating electricity are not only exceedingly wasteful of energy, but they seem to have come to a stand …Professor Hertz's results, coming at just this crisis, are most opportune."[5] The article's author looks forward "to a time when an audience-room or a street may be filled with artificially produced ether-waves…and when these ether-waves can be picked up by conveniently situated receivers and reproduced as light or heat or motive powers."[6] The author's priority is understandable: in the early 1890s most homes lacked access to electric light, which, along with heating, might have presented a more urgent need than floating telegrams.[7]

Still, the communicative potential of Hertzian waves was not lost on scientists and inventors devoted to wireless telegraphy. In fact, the flurry of research in this area at the turn of the century led to a series of public patent disputes; and scholars today continue to debate the rightful father of radiotelegraphy.[8] Some cite Guglielmo Marconi as radio's inventor; others characterize him as a thief who ripped off the ideas of researchers like Nikola Tesla and Oliver Lodge.[9]

A physicist by training, Lodge worked in parallel with Hertz towards establishing the existence of EM waves during the 1880s.[10] Based on ideas from Edouard Branly, Lodge later developed a receiving apparatus, the coherer, which featured in early iterations of the radiotelegraph.[11] The coherer comprised a glass tube with metallic particles that *cohered* in response to a certain frequency of EM radiation. Lodge announced this invention at a memorial for Heinrich Hertz, following his untimely death in 1894 (Hertz was 36). "This arrangement, which I call a 'coherer,'" Lodge proclaimed, "is the most astonishingly sensitive detector of Hertzian waves."[12] Lodge's decision to make this announcement at a memorial service resonates as astonishingly *in*sensitive; however the coherer, in its own way, contributed to the legacy of Hertz and his waves.

When Marconi successfully transmitted his first radio waves in 1895, he used a coherer for reception and, like Hertz, a spark gap apparatus for transmission.[13] A subsequent iteration of the device also included a "tapper," which, triggered by the coherer, translated the radio frequency into a discernable signal. Marconi later described:

> [The] arrangement which I adopted was to place the coherer in a circuit containing a voltaic cell and a sensitive telegraph relay actuating another circuit, which worked a tapper or trembler and a recording instrument. By means of a Morse telegraphic key placed in one of the circuits of the oscillator or transmitter it was possible to emit long or short successions of electric waves, which would

> affect the receiver at a distance and accurately reproduce the telegraphic signs transmitted through space by the oscillator.[14]

Marconi's system established the feasibility of delivering messages via EM waves, if initially at a very slow rate. In the years immediately following this initial breakthrough, wireless telegraphy remained in a prototype state as Marconi travelled around Europe and the United States, spreading the gospel of his new technology.

The prospect of wireless telegraphy immediately garnered excited news coverage; however, journalists often could not clarify when or whether the innovation would become a practical reality. Mixed with news that the Marconi system was "nearing perfection" were accounts of technical and financial setbacks.[15] In March of 1898, for example, the *Chicago Tribune* reported: "The Marconi wireless telegraphy boom seems to have petered out, and the syndicate which kept it going for over a year has arrived at the conclusion that there is no money in it."[16] Still, such news did not impede wireless enthusiasm.[17] An 1899 article describes:

> Wireless telegraphy is in the air…we are all feeling that vague anticipation that goes before a vast change in modes of thought and action which is in spite of all, the true "end-of-the-century" feeling. For, indeed, nothing less than a revolution in modes of thought and business relations the world over may not improbably be the outcome of this wireless electricity.[18]

Throughout the early 1900s, coverage of radiotelegraphy expanded views of what was technologically possible; at the same time, radiotelegraphy seemed only tenuously possible itself. A telling 1903 headline reads: "Wireless Telegraphy Says Inventor Marconi Has No Limitations. Messages Can Be Flashed Any Distance Overland and He Is Almost Ready for Business."[19] By this time, "almost ready" was effectively a slogan of the Marconi system.

While civilians could not yet receive their news *via* wireless telegraphy, news *about* wireless telegraphy was abundantly available. As a byproduct of this coverage, EM waves also penetrated popular discourse. The ability to transmit invisible messages through space, understandably, warranted some account of *how* this system worked—and that explanation came in the form of waves. In this way, Marconi's invention brought belated popular attention to Maxwell's equations and Hertz's experiments. EM waves thus shifted from an esoteric theoretical concept, to a mechanism that explained how new technologies functioned, and what future innovation may hold.

An Electromagnetic Ocean

Marconi's success coincided with the 1895 discovery of X-rays by Wilhelm Röntgen in Germany.[20] These concurrent EM developments seemed to confirm suspicions that waves sustain forces more extraordinary than light or even electricity; and the framework of an EM spectrum suggested that a range of miracles could be attributed to a range of distinct frequencies. Overeager exploration this spectrum yielded the infamously erroneous detection of "n-rays" by Prosper-René Blondlot in 1903.[21] However misguided, Blondlot's blunder reflects a certain readiness to uncover new types of EM radiation—a readiness that both motivated esoteric research and enchanted the public.

In the July 1905 issue of *Harper's*, Caleb W. Saleeby writes:

> [Ether] has the power of vibrating from side to side, and these vibrations, according as they are fast or slow, have the most varied results upon us. They all travel along at the same speed, which is that of light...but the waves may oscillate from side to side as they go... When the waves are very slow we call them electric waves. When they are a little faster we call them Hertzian waves, and telegraph across the oceans with them. When a little faster we call them Blondlot rays--a new discovery...A little faster, they are called heat rays, or radiant heat. A little faster, they are called red light, then yellow, and so on to violet. Then they

> become invisible again, as they were before, and we call them ultra-violet light. Then a little faster, we call them Becquerel rays, and the fastest we know yet we call Roentgen rays. I have missed out more than I have named, and there are many gaps yet to fill.[22]

An EM view of the world reflected new scientific horizons and also revived older, mystical accounts of action at a distance. The vocabulary of frequencies imbued occult explorations with enhanced specificity and scientificity; and even as attention increasingly flowed to waves, ether provisionally connected novel technology to older spiritualist frameworks. Natale writes: "Like wireless, X-rays were also framed in the beliefs about the existence of the invisible substance, the ether…The link between Röntgen's discovery and etheric substances can be found, for instance, in the renewal of beliefs in mesmerism at the end of the nineteenth century."[23] EM theory and technology indeed provided a validating language in which to discuss otherwise outlandish ideas—among the laity and among some of the scientists contributing to the wireless revolution.

In addition to developing the coherer and working on the problem of radio syntony (*i.e.,* tuning), Oliver Lodge investigated such topics as telepathy and telekinesis. Raia argues that Lodge's spiritual beliefs complemented his empirical success, and highlights a broader conceptual affinity between experimental physics and spiritualism. She writes:

> Ether, the medium for pondering the imponderable, was a legitimating space where Lodge could launch an inquiry into "non-sensuous reality" while maintaining the object of his curiosity to be, still, "reality."
>
> …With its cable telegraphy, fluorescent radiation, cathode rays, odic force, electromagnetic waves, and, eventually, the wireless, x-rays, and dubious n-rays, the world of physics often depicted a reality of strange possibilities.[24]

An early member of the SPR, Lodge investigated the so-called miracles performed at séances, including levitation and contact with the deceased—an interest that Lodge pursued with extra vigor after he lost his son, Raymond, to the First World War.

Lodge, in fact, eventually wrote a book that documented his views on spiritualism, titled, *Raymond or Life and Death with Examples of the Evidence for Survival of Memory and Affection After Death.*[25] Though some researchers outside the SPR deemed his spiritualist work unscientific, Lodge maintained a reputation as an expert on wireless technology. Mainstream coverage of his telepathic research thus lent some legitimacy to the topic. In 1908, an author from the *Chicago Daily Tribune* wrote: "Telepathy takes a new turn when investigated by a master mind like that of Oliver Lodge."[26] The author offers no details about Lodge's empirical findings, but asserts that this sort of research "tends mightily to strengthen the argument for transcendence of mind over body, so that we may reasonably expect the one to be capable of existing independently and of surviving the other."[27]

Like Lodge, William Crookes split his time between technological and spiritual pursuits. During the early 1870s, he developed the Crookes tube—a precursor to the vacuum tube, which would later feature in radiotelegraphy.[28] Crookes's early work on this invention coincided with his investigation into séances and the Psychic Force (see Chapter 2). When Crookes first posited his force, he could not point to definitive proof of its existence—a shortcoming that wasn't deadly to his theory since, at that time, EM waves similarly evaded detection.

Following the measurement and application of EM waves, Crookes refined his views in ways that cohered (so to speak) with the action of available technologies. In 1898, as news of Marconi's apparatus became popular fodder, Crookes opined about how wireless transmission might work in the brain. He writes:

> All the phenomena of the universe are presumably in some way continuous, and it is unscientific to call in the aid of mysterious agencies when with every fresh

> advance in knowledge it is shown that ether vibrations have powers and attributes abundantly equal to any demand, even to the transmission of thought. It is supposed by some physiologists that the essential cells of nerves do not actually touch, but are separated by a narrow gap which widens in sleep while it narrows almost to extinction during mental activity. *This condition is so singularly like that of a Branly or Lodge coherer as to suggest a further analogy. The structure of brain and nerve being similar, it is conceivable there may be present masses of such nerve coherers in the brain whose special function it may be to receive impulses brought from without through the connecting sequence of ether waves of appropriate order of magnitude.* Roentgen has familiarised us with an order of vibrations of extreme minuteness compared with the smallest waves with which we have hitherto been acquainted…and there is no reason to suppose that we have here reached the limit of frequency. It is known that the action of thought is accompanied by certain molecular movements in the brain, and here we have physical vibrations capable from their extreme minuteness of acting direct on individual molecules, while their rapidity approaches that of the internal and external movements of the atoms themselves."[29]

Here, Crookes's ideas recall Knowles's original theory of brain waves, but fortifies said theory with trendy technological language. Creating an analogical bridge between the brain and wireless devices, Crookes uses his familiarity with novel tools to make old spiritual dreams sound newly rational.

For Crookes and others, rapid advances in technoscience did not bring disbelief in invisible forces. On the contrary, the detection of EM waves showed that human sensory organs often fail to detect important undulations. Further, the success of new EM technologies suggested that identifying and measuring elusive waves merely requires constructing the appropriate apparatuses.

The application of EM language to the concept of thought transmission followed logically from extant analogies between the telegraph and the nervous system. As I previously described, *wired* telegraphy established a precedent for discussing nervous and technologic electricity in similar terms. Given the liberation of telegraphy from its wires, one might reasonably extend this technological development to the brain: nervous transmission independent of nervous wiring.

And, indeed, lingering theories of brain waves and telepathy gained new currency in a culture enamored of wireless technology. Marconi's much-publicized apparatus served as proof of concept not only for wireless telegraphy proper, but also for the notion that EM waves can *carry messages*. Further, wireless discourse introduced exciting, technical terminology with which to dress up dreams of thought transference. For example, the headline of a 1902 *New York Tribune* article asks: "Are Brains Coherers?" Apparently answering in the affirmative, the author writes:

> The possibility that one mind communicates with another by other than generally recognized means has long been suspected…As soon as Marconi [and] his wireless telegraph experiments brought Hertz waves into prominence it was easy to [see] a close resemblance between the two…and to expect that they were accompanied by the same agency.[30]

In the early years of radiotelegraphy, speculation about telepathy became more confident, and more reliably expressed in terms of waves or vibrations. For example, in 1903 the influential English journalist William Stead asserted: "I have to make without qualification the statement that transmission of long-distance messages by direct mental vibration, i.e., telepathy, is an accomplished fact."[31] Reprinting Stead's comments, an author from the *Los Angeles Times* offered additional commentary on the topic. He writes: "The range of possibilities contained in telepathy is almost staggering. Perhaps the day may come when every man will be his own operator, carrying his 'instrument' around with him, and the telegraph and telephone companies, including even the wireless, would have to go out of business."[32] Here, the author depicts telepathy as not only analogous to wireless telegraphy, but as the pinnacle of telecommunications technology.

During the first two decades of the twentieth century, scientists and journalists used the term "thought waves" with greater frequency than "brain waves," though both appear in publications from the era.[33] The former term links waves more directly to telepathy: whereas "brain waves" prioritize the biological source of vibrations, "*thought* waves" necessarily evoke conscious experience (thoughts). The later preference for "brain waves"—which began to outshine thought waves in the early 1930s—likely reflects the invention of EEG, greater interest in brain science broadly, and perhaps a decrease in explicit subscribers to telepathic theory. For later generations, the language of neuroscience would provide a seemingly empirical outlet for the discussion of telepathic dreams. At the turn of the century, however, waves themselves seemed sufficiently scientific to sustain such hopes.

In 1906 the *Chicago Tribune* reported on the efforts of John Howard Williams, a purported "Psychic Expert" who believed that he had discovered a means of generating "electro mental" thought waves via "conscious effort of the will."[34] Using the EM language of the day, Williams asserts that such waves are "projected in the same way as Hertzian waves in wireless telegraphy, making communication possible between mind and mind." He continues: "Ether, the subtle fluid which fills space, acts as a conducting medium for 'thought waves' in the same way as it acts as a conducting medium for light waves."[35]

The article refers vaguely to a hypothetical apparatus that would measure these waves, framing the interception of thoughts as a technical challenge. Though no such devices existed at the time, the actual construction of thought-reading machines was hardly necessary to conceive of mental activity as EM or etheric waves; existing wireless technology acted as adequate fruit for the imagination. As Williams puts it,

> Seeing that wireless telegraphy is an established fact…and is brought about by the vibrating of electricity, is it not reasonable to infer that thought, which is also

> subject to the same electrical influence, may also be transmitted from one brain to another, as a message is transmitted from station to station in wireless telegraphy?[36]

Here, Williams exemplifies the more general trend of applying new EM logic to older telepathic beliefs.

At the turn of the century, dreams about the future of wireless mingled with more immediate concerns about widespread adoption of radiotelegraphy. Journalists discussed apprehension about malicious third party interception, or a potential "conflict of ether waves" in air dense with messages.[37] Marconi publically dismissed these fears on multiple occasions. In 1904 he stated: "Those who talk about the danger of having our messages read by outsiders do not understand the subject."[38] At the time, commercial radiotelegraphy faced more than security challenges: transmission remained unreliable, particularly over long distances. Protestations to the contrary notwithstanding, Marconi would have been well aware of the technical issues impeding popular adoption of his system.

The future of wireless depended on improvements in signal amplification and syntony. Researchers working towards these goals recognized the need for a receiving apparatus of greater sensitivity than the coherer. On this front, a triumph came by way of the thermionic valve, or Fleming valve, developed by John Ambrose Fleming in 1904.[39] A simple vacuum tube or diode, the Fleming valve consists of a heated cathode that releases electrons to an anode. Two years after Fleming's contribution, Lee De Forest improved the valve by adding an additional electrode, thus creating the first triode, or audion.[40] Future refinements of the technology included the addition of more electrodes, or control grids, permitting greater regulation of electron flow and thus the ability to amplify weak signals.[41]

The audion replaced the coherer and opened the door for future improvements in radio. The iterative refinement of vacuum tubes both enhanced signal quality and made radiotelegraphy accessible to a wider population. Hong writes:

> In the 1910s the amplifying and oscillating audion made the production, transmission, and reception of continuous waves much easier and cheaper. Before the audion revolution, it was expensive to produce continuous waves…After the audion revolution, it became much easier for anyone to set up a small transmitting station.[42]

As electric components grew cheaper, a population of curious amateurs began to experiment with the technology. As early as 1905, the *New York Times* suggested that hobbyists might "tap" into the ether by using materials "obtained in any large electrical supply store," and that one might "carry on many interesting experiments in long-distance wireless telegraphy at small expense."[43]

The ensuing development of electric hobby can be thought of as of two distinct, but related practices: (1) material engagement with electric tools; and (2) discursive engagement with contemporary science. Just as hobbyists learned to assemble makeshift radios from parts accessible at a local store, they could similarly assemble a system of beliefs about the universe based on parts, new and used, of (pseudo)scientific theory.

Playing with Waves: Hugo Gernsback & The Amateur Electrician

A recent immigrant from Luxembourg, Hugo Gernsback identified a growing market for electric parts and, in 1905, established an importing company in New York.[44] In addition to selling standard components, Gernsback also developed unique and user-friendly wireless products. One of his first devices, the Telimco wireless, was an early success. Intended for domestic use, this "radio" included both a receiver and a transmitter—the first home device to offer as much. Massie and Perry write:

> The kit allowed the radio hobbyist to use the transmitter only to ring a bell on the receiver, much like Guglielmo Marconi had done in his initial tests with wireless. Even so, this rudimentary radio device that worked up to a one-mile distance was a hot seller for Macy's, Gimbels, and Marshall Field's department stores.[45]

Gernsback boosted revenue with a mail-order business that made his parts and products available to hobbyists nationwide. In addition to increasing sales, Gernsback's catalog served as a segue into the publishing world. His first non-catalog publication, *Modern Electrics,* debuted in 1908, pioneering the technical hobby genre.[46] If Gernsback's shop provided amateurs the ingredients necessary for home-baked contraptions, these publications contained the recipes. The hobbyist magazine occupied a unique space between increasingly esoteric science journals and popular newspapers that did not carry details sufficient for construction projects. This explicitly *non*-professional forum offered a home for ideas and people outside of mainstream science.

Modern Electrics included technical advice, entertainment, and inspiration. Gernsback opened his arms to amateurs with a slogan on the magazine's cover that read: "The Electrical Magazine for Everybody." Gernsback's body of work suggests that he genuinely believed his readers could make important contributions to industry and society. Of course, Gernsback also had self-serving reasons for such widely open arms: the manufacturers to whom he sold ad space benefited from the broadest possible community of participants.

Typical advertisements featured an assortment of radio parts, such as radiometers, induction coils, and various ringers. The magazine also promoted books that promised to teach readers the nuances of invention patenting, or other skills that might help the amateur become a bit more professional. More than inspirational, Gernsback's magazines were aspirational. They offered readers hope that they might become the next star inventor, or at least become a valid participant in the world of wireless. The publications were also aspirational with respect to the direction of the industry as a whole. Amidst reports describing the current state of radio and electrics, Gernsback's magazines presented glimpses into the future, featuring accounts of fanciful inventions that were, maybe, just around the corner.

The hypothetical devices imagined by Gernsback and his contributors sometimes read as brilliantly ahead of their time, and sometimes sound comically implausible. Yet even the magazine's more outlandish concepts took inspiration from existing technologies and underlying scientific theory. Descriptions of future devices held technical detail akin to that of apparatuses already on the market, leaving an *X* where the necessary mechanical link remained to be defined.

Gernsback's magazines emphasized that scientific shortcomings of the day should not stifle the imagination—that ingenuity requires thinking *beyond* reality. Notably, today Gernsback is often remembered not as publisher of technical magazines, but as one of the fathers of the science fiction genre.[47] In fact, authors of outstanding sci-fi and fantasy works now receive "Hugo Awards," named after Gernsback—an impressive legacy for a man who started his career selling hardware. In this respect, both Gernsback and his publications exemplify the interplay between real technology and creative fantasy.

In 1913 *Modern Electrics* became *Electrical Experimenter*; and in 1920 it took the name *Science and Invention.*[48] With each rebranding, the technical magazine became more imaginative, featuring creative speculation alongside scientific innovation. I will below focus on excerpts related specifically to brain technologies; however, the magazine covered a much, much broader array of subjects, ranging from proto-television to interplanetary communication.

Gernsback took several stabs at imagining some sort of brain recording device; and, in each case, the proposed apparatus worked by somehow ascertaining wavy signals from the scalp. For example, a 1915 article in *Electrical Experimenter* asks: "Can Electricity Transfer Thought Waves?" The piece carries no byline, but refers to Gernsback's views on the subject. The author writes:

> Mr. H. Gernsback, who has studied considerably such matters as mental telepathy and also such matters as "thought transmission" in so far as the matter can be studied at this time, has made a suggestion which may be mentioned as worthy of trial in this field. This suggestion embodies the use of a set of one or more sensitive Thermo-couples, which, as we know, produce an electric current whenever they are heated. It has been found that invariably whenever the brain is concentrated on some problem, or thought, that heat is produced in such a way that it will cause the forehead of a person to perspire, even though slightly. Now if this Thermo-couple arrangement is placed against the forehead there is a possibility that waves might be picked up and transmitted over a wire to a proper receiving apparatus or instrument attached to the head of a second person.[49]

The article also includes commentary from the electrical engineer Giuseppe Musso who, the author notes, "has said that in thought transference it has been invariably noted that best results are obtained between two persons having a strong affection for each other, which in another sense might be considered as two minds 'in tune' or syntony."[50] It is unclear whether the reader is meant to believe that strong affection manifests as literal synchronization of brain waves or if the tuning analogy functions as topical metaphor. Either way, the statement evidences the application of radio terminology to discussion of the brain and mind.

In the April 1919 issue of *Electrical Experimenter*, Dr. Charles Merlitz frames brain activity as a form of "radiant energy."[51] In Gernsback's publications—and elsewhere during the era—the terms "waves," "rays," and "radiation" are used somewhat interchangeably. Today, these words may not seem synonymous. In 2018 "radiation" tends to describe something dangerously potent, to be used with caution, even in a medical context. Yet, early in its popularization, the term "radiation" connoted excitement without alarm; it described EM waves that *radiate* from their source, such as radio waves, or perhaps thought waves.

Though EM waves and rays share a single scientific referent, the imagistic distinction between the two terms is nontrivial. Whereas a ray registers as a direct line from point to point, a wave connotes a wobbly path. The use of "waves" thus connects EM forces to the undulations of past centuries—the etheric waves that characterized discussions of physical and psychical forces alike. Furthermore, the curvaceous aesthetic of waves will later provide stark contrast to the curt, binary aesthetic of computer languages (see Chapter 5).

Though more radiant than wavy, Merlitz's 1919 account resembles prior mesmeric views and contemporaneous discourse on thought waves. He writes:

> These radiations emanating from the brain when the mind is concentrated… traverse great distances without perceptible decrease in intensity… The fact that the brain actually radiates energy has been demonstrated by several scientists. Charpentier showed that the human body emits what he has called "N- rays." He found that the phosphorescence of certain substances is increased when they are brought into the vicinity of contracting muscles or one of the nervous centers of the cerebral cortex.[52]

Never mind that N-rays were highly disputed, if not entirely discredited, by the time that Merlitz published his article.[53] Blondlot's "discovery" resulted from the seemingly boundless promise of EM waves—a promise that continued to inspire creative thinking in the pages of Gernsback's publications into the 1920s.

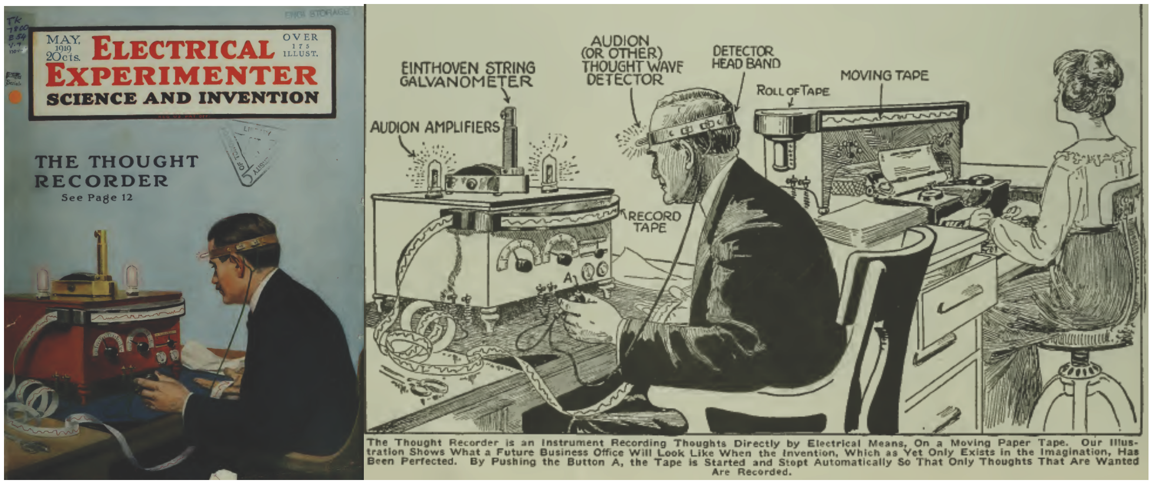

Figure 2. The Thought Recorder. Left: Cover of *Electrical Experimenter,* May 1919. Right: Illustration of the Thought Recorder. Original caption: "The Thought Recorder is an Instrument Recording Thoughts Directly by Electrical Means, On a Moving Paper Tape. Our Illustration Shows What a Future Business Office Will Look Like When the Invention, Which as Yet Only Exists in the Imagination, Has Been Perfected. By Pushing the Button A, the Tape is Started and Steps Automatically So That Only Thoughts That Are Wanted Are Recorded." Reprinted from Hugo Gernsback, "The Thought Recorder," *Electrical Experimenter*, May 1919, 12.

A month after Merlitz called attention to the brain's radiant energy, Gernsback fleshed out his model. In an article published in May of 1919, he confidently asserts:

> Already we have indications that man's thoughts, or the effects therefrom, do not necessarily have to remain within his skull, but that they actually radiate from the latter in a very imperfect manner. As the human race advances, there is no doubt that thought transference proper will become an accomplished fact.[54]

Gernsback places this description in the "Coming Inventions" section of his magazine, proposing a "Thought Recorder" that might capture mental radiation. The hypothetical device involves an audion—or something like it—to amplify weak signals emitted by the brain.[55]

Though Gernsback seems quite confident that brains will become readable via some variation on radio technology, he is less confident on the details. For example, Gernsback expresses uncertainty as to whether he should treat thought waves as essentially electrical or chemical in nature; however he makes provisions for either scenario. The electrical case, naturally, is simpler. “If thoughts give rise to electrical waves,” Gernsback writes, “then by winding a few turns of wire on a headband and slipping it over the head, it should be possible to detect the presence of thought waves in the audion.”[56]

If, however, the brain does not produce its own electrical waves, Gernsback maintains, the audion-like amplifier will still be of use. He considers: “let us assume that active thinking does not give rise to waves, electrical or otherwise.” Even in this case, Gernsback reasons, “the mere chemical action (and resulting capacity effects) should produce a disturbing influence upon the audion.” He continues:

> These variations, if ever so slight, could then be amplified by the use of an audion or other amplifier, and the resultant effect be sent into an Einthoven string galvanometer. The small mirror attached to the string of the galvanometer will send its luminous pencil upon a light-sensitive paper tape which moves at a certain rate of speed in front of the mirror. The result will be a wavy line traced upon the paper tape in the well known manner…. A man sitting in front of his Thought Recorder will be able to actually see on a tape his recorded thoughts, the same as the telegrapher working on a trans-Atlantic cable watches his tape and its wavy line produced by the Syphon recorder, emerging from the latter.[57]

Here, telepathy transitions from an organic psychic force to a feat potentially achievable via contemporary technology. Gernsback references new, impressive tools to bring thought transference into the realm of reality—a strategy used by other writers at the time, and also by twenty-first century neuro-entrepreneurs (see Chapter 9). Yet, by emphasizing the power of novel inventions, Gernsback, at times, strays from older beliefs in telepathy-sans-technology.

Despite his sureness regarding the future of though transference, Gernsback wavers with respect to the ontology of thought waves. That is, Gernsback does not commit to whether thought waves exist “in here” or “out there”—whether they refer to “a wavy line traced upon the paper tape," or to undulations that naturally flow from the brain. First, he posits that "man's thoughts…do not necessarily have to remain within his skull"—that they radiate outward. Later, he admits that organic EM thought waves might not exist, and accordingly proceeds to propose a technology that would *produce* waves in response to chemical changes within the brain.

Gernsback's wavering exemplifies two superficially similar views of brain or thought waves, which I will classify as strong and weak. The *strong view* holds that thought automatically manifests as waves (likely EM in nature), which escape the skull unaided. Other brains may intercept this type of wave, thus explaining instances of spontaneous telepathy. According to the strong view, the generation of brain waves requires nothing beyond cognition itself; however, in some cases, the *reception* of brain waves might call for amplifying technologies.

The *weak view* of brain waves holds that cerebral activity is exclusively local. In this instance, waves refer to artifacts produced by a measurement apparatus that detects physiological fluctuations (*i.e.*, variations in any biometric: thermal, chemical, electrical or otherwise). The wave artifact may come in the form of manufactured EM waves; or the artifact may be as simple as an ink-drawn waveform that represents cerebral dynamics. The manufactured wave may be read by or otherwise transferred to a second party to produce a sort of synthetic telepathy. However, weak waves do not flow from brain to brain on their own. The conflation of strong and weak views characterizes not just early hobbyist literature, but discussion of brain waves throughout the term's history. For example, when early EEG produced its scribbles (weak waves), these oscillatory artifacts would sometimes be taken as content-carrying waves, *out there.*

Gernsback's publications featured articles adhering to the strong view, the weak view, and some combination of the two. Thought waves appeared in yet another cover story in 1922, by which time the magazine answered to the name *Science and Invention.* The story is a piece of science and fiction written by the author-inventor Thomas Willing Hicks. Unlike Gernsback's 1919 feature, the article espouses a decidedly strong view on thought waves, placing them alongside other EM frequencies that exist independent of their measurement.

Hicks writes: "Science has segregated and tabulated five different forms of electro-magnetic waves, namely, light waves, heat waves, wireless waves, Gamma-ray waves and X-ray waves. The new wave to be added to this list, and the most important and far-reaching of all is the thought wave." He elaborates:

> [T]he brain "struck" with a thought... causes a wave—just as the tossing of a pebble into a pool causes a shock to, and a rearrangement of, the electrons composing the hydro-oxygen molecules that make up what we call water-and a visible wave results. Now induce a healthy normal brain to perform the act of thinking…The result is the creation of an electro-magnetic wave—a wave caused by the mechanical act of the material brain registering a change in the condition of the mind, or a metaphysical thought—a thought wave.[58]

Hicks proposes that these wave travel beyond the skull and may be detected via processes resembling the reception of radio waves. In this case, successful thought transference requires a mechanical receiver; however, the brain itself serves as a transmitter. Hicks contends that thought waves "can be measured and recorded when the disturbance is properly amplified by the new scientific instrument known as a Multiple-Electrode-Vacuum-Tube-Amplifier."[59] Here, Hicks is referring to the technique, described above, whereby the addition of multiple control grids enhances the receptive precision of a radio.

Hicks displays a real understanding of the state of radio technology. However, part way through his piece, he abandons reality to relay the fictional story of a man who uses his Thought Wave Detector to sense the “Buying Thought” on the floor of the stock exchange. To the reader accustomed to a clear demarcation between fact and fiction, this transition is somewhat disorienting. Yet, the piece is consistent with the editorial mission of Gernsback, who saw imagination as a crucial instrument of invention.

Like pseudoscience spectacles of the nineteenth century, hobbyist magazines fused entertainment and education to create a form of scientific discourse that was at once practical and playful. Gernsback’s publications, like a mesmeric show, captured the *spirit* of new discoveries, even if they sometimes exaggerated the details. In both instances, a public forum for scientific engagement permitted the inclusion of creative, and even spiritual applications of new research—a place where *hopes* for the power of science mixed with science proper.

Rather than display healing miracles, Gernsback’s magazines featured seemingly miraculous inventions. Spiritualist feats like telepathy became acts performed not by mediums, but by vacuum tubes. And whereas Edward Hitchcock envisioned thought transference as something achieved by angels or men in a “in a future spiritual state,” Gernsback merely waited for a future technological state. Indeed, the articles in hobbyist magazines reflect a cultural turn in which rational thinkers increasingly justified whimsical beliefs via faith in the power of technology.

Pseudo-Science-Fiction

Twenty-first century scientists don’t tend to invoke ether to explain natural phenomena. In accounting for the medium’s fall from grace, one may point to a number of anti-ether events: the failure of Michelson and Morley to detect etheric drag and Einstein's theory of relativity are common contenders. However, ether did not succumb suddenly at the hands some scientist who proved its absence. Rather, I argue, ether slowly faded from relevance as waves achieved ontological independence.

Though turn-of-the-century technologies were usually described as working by virtue of sending waves through ether, they simultaneously popularized the notion of waves as independent, agential objects. The replacement of ugly cables with invisible, impalpable waves changed what technology—and transmission—looked like. This transformation also changed the status of waves: in a wireless EM framework waves do not flow in or through a medium, they *are* a medium.

At the time, proposed applications of EM waves ranged from pragmatic to fantastic. Falling somewhere in between, wireless energy transmission long remained a goal of both Marconi and Tesla. In 1912 Marconi articulated a vision for the future in which wireless overtook all forms of transmission. He describes:

> Further in the progress of wireless stands wireless lighting, heating and transmission of motor power. Each of these systems is based on the same principle as wireless telegraphy, only the transmitting and receiving instruments are different and the vibrations of the etheric waves have a different nature, intensity and length.[60]

Marconi's vision summarizes a broader hope that the success of wireless telegraphy would translate to other sorts of wireless transmission, presumably by tapping into different EM frequencies. In their own ways, both the notion of thought waves and of wireless energy follow logically from the achievement of radiotelegraphy. The primary challenge, it seemed, was to develop "transmitting and receiving instruments" that effectively exploited some powerful wavelength in the EM spectrum.

Early twentieth century theories of “thought waves” thus represent a maturation of telepathic theory that mirrored contemporary innovations in technoscience. During the nineteenth century, the notion of thought transmission grew from two distinct (but related) advancements. First, EM science demonstrated that powerful, invisible undulations pervade the universe; second, the invention of (wired) telegraphy exemplified the transmission of messages without the movement of bodies. Wireless telegraphy fuses these two premises, suggesting that wavy messages can travel not only independent of bodies, but also independent of tangible matter.

In light of this apparent dematerialization of transmission and the new ontological status of waves, a theory of brain waves becomes both more plausible and more potent. If telegrams do not require cables, then perhaps brain messages are not dependent on bodily matter. Perhaps the body, like a cobweb of telegraph wires, is nothing more than an unnecessary eyesore—a vulnerable vessel for messages that just might flow ably on their own.

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[52] Ibid.

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[55] In this article, Gernsback solicits feedback from Tesla, De Forest, and inventor Greanleaf Pickard. Though none of these men offer an unqualified endorsement of Gernsback’s machine, neither do they reject it outright. Tesla, for example, describes an alternative (but equally hypothetical) brain-reading invention that replicates mental images by reproducing the activity of the retina. Pickard is compelled by Gernsback’s idea but worries that audions are not up to the job. He believes brain waves would likely

fall in the range "from 3 X 10^2 cm. down to 3 X10^{10} cm," where "the audion would be useless." Gernsback, "Thought Recorder," 12.

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Chapter 4. Making Waves with Hans Berger (and sans Berger)

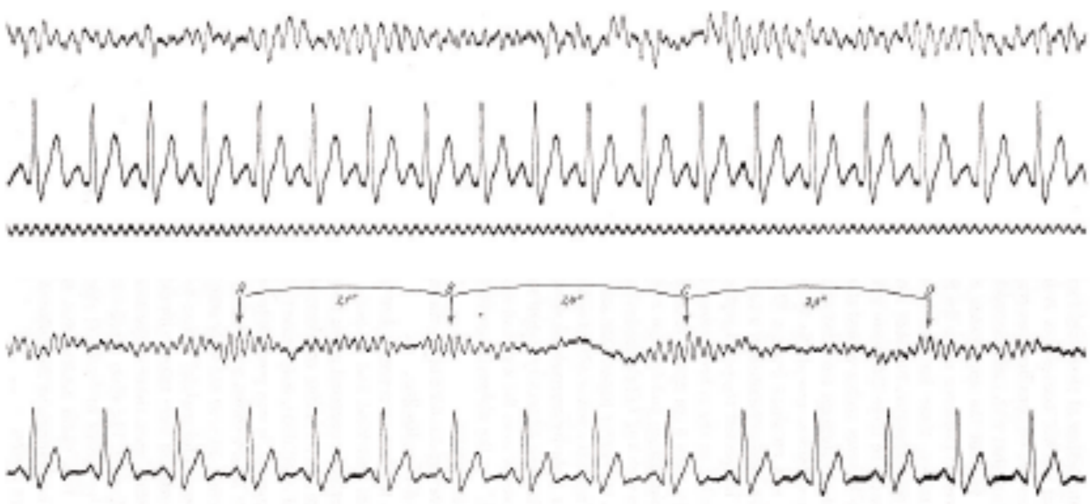

Figure 3. Early electroencephalograph recordings, obtained by Hans Berger, 1928-1929. Reprinted from David Millett, “Hans Berger: From Psychic Energy to the EEG,” *Perspectives in Biology and Medicine* 44, no. 4 (2001): 537.

In an age of brain scan abundance, one takes for granted the ability to see inside an active cerebrum. By tracking neurophysiological changes over time, techniques like fMRI and positron emission tomography (PET) yield colorful, three-dimensional pictures that neatly demarcate brain regions and their purported role in cognition (see Chapter 7). These maps are conceptually and aesthetically pleasing—yet their prioritization of the brain’s geography undermines its temporal dynamism.

Amidst such pretty pictures, the black and white waves of a basic electroencephalogram hardly register as a genuine brain image. They don’t *look* like the lobed structure we’ve come to associate with the mind. Yet, relieved of this structure, wavy lines become pure temporality. Like airborne Morse, apparent “brain waves” transcend geography and the conventional rules of biology.

The 1929 debut of EEG represents the first scientific depiction of the human brain as source of *activity*, rather than stagnant mush. Nineteenth century scientists were aware of the brain's dynamism; however, prior to the advent of EEG, they lacked tools specifically devoted to probing the brain in action.[1] Thus, even as wireless telegraphs transmitted EM signals across increasingly vast distances, the signals of the brain remained confined to the skull—undetected, unamplified, unread.

The Nerve of It All

While early electrophysiologists hesitated to tap into the central nervous system, the peripheral nervous system enjoyed ample prodding. In 1848 Emil Du Bois-Reymond introduced instruments that galvanized the field of electrophysiology. Specifically, he constructed clay electrodes particularly suited for biological work and a galvanometer of unprecedented sensitivity. Using these instruments, Du Bois-Reymond demonstrated a reliable correspondence between peripheral nerve activity and variation in electrical potential.[2] Du Bois-Reymond's tools and his research created a standard of practice for his field, which expanded considerably during the second half of the century.

Electrophysiologists used the same types of tools and often spoke the same technical language as telegraph engineers. Yet, there existed a distinction between the types of messages sent via wires and those conveyed along nerve fibers. Whereas operators receiving Morse translate dots and dashes into meaningful messages, the receivers at the end of peripheral nerves react mechanically. Muscles, being the simple meat matter that they are, respond to a limited number of instructions, such as, "move leg," "clench fist," and so on; they do not entertain the more lofty dialogue that one might expect of, say, a brain.

Through the end of the nineteenth century, surprisingly few researchers even considered applying their galvanometers to the brain proper. When researchers did prod the cortex, it was not to analyze the temporality of electrical dynamics, but to furnish proof for theories of brain localization. Localizationists argued that different aspects of sensation and behavior correspond to discrete brain regions; by contrast, holists (or associationists) viewed cognition as a distributed process.[3] The localizationist-holist debate continues, in some form, today. The former group currently tends to make its case via fMRI research that maps cognitive functions onto various cortical regions. Lacking high-tech brain scanners, localizationists of the nineteenth century used more coarse methods: their research primarily consisted of removing bits of animal brain to observe resultant behavioral deficits.

In 1875, however, Richard Caton devised a novel approach to localization. Rather than cut chunks of brain from unsuspecting subject animals, Caton instead removed portions of their skulls such that his Du Bois-Reymond electrodes might detect cortical currents. He coupled his electrodes with a mirror galvanometer that deflected light in response to any variations in current.[4] Caton concerned himself with electric waves only to the extent that they strengthened the case for localization. He focused on neural regions with known functions (in rabbits and monkeys); and his findings confirmed previously established claims. For example, Caton observed that "the currents of that part of the rabbit's brain which Dr. Ferrier has shown to be related to movements of the eyelids, were found to be markedly influenced by stimulation of the opposite retina by light."[5] Caton's work tallied a win for the localizationists, which overshadowed the fact that he had effectively invented an early EEG.

By extending electrophysiology to the brain, Caton's work broke new methodological ground. However, his conclusions did not immediately alter views of the brain. Like modern fMRI researchers, Caton used his temporal data, ironically, to bolster a geographic view. Further, his publications treat the brain as a sensorimotor system—effectively an extension of the peripheral nerves familiar to physiologists—rather than an organ of cognition. Given his nonhuman subjects, it is understandable that Caton did not venture to interrogate complex thought. By limiting his recording to animals, Caton avoided tricky questions of consciousness commonly reserved for human brains.

In Caton's time, researchers generally deemed *thought* beyond the purview of physiology, and perhaps beyond the purview of science at large. The field of psychology had yet to cohere; and efforts to understand the mind were distributed across mesmerism, phrenology, and psychical research—all of which, towards turn of the century, attracted increasing incredulity among the empirical elite. Though emerging research in psychophysics was better tolerated within the scientific orthodoxy, again, this field concerned itself with basic perception, rather than cognition or emotion.

In 1890, William James published *The Principles of Psychology,* which helped psychology gain entrée into proper science.[6] However, in the coming decades, James's humanistic work was somewhat eclipsed by behaviorists satisfied to relegate the mind to a black box. In his influential 1913 work, "Psychology as the Behaviorist Views It," John B. Watson asserts:

> Psychology as the behaviorist views it is a purely objective experimental branch of natural science. Its theoretical goal is the prediction and control of behavior. Introspection forms no essential part of its methods, nor is the scientific value of its data dependent upon the readiness with which they lend themselves to interpretation in terms of consciousness.[7]

A leader in behaviorist psychology, Watson efficiently summarizes his field's distaste for the imprecision of introspection. Thus, during the early twentieth century both psychologists and electrophysiologists largely neglected subjective experience. But then, subjectivity has a way of inserting itself into science.

Berger & His Machine

In 1893 a German teen was thrown from his horse. The teen, named Hans Berger, survived the accident without cracking his skull; and yet, he believed a bit of his brain had escaped. Forty-seven years later, Berger recounted this experience. He writes:

> Mounted on a rearing and overturning horse in battery traveling in the valley of a narrow pass, I fell… and came to lie under the wheel of an artillery gun. At the last moment, the gun drawn by six harnessed horses stopped and I escaped with no more than a fright. This happened in the morning hours of a beautiful spring day. In the evening of the same day I received a telegraphed inquiry from my father asking how I was doing. It was the first and only time in my life that I received such an inquiry. My older sister, with whom I am in particularly intimate familial contact, had arranged this telegraphic inquiry since she suddenly told my parents that she distinctly knew that an accident had happened to me. My relatives lived in Coburg at that time. That was a case of spontaneous telepathy in which at the moment of mortal danger, envisioning certain death, I acted as sender and my sister, who was particularly close to me, acted as receiver.[8]

This incident, though certainly jarring to the young Berger, was a rather typical example of spontaneous telepathy, according to contemporaneous texts produced by the SPR. Composed by Frederic W.H. Myers, Edmund Gurney, and Frank Podmore, *Phantasms of the Living* (1886) details hundreds of these uncanny events.[9] Many of the anecdotes follow the same trajectory as Berger's ordeal: a dangerous or near-death incident, then the inexplicable sense of worry experienced by dear friends or relatives at a remote location. Thus, when Berger later read *Phantasms of the Living* he found affirmation of his experience.[10] Berger did not interpret telepathy as a miracle, but rather as evidence that psychological events somehow interact with the physical universe.

In 1929 Berger debuted what he called the electroencephalogram, the first device to measure human brain activity; and he described this activity in terms of electrical waves. Given his formative telepathic experience and the nature of this invention, one comes to the alluring conclusion that Berger's lifework was in pursuit of brain waves qua telepathic medium. One might also note that, working in Germany, Berger should have been influenced by recent momentum in EM research, per the work of Hermann von Helmholtz, Heinrich Hertz, Ferdinand Braun, and others. In this sense, Berger seems an ideal locus for the convergence of telepathy, physics, and technology at the turn of the twentieth century. However, Berger's actual journey from equestrian to electrophysiologist was hardly so tidy.

Following the accident, Berger redirected his academic focus from astronomy to medicine, ultimately becoming a psychiatrist at the University of Jena. There, Berger's *official* research pertained to psychophysics and made no mention of thought transference. Antisocial by nature, and perhaps fearing negative opinions of his less conventional work, Berger pursued extracurricular brain prodding with the utmost discretion. Until the final years of his research, even Berger's close colleagues were unaware of his passion project—namely, to identify a physiological correlate of mental work (*i.e.* cognition) in the living brain.[11] At its core, the logic of this project was simple: if thought is a material process, then *some* measurable aspect of the brain must change in a way that corresponds to subjective events. This basic premise, however, does not prescribe any particular technique by which to monitor the brain: Should one track blood flow? Electrical changes? Temperature? Berger would try his hand at all of the above.

Early in his career (1902), Berger attempted to measure electrical fluctuations in the brains of dogs. He applied a capillary electrometer to the exposed canine cortex with the hope of observing the brain's response to sensory stimulation. However, Berger experienced considerable difficulty in obtaining a reliable signal—he was not a natural electrophysiologist. Following this failed exercise, Berger attempted to measure cerebral blood flow in a (human) subject whose brain was conveniently exposed, thanks to a recent medical craniotomy. In keeping with his goal to associate brain with mind, Berger tracked vascular changes as the subject encountered pleasant or aversive stimuli, or performed mental tasks requiring concentration. In 1907 Berger managed to obtain some data from this experiment; however, his observations did not deliver satisfying conclusions.[12]

During the same years that Berger experimented with various technical approaches, he also consulted theoretical literature with the hope of identifying a cohesive framework through which to interpret his data. He was impressed by the writing of Theodor Meynert and Alfred Lehman, who developed a cerebral energetics model based on the law of conservation of energy. Lehman's writing was attractive to Berger because it acknowledged the importance of both subjective and physiological events, and was logically consistent with psychophysics. Millett writes:

> Lehmann recognized that if one goal of psychophysical research was to determine the physical equivalent of feelings, emotions, and mental work, then it is essential to precisely measure all the components of cortical energy. The brain, like all organs, produces a store of chemical energy that it derives from various metabolic processes. Lehmann argued that this chemical energy is converted into three major forms of energy in the brain: heat, electricity, and what Lehmann called "P-energy," the psychic energy associated with different mental states… Given precise measurements of the cortical energy converted into heat and electricity, [one] could theoretically calculate the energy converted into conscious perception, emotion, thought, and perhaps even mental telepathy.[13]

Lehman's model suggested an organized research plan for Berger: he would conduct thermal and electrical studies and, hopefully, gain insight into the physical foundation of mental phenomena.

Berger's thermometric experiments were more successful than his initial trials with the electrometer. He accumulated a monograph worth of data, publishing "Investigations on the Temperature of the Brain" in 1910.[14] Still, Berger knew that his research was wanting: the picture of the brain would not be complete without a reliable index of the brain's electricity. By 1910 Berger had acquired an Edelman string galvanometer that might have compensated for his lack of electrophysiological finesse.[15] But before Berger could produce meaningful studies, a series of personal, professional, and national events stalled his work. The 1910s included marriage, the birth of two children, new professional responsibilities, and a world war in which Berger served as an army physician. His experiments in cerebral energetics did not resume in earnest until 1920.[16]

When he finally picked up his electrical work, Berger was just as deficient an electrophysiologist as when he left it. Failing again to effectively record from the brain, Berger instead attempted to electrically *stimulate* the brain—a tactic used previously by localizationists.[17] Over the course of his stimulation experiments Berger had the idea to connect Du Bois-Reymond electrodes to his string galvanometer. The combination of these devices represents the fundamental EEG: electrodes detect the flow of electrons; the galvanometer measures and amplifies fluctuations in this electric current; all else being controlled, any oscillations of the galvanometer should reflect electrical oscillations in the brain. Still, to adequately control "all else" and create a reliably functioning device would take several years of trial and error.

Berger was not, per se, an engineer. However, he made intelligent use of the tools to which he had access. The string galvanometer served as an early EKG and thus would have been available at Jena. Also among the hospital's resources was a store of patients with partially exposed brains. In 1924 Berger began measuring the brain of a teenager who had recently undergone trepanation. Working with this subject Berger observed, for the first time, convincing evidence of electrical fluctuations in the cortex. Initial trials did not confirm a correlation between mental effort and electrical activity; however, this small victory convinced Berger to further pursue this line of research.[18]

As Berger inched towards empirical success, his telepathic inclinations lingered. Millett quotes a telling diary entry, composed by Berger on January 3, 1926. It reads, in full:

> But still <u>Pantheism</u>!
>
> God in inconceivable thoughts!
>
> But it is just that our purely scientific understanding of psychical processes is too narrow!
>
> <u>Telepathy</u>.[19]

Though it is difficult to discern Berger's precise intention from this short passage, the entry makes clear that the influences of the SPR and his experience of telepathic sympathy had not left him. During the very years that Berger worked on perfecting EEG, thoughts of pantheism and thought transference vibrated through his brain.

Berger spent the bulk of the 1920s modifying his device and his technique. He aimed to rule out various sources of noise that might distort the electrical signal, such as electrodermal activity, blood flow, muscle movement, or his own clumsiness. By 1928 the machine had acquired a Siemens and Halske double-coil galvanometer, which was more sensitive than previous apparatuses; and Berger had finally acquired decent skills as an electrophysiologist.[20] His new setup also included a means of transforming ephemeral signals into lasting visual artifacts. La Vaque describes: "In order to obtain a permanent record with time markers available, a mirror was attached to the 'string', and the minute vibrations were reflected to a strip of photographic paper moving at a constant speed inside of a light-tight chamber."[21]

The improved device was sufficiently sensitive to detect signals from subjects with intact skulls (though it helped if they were bald). Berger recorded from a number of individuals and found a consistent and intriguing result: his photographic paper showed stereotyped waves, suggesting voltage fluctuations at regular time intervals. Berger identified two distinct frequencies, which he would later term alpha (α-w) and beta (β-w) waves. In 1929 Berger detailed this finding and more in his paper, "On the Human Electroencephalogram."[22]

The forty-three page report contextualizes Berger's research within the broader field of electrophysiology, includes data from male and female subjects of various ages, and outlines ideal locations for electrode placement. Berger's conclusions are fairly conservative, avoiding claims that lack sturdy evidence. However, in the final pages of his report, Berger takes up the subject that had been stimulating his brain for the past thirty-six years. He writes:

> Is it possible to demonstrate the influence of intellectual work upon the human electroencephalogram, insofar as it has been reported here? Of course, one should not at first entertain too high hopes with regard to this, because mental work…adds only a small increment to the cortical work which is going on

> continuously and not only in the waking state. But it is entirely conceivable that this increment might be detectable in the electroencephalogram which accompanies the continuous activity of the brain. Naturally I have performed numerous such experiments, but I did not arrive at an *unequivocal* answer. I am inclined to believe that with strenuous mental work the larger waves [β-w] …are reduced and the smaller [α-w]…become more numerous.[23]

After keeping his project a secret for decades, Berger's report came as a surprise to his colleagues at Jena.[24] Beyond Jena, Berger was effectively unknown. In the five years immediately following publication of "On the Human Electroencephalogram," few recognized the significance of Berger's accomplishment. Yet, feeling confident in his machine—and motivated as ever to *unequivocally* confirm his suspicions about mental work—Berger continued recording. In the following decade, he released thirteen additional papers about EEG. The alpha wave and its (apparently less interesting) counterpart, beta, were a common topic in these reports. Alpha waves, as defined then and now, are electrical oscillations in the range of seven to thirteen hertz; beta waves fall between twelve and thirty-five hertz. Berger came to believe that, whereas beta waves arise from unconscious metabolic activity, variations in the alpha rhythm correspond to conscious mental processes.

Despite the wireless enthusiasm characterizing the years in which he worked, Berger does not seem to have been metaphorically swayed by the wider technological landscape. He did not depict alpha waves as EM radiation, nor did he liken his device to radio. Instead, he compared EEG to EKG, describing observed oscillations as "a concomitant phenomenon of the continuous nerve processes which take place in the brain, exactly as the electrocardiogram represents concomitant phenomenon of the contractions of the individual segments of the heart."[25] Yet, unlike EKG, EEG represents changes in *the brain* and thus invites semiotic interpretation that one would not immediately attribute to cardiac rhythms. EEG tempts the interpreter to *read* its waves—or, at least, to read too much into them.

Amplifying the Signal

By 1933 Berger had published seven of his fourteen reports, all of which went largely unnoticed by peers and press. When physiologist (Lord) Edgar Douglas Adrian discovered Berger's work in 1934, he viewed the research skeptically. Adrian set out to replicate Berger's experiments with the initial intent of discrediting the alpha wave.[26] He thus surprised himself and colleagues upon detecting such waves in the brains of his lab mates. A Nobel laureate and an acclaimed electrophysiologist, Adrian received the respect and fanfare for this work that Berger did not initially enjoy; but Adrian consistently credited Berger for his contribution, rechristening alpha waves "the Berger rhythm."[27]

In addition to bringing public attention to Berger's findings, Adrian and partner Bryan Matthews considerably enhanced his machine. A proper engineer, Matthews had previously developed an amplifying system that recorded from multiple brain regions simultaneously—a tool he and Adrian had used on nonhuman subjects in the past. In the course of this animal research, Matthews had also built an ink-writing oscillograph, which he incorporated into the new EEG system. This modification both eased the documentation process and rendered the device's artifacts aesthetically consistent with other ink-writing technologies of the time.[28]

Using an improved machine and a depth of experience in electrophysiology, Adrian and Mathews confirmed many of Berger's findings and introduced data of their own. The team noted, for example, that the alpha rhythm was particularly strong when electrodes lie above the brain's occipital lobe, which was (and is) thought to be involved in vision. Adrian and Matthews further investigated this outcome by monitoring EEG signals under various visual conditions (*e.g.,* complete darkness, flashes of light, *etc*.). Following these trials, the pair concluded that the alpha rhythm is specific to neurons that process visual information—an interpretation that contradicted Berger's assertion that alpha is a brain-wide phenomenon related to mental work. Admitting that his own alpha rhythm was effectively indistinguishable from that of a water beetle, Adrian hesitated to associate the frequency with complex cognition.[29]

Following Adrian's endorsement of the technique, EEG was adopted in a number of labs internationally, though it was received with particular enthusiasm in the United States. During the 1930s work from Hallowell Davis, Frederic Gibbs, and Erna Gibbs (among others) made the U.S. a leader in EEG technology and research.[30] Borck attributes EEG's American popularity, in part, to "greater availability of electronic amplification technology in the US and the focus of neurophysiology on recording electric potentials."[31]

The relevant amplification tools often came not from scientific laboratories, but from the telecommunications industry. American physiologist Alexander Forbes was particularly instrumental in repurposing broadcast technology for biological studies. Forbes gained familiarity with techniques for signal amplification while working as a radio officer to the American navy during World War I.[32] After the war, Forbes established a system by which to dramatically amplify signals obtained by a string galvanometer via incorporation of a triode—a design which he shared with Adrian.[33]

Lord Adrian was keenly aware that popular technologies contributed to progress in his field. In 1928 he commented:

> Fortunately the detection of very small and very rapid electric changes has recently become a problem not confined to physiology, and our difficulties can be solved by the use of methods devised for wireless communication. When the academic scientist is forced to justify his existence to the man in the street he is inclined to do so by pointing out the essential part played by academic research in the development of our modern comforts. It is only fair, therefore, to point out that in this case the boot is on the other leg and the academic research has depended on the very modern comfort of broadcasting.[34]

Adrian's comment captures well the ongoing cross-fertilization of the radio industry and electrophysiology—both of which strived towards optimized signal detection and amplification.

Indeed, the state of American radio in many ways primed the country, culturally and technologically, to receive EEG. What remains peculiar, then, is why the technology had not been developed independent of Berger's isolated efforts. Borck writes: "Between 1901 and 1929, apparently no physiologist pursued a similar line of investigation although probably the majority of physiological laboratories in the Western world were better equipped to record an EEG than Berger's makeshift laboratory in the basement of the Psychiatric Clinic of Jena."[10]

Borck's argument is against strict technological determinism, which suggests, perhaps, that Berger's very personal motivation was instrumental to his success. As I discuss below, Berger would ultimately distance himself from the notion that brain waves carry telepathic messages. Still, he believed that that EEG communicated *something* important about subjective experience. The precise significance of the Berger rhythm—and of other so-called "brain waves"—remained to be determined, disputed, and distorted.

Finding Brain Waves…Everywhere

News of EEG did not circulate widely until after the publication of Adrian's 1934 report. However, brain waves existed in popular discourse prior to, and independent of, this research. As I have described, wireless technology inspired some to view the brain as a generator of EM waves that might succumb to technological interception. Pre-EEG accounts of brain waves (or thought waves) included conjecture that, per Hugo Gernsback, "man's thoughts, or the effects therefrom, do not necessarily have to remain within his skull, but that they actually radiate from the latter in a very imperfect manner."[35] Elsewhere, the term "brain waves" was used to describe peripheral nerve impulses, or simply as a colloquialism for bright ideas.

Just as Berger did not coin the term "brain wave," neither was he the first to propose a device for detecting such waves. Though Gernsback never constructed his Thought Recorder, in 1925 the Italian inventor Ferdinando Cazzamalli produced a device that was similarly inspired by wireless technology. Unlike Berger, Cazzamalli did not hesitate to frame his work in suggestive terms. The title of his 1925 paper, "*Fenomeni Telepsichici E Radioonde Cerebrali*," translates approximately to "Telepsychic Phenomena and Brain Radio Waves."[36] Cazzamalli's device departed from physiological orthodoxy in that it (supposedly) detected neural activity via receptive antennae rather than electrodes. Describing Cazzamalli's invention, the *Baltimore Sun* announced, "'Brain Waves' Located," as if to suggest some ongoing search for such undulations.[37]

During the 1920s the press classified a broad range of scientific endeavors as "brain wave" research. In April of 1926 the *New York Tribune* described Cazzamalli's work alongside unrelated investigations to suggest that his research was part of a cohesive trend. Titled, "The 'Brain Wave' Problem Again," the article reads:

> For a third time within a year a scientist reports that he has detected "brain waves," using a delicate radio apparatus to do so. The first report was from Professor Ferdinando Cazzamalli, of the University of Milan. He was followed promptly by a group of Russian Investigators. Now Dr. E. D. Adrian, of Cambridge, England, repeats the feat and obtains the same results. Dr. Adrian's experiments seem to have been controlled rather more carefully than were the others, and he is properly cautious.[38]

The author is correct to note that Adrian's work was more careful than the others mentioned; the author is less correct in suggesting that these three studies demonstrate "the same results" or solve some unified "brain wave problem." Still, for the present purposes this account usefully highlights the spectrum of research that would influence later interpretations of EEG.

The *Tribune's* allusion to "Russian investigators" is likely a response to the work of Vladimir Behterev, whose research was also covered by *Popular Science*, the *Boston Globe,* the *New York Times,* and others in the same year.[39] According to these reports, Behterev had developed a new model of supposed thought transmission by recording EM waves produced by the body. This news echoed earlier theories, articulated in hobbyist magazines and by neo-mesmerists, asserting that mental content manifests as EM radiation. Some outlets covering Behterev's work reported skepticism from the American scientific community; but these outlets did not withhold excited commentary. *Popular Science,* for example, suggested: "Telepathy soon may be added to radio, telephone, and telegraph as a means of communication with distant persons."[40]

Cazzamalli and Behterev were known to make provocative claims about thought transmission; thus, the press does not bear complete responsibility for telepathic interpretations of their work. However, it is curious that Adrian's research is included under the *Tribune's* brain wave umbrella, considering that during the 1920s Adrian remained largely devoted to the *peripheral* nervous system. Adrian's inclusion among brain wavers is likely a reference to a 1926 study in which he isolated the electrical activity of a single nerve fiber in a feline foot. The newsworthiness of this research lay not in a cultural obsession with cats, but rather in the technology used on this subject: Adrian's latest apparatus incorporated the three-valve amplifier (*i.e.,* a vacuum tube amplifier; *i.e.,* an audion), as inspired by Forbes. This instrument augmented signals tremendously and thus represents an important achievement in electrophysiology. Popular publications, however, focused on the wireless provenance of the device.

Though Adrian, in this instance, probed neither a brain nor a human, his use of broadcast technology sufficed to qualify this instrument as another iteration of brain radio. The *Tribune's* extravagant coverage of the apparatus began in March of 1926, with an article titled,

> Listens to Brain Messages with Wireless Device
>
> Dr. E. D. Adrian, of England, Reads Signals to Muscles With His Adaptation of Radio Apparatus
>
> Eavesdrops on the Mind
>
> "Decodes" Nerve Impulses by Segregating Single Fiber of System.[41]

The article continues: "Dr. Adrian expressed the belief that within the next few years it should be possible to read the main types of brain messages... and that the time is not far away when scientists will be able to record the actual events in the brain."[42] The article further uses the language of "decoding" and the standard analogy to telegraphy. Other newspapers similarly described Adrian's findings as "brain messages" and suggested that biological signals might be transmitted via radio.[43] In this way, Adrian received a reputation as a "brain wave" researcher eight years prior to confirming the alpha wave.

Thus, when the press began discussing EEG in 1935, it would not be the first time that they announced the discovery of brain waves. Some reporters placed the invention in the existing narrative of thought recorders and brain radio; others depicted the technology more carefully. Unsurprisingly, the definition of "brain wave" remained imprecise.

Interpreting EEG

> The human brain is constantly beating out a rhythm of brain waves. In its own unrecorded code, the seat of man's intelligence is tirelessly sending signals.
>
> Where do they go? What happens to them?
>
> …[W]e are used to thinking of electrical impulses as traveling. Signals are not only sent out but usually also received. Messages have a destination as well as a point of origin.
>
> What is the destination of the brain's messages? No one knows.
>
> —"Waves Sent from Brain Are Puzzling"[44]

A brain wave qua EM radiation, telepathic medium, or mental radio connotes some signal that transcends the brain and, potentially, carries meaningful content (the strong view). Brain waves per Berger are an artifact produced by EEG, representing a physiological rhythm within the brain—something akin to a heartbeat (the weak view). Popular interpretation of the EEG would conflate and confuse these connotations— a confusion from which the broader public has yet to fully recover.

Berger did not appreciate the more creative depictions of EEG research, and neither did he view brain waves as a vehicle for thought transmission. He made this point clear through critiques of Cazzamalli's work, which he took as a bastardization of his own project. Though Berger maintained until late in life that his horse incident was a genuine telepathic experience, he did not view the alpha wave as a mechanism for such experiences. To Berger, these two convictions were not contradictory.

Berger believed that some physical trace of mental activity might genuinely travel from one brain to another; however, his EEG research suggested that the rhythms he discovered were not good candidates for such a process. In 1938 Berger commented:

> Previously I had already indicated that my α-w and β-w bear no relationship to the electromagnetic oscillations which according to Cazzamaii [sic] emanate from the human brain. It is out of the question that the α-w and β-W of my E.E.G. exert any influence at a distance; they cannot be transmitted through space.[45]

Here, Berger is unequivocal as to limited mobility of his waves. Yet, by inventing an instrument that yields wavy artifacts, Berger himself unleashed brain waves into the cultural ethos, if not the ether.

Unlike alpha waves, EEG discourse indeed travelled far beyond its point of origin, enduring dramatic distortions in the process. Journalistic depictions of EEG in the 1930s and '40s varied from month to month, outlet to outlet. Many articles included references to alpha waves as a universal human phenomenon, while also stressing the uniqueness of an individual's electrical patterns (discussed below)."[46] Though popular coverage did not tend to extrapolate to the point of telepathy, genuine EEG research inevitably collided with preexisting conceptions of brain or thought waves.

Describing an EEG demonstration in April of 1935, William Laurence of the *New York Times* writes: "Thoughts in a human brain were harnessed to an electric pencil and made to write their record on paper."[47] In his article, Laurence refers to the machine as a "thought-detector," but complements provocative language with more faithful accounts of EEG research. In a second *Times* piece, eight days later, Waldemar Kaempffert more carefully distinguishes science from sensationalism. Referring to Laurence, Kaempffert writes that a member of the *Times* staff "had himself tested by an 'electroencephalogram,' which the press, by common consent, picturesquely but misleadingly shortened to 'thought recorder.'"[48] This description allows Kaempffert to both disparage the provocative terminology (previously used by Gernsback), while also perpetuating it. Among the "astonishing facts about thinking" revealed by the device, Kaempffert mentions studies indicating that "men and women think in different patterns," and that "each one of us makes a record which is as distinctive as a fingerprint."[49]

Kaempffert cautions that some interpretations of EEG may be overblown. "Do we really see our thoughts on the tape?" he asks. "The Harvard physiologists would be the last to say so." Still, his writing is provocative in its own way. Kaempffert highlights the connection between EEG and the greater technological landscape, writing: "Wires connected the electrodes with a set of vacuum amplifying tubes, like those in a radio set, and other wires connected the tubes with the 'thought recorder.'"[50] The choice to couch *thought recorder* in quotations—rather than avoid the term entirely—betrays a broader journalistic trend. In popular news articles, historic and current, the term *brain wave* often appears protected by qualifying quotations. This tactic indicates journalists' noncommittal stance with respect to the phenomenon. Certainly, "'brain wave'" is more succinct than "changes in electrical potentials within the brain, as indicated by the electroencephalograph." However, the term is ontologically suggestive, particularly in the context of radio and EM science more broadly. A brain wave—even in quotations—suggests the existence of a wave-thing, *out there,* in a way that more nuanced discussion of EEG does not.

Kaempffert continued to report on EEG for the *Times* into the 1940s, often using the term "brain wave," but alternately referring to brain "patterns" or "cerebral waves." Kaempffert became one of the more responsible journalists on this beat, describing the use of EEG for sleep studies (1937) and for diagnosing epilepsy (1940).[51] From the 1930s through the present, research on sleep and seizure disorders have been the most successful clinical applications of EEG; and the reason is somewhat intuitive. A seizure is the result of uncontrolled activity in the brain; and sleep is characterized by tame, predictable electrical patterns, with any disturbance to those patterns indicative of upset slumber. The utility of EEG for monitoring sleep is uncontroversial, but it is also unexciting. Thus, pronouncements about "brain waves" often pertain to less soporific subjects.

Early EEG frequently appeared in news stories as a sort of curiosity—a topic of conversation in itself, even in the absence of novel scientific data. For example, in October of 1939 journalists from the *Sun* mused about the potential "use of electric brain waves to decide the long-standing question of how quickly a human head dies when the French guillotine or executioner's ax cuts it from its body."[52] Much as with modern neurotechnologies, inclusion of EEG in a news event added an enticing piece of novelty to a story. In April of 1939, for example, the *Boston Globe* reported that, for the first time, a court admitted evidence obtained from a "brain wave machine." The device apparently testified that the defendant did not have the epileptic condition that, he claimed, caused him to murder the victim.[53]

Despite a lack of clarity as to what one could or could not determine with EEG, the very existence of a "brain wave machine" was cause for speculation and spectacle. In

1939 over two hundred attendees gathered for a public demonstration of EEG at New York University.[54] The crowd watched brain waves projected in real time as a student-subject completed perceptual and cognitive tasks (*e.g.,* multiplication problems of varying complexity). This experiment, led by Dr. C.C. Clark, was fairly consistent with Berger's efforts to correlate mental work with EEG rhythms. Yet, Dr. Clark also reportedly believed that EEG might "give clews to personality."[55]

According to the *Tribune,* Clark claimed that "the lines recorded from a nervous, worrying person are always irregular"—a statement that might have been a step too far for Berger, but that aligned with the direction of brain wave discourse at the time.[56] Though coverage began to abandon the notion of outright thought reading, reports increasingly suggested that EEG charts contain decipherable information about a person's character.

Becoming Brain Waves

Despite diversity in early discussions of EEG, one claim repeatedly surfaced. Namely, researchers and news outlets frequently forwarded the notion that every brain produces a unique electrical signature.[57] William Laurence, for example, declared that "[brain waves] may be said almost to resemble finger-prints, so that in the future it is not impossible to expect that the criminologist may add brain-prints to his methods of identification."[58] The concept of forensic "brain prints" has indeed reemerged in the twenty-first century, though its modern use is closer to a lie detector than fingerprinting technology (see Chapter 8).

Accompanying early discussion of individualized brain waves was the suggestion that neural frequencies codify personality—that by reading brain waves one might better understand the character of the person from whom these ripples flow. Though EEG did not *create* the idea of brain qua locus of character, it certainly contributed to the tendency to link identity to some component of neurobiology.[59] Further, EEG importantly introduced an empirical, technological means by which to parse neural traits—a way to discriminate among brains with new accuracy and authority.

Phrenology previously posited an important relationship between personality and the brain; however, this school tended to reserve a place for an agential soul, independent of biological tissue. Furthermore, whereas phrenology pertains to the brain qua mushy organ, EEG emphasizes the electrical activity produced by said organ. According to this view, the brain remains simple tissue, allowing the brain *wave* to assume a more active and transcendent role. Of course, researchers did not explicitly propose that brain waves absorb the responsibilities of the soul. Yet, if "human brain potentials have individuality"—as was stated by Drs. Abraham Gottlober and Lee Edward Travis—one might question whether brain waves, and thus some trace of the individual, linger in the EM ether after the body perishes.[60] Under these conditions, one could hypothetically contact the dead via detection of their unique electrical frequencies—a sort of neural spiritualism that forms the premise of the 1941 film, *For The Devil Commands.*[61]

The film tells the story of Dr. Julian Blair, a scientist developing a new brain wave machine that he plans to use as a kind of thought transmitter. At the beginning of the film, Julian's wife, Helen, serves as a subject in her husband's experiment. Soon after, Helen dies in a tragic car accident. Following Helen's death, Dr. Blair comes to believe that he can reunite with his love by summoning her distinct oscillations. Like other fictional scientists overcome by hubris, Blair's devotion to this project ultimately drives him to madness.

Figure 4. Mrs. Blair and her brain waves. This frame directly precedes the dialogue quoted below. From *For the Devil Commands*, directed by E. Dmytryk (Columbia Pictures, 1941).

Despite standard cinematic outlandishness, many motifs of the film draw from common claims regarding EEG during the 1930s and '40s. Consider, for example, the following dialogue, which transpires early in the film (just after Dr. Blair records Helen's waves in the lab):

COLLEAGUE 1: Has Mrs. Blair's graph ever varied?

BLAIR: The individual wavelength never varies.

COLLEAGUE 1: Well, I'll believe what I can see. Now, tell me where you'll go from there.

BLAIR: Well, eventually, *conceivably*, we may be able to record and read the thoughts of every human brain without a word being spoken.

COLLEAGUE 2: You actually believe that someday you can push a button here and read what I'm thinking in Chicago?

BLAIR: Well you'll be able to read my thoughts too!

COLLEAGUE 1: Impossible.

BLAIR: Well they called radio impossible…[62]

The film, like popular newspapers of the era, emphasizes the uniqueness of individual brain waves. And, as the above excerpt exemplifies, the technology of the day serves as a precedent that supports the plausibility of transmitting wireless mental messages. Further, the film's fictional scientist expresses beliefs not dissimilar from those held by real scientists of the nineteenth and early twentieth century. Dr. Blair's obsessive pursuit of his wife's brain waves recalls both Edward Hitchcock's vision of immortal electric impressions, as well as the spiritualist research of Oliver Lodge, who was similarly motivated by the death of a loved one.

The immortal electric soul is a particularly imaginative extrapolation of personalized brain waves. However, the film presents a dramatized version of a more pervasive view: that an individual, in some respect, *is* his or her brain frequency. Beyond spiritual implications, the equation of the mind with quantifiable brain waves had immediate social implications; for, the quantification of the psyche establishes a means by which to define a range of mental normalcy. An assertion that alpha waves "vary in frequency from eight to 10 cycles per second in a normal adult" is not overtly prescriptive.[63] However, one can predict how empirical measurement of mental activity might lend itself to the construction of neural—and therefore psychological and social—norms.

In 1939 Dr. George Kreezer of Cornell performed a study that investigated potential links between EEG patterns and intelligence.[64] Kreezer reportedly found that particular alpha rhythm subtypes correspond to low mental aptitude. Accounts of the study contain unsubtle racial intimations: “The chief result,” reports the *New York Times,* “has been the discovery of a definite correlation between characteristics of the E.E.G. records and differences in intelligence level. Thus, in one type of mental deficiency, the Mongolian type (so-called because they look like Mongols), the alpha index…increases progressively as the intelligence level increases.”[65] Elsewhere it was suggested that errant brain waves underlie mental deviance in crooks, and that schools might use EEG to identify intellectually gifted children “to guide their outstanding talents into the best channels to bring the benefits to the human race.”[66]

Adoption of EEG coincided with tactics of neural normalization in other corners of brain science and medicine. Early techniques in corrective psychosurgery, for example, emerged during the same years that EEG came into popular awareness. In 1935 Egas Moniz conducted the first human leucotomies, which inspired the clinical lobotomies of the 1940s and ‘50s.[67] I am not making a causal claim about the development of EEG and of lobotomy, but rather noting that multiple scientific movements in the 1930s attributed mental, behavioral, and social deviance to the brain.

Lobotomists aimed to restore psychosocial order by excising a specific region of the brain—a distinctly territorial, pre-telegraphic model that does not align with wave-based theories of personality. However, electroconvulsive therapy (ECT), introduced in

1934, was consistent with the language of EM technology generally, and with the notion of personality frequencies specifically.[68] In fact, some of the earliest representations of EEG in the popular press accompanied discussion of ECT. For example, a 1938 *Washington Post* article titled, “Diabolic Madmen Made Docile With New ‘Shock’ Treatment” features a photograph of a patient undergoing EEG observation, with the title “Brain Waves of Mentally Ill Measured.”[69] Though brain waves proper maintained a mystical charm, the machinery of EEG was often linked to illness or deviance.

The rise of interventions to correct problematic brains accompanied a discursive replacement of moral defects with brain defects. This shift points to an increasingly materialistic view of the self, and the conflation of neural and moral aberrance. Still, efforts in brain wave psychology were not entirely limited to the study of “madmen” and “Mongols.” Physiologist Hallowell Davis proposed the use of EEG to understand mental processes more generally and hoped to establish common ground between electrophysiology and psychology.

“It is obvious,” Davis told the *New York Times* in 1937, “that the study of human electroencephalograms has brought us close to psychology. Attention, interest, emotional tension, consciousness and so forth, appear repeatedly in the literature on the subject.” Davis concludes: “Here is a wide field for the future and a challenge to those of us who believe in the fundamental unity of psychology and neurophysiology.”[70] Despite Davis’s optimism, many electrophysiologists were slow to apply the language of mental states to EEG data. Recall that these researchers more typically recorded impulses from cat feet and frog legs—electrical subjects that do not raise troublesome questions about thoughts and feelings.

Physiologists were not the only researchers leery of feelings: at the time, even psychologists tended to resist adoption of introspective terminology. At the turn of the century, Ivan Pavlov forwarded his model of conditioned reflexes as an objective approach to the study of animal behavior; a decade later, Watson published "Psychology as the Behaviorist Views it;" and by the 1940s B.F. Skinner's version of radical behaviorism achieved prominence.[71] Thus, various forms of behaviorism dominated psychology departments for the first half of the twentieth century. Though the language of conditioning did not immediately jibe with ongoing work in EEG, electrophysiology and behaviorism would eventually find common ground.

During the 1940s and '50s the intertwined trajectories of brain science and technology would meet head on, yielding the fields of information theory and cybernetics. In this context, electrical brain patterns did not provide a strategy for investigating consciousness; on the contrary, they provided a strategy for reducing the mind to a machine, and its emissions to information.

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[1] Nonetheless, scholars and pseudoscientists of the nineteenth century devised creative methods to (attempt to) determine correlations between the contours of the brain and the contours of character. For example, the Society of Mutual Autopsy in fin-de-siècle France asked members to sign away their brains upon entrance to the group: when a member died, surviving members would dissect their friend's brain, hoping to identify relationships between neural morphology and the character of the individual during life. The society was slightly more empirical—and significantly more morbid—than phrenology, which was popular across Europe and the United States throughout the nineteenth century. See Jennifer Michael Hecht, *The End of the Soul: Scientific Modernity, Atheism, and Anthropology in France* (New York: Columbia University Press, 2005).

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[7] John B. Watson, "Psychology as the Behaviorist Views It," *Psychological Review* 20 (1913): 158.

[8] Quoted in David Millett, "Wiring the Brain: From the Excitable Cortex to the EEG, 1870–1940" (PhD diss., University of Chicago, 2001), 238; Millett's impressive historical research into Berger's life and his science was central to developing the present chapter. The repeated citation of Millett here speaks to the uniqueness of his research, and the key insights it provides for understanding Berger and his work.

[9] Gurney, Myers, and Podmore, *Phantasms of the Living*.

[10] Millett, "Wiring the Brain," 238.

[11] Raphael Ginzberg, "Three Years with Hans Berger: A Contribution to His Biography," *Journal of the History of Medicine and Allied Sciences* 4, no. 4 (1949): 361–371

[12] Millett, "Wiring the Brain," 268.

[13] David Millett, "Hans Berger: From Psychic Energy to the EEG," *Perspectives in Biology and Medicine* 44, no. 4 (2001): 526.

[14] Hans Berger, *Untersuchungen über die Temperatur des Gehirns* [Investigations on the temperature of the brain] (Jena, Germany: Gustav Fischer, 1910).

[15] Millett, "Wiring the Brain," 277.

[16] Ibid., 280.

[17] Ibid., 284.

[18] Ibid., 286-289.

[19] Quoted in Millett, "Wiring the Brain," 295.

[20] Millett, "Wiring the Brain," 294-295.

[21] Theodore J. La Vaque, "The History of EEG Hans Berger: Psychophysiologist. A Historical Vignette," *Journal of Neurotherapy* 3, no. 2 (1999): 3.

[22] Pierre Gloor, trans., "Hans Berger on the Electroencephalogram of Man: The Fourteen Original Reports on the Human Electroencephalogram." *Electroencephalography and clinical neurophysiology* 28, no. S1 (1969).

[23] Ibid., 72

[24] Ginzberg, "Three Years." Emphasizing the uncharacteristic unorthodoxy of Berger's research, colleague Raphael Ginzberg later commented: "What could we expect from a chief who was tense, who hardly spoke to us, whose only topic of conversation was hospital affairs, who was always anxious to avoid trouble, who was seldom able to help us with complicated cases? He never overlooked a deviation from established routine, nor would he ever take any step that was not in accordance with this routine." "Three Years," 368.

[25] Gloor, "Hans Berger," 72; italics in original.

[26] Cornelius Borck, "Recording the Brain at Work: The Visible, the Readable, and the Invisible in Electroencephalography," *Journal of the History of the Neurosciences* 17, no. 3 (2008): 367–379.

[27] Edgar D. Adrian and Bryan H. Matthews, "The Berger Rhythm: Potential Changes from the Occipital Lobes in Man," *Brain*, 57, no. 4 (1934): 355–385.

[28] Millett, "Wiring the Brain," 334.

[29] Adrian and Matthews, "Berger Rhythm," 373.

[30] Thomas F. Collura, "History and Evolution of Electroencephalographic Instruments and Techniques," *Journal of Clinical Neurophysiology*. 10 (1993): 476–504.

[31] Cornelius Borck, "Between Local Cultures and National Styles: Units of Analysis in the History of Electroencephalography," *Comptes rendus biologies* 329, no. 5 (2006): 454.

[32] John K. Bradley and Elizabeth M. Tansey, "The Coming of the Electronic Age to the Cambridge Physiological Laboratory: E.D. Adrian's valve amplifier in 1921," *Notes and Records of the Royal Society of London* 50 (1996): 217–228.

[33] Alexander Forbes and Catharine Thatcher, "Amplification of Action Currents with the Electron Tube in Recording with the String Galvanometer," *American Journal of Physiology* 52 (1920): 409–471.

[34] Edgar D. Adrian, *The Basis of Sensation: The Action of the Sense* (London: Organs, Christophers, 1928), 39, quoted in Borck, "Local Cultures," 451.

[35] Gernsback, "Thought Recorder," 12.

[36] Ferdinando Cazzamalli, "Fenomeni telepsichici e radioonde cerebrali," *Neuroloaica* 42 (1925): 193–218.

[37] "'Brain Waves' Located," *The Sun*, August 22, 1925.

[38] "The 'Brain Wave' Problem Again," *New York Tribune*, April 8, 1926.

[39]"Claims Success in Field of Telepathy," *Boston Daily Globe*, February 18, 1926; and "Thought Wave Capture and Transmission Reported in Russian Scientist's Experiments," *New York Times*, February 19, 1926. Though some of his ideas were outlandish, Behterev was, for many years, a serious researcher and a major force in psychology and neurology. His laboratory also cultivated a strong electrophysiology program, recording brain activity using a galvanometer—though he did not apply this method to the human brain. In his later years, Behterev expressed belief in the ability of thought to manifest as physical energy. See Vladimir Lerner, Jacob Margolin, and Eliexer Witztum, "Vladimir Bekhterev: his Life, His Work and the Mystery of His Death," *History of Psychiatry* 16, no. 2 (2005): 217–227.

[40] "Thought Messages Stir Controversy," *Popular Science*, May 1926, 56.

[41] "Listens to Brain Messages with Wireless Device," *New York Tribune*, March 29, 1926.

[42] Ibid.

[43] "Brain Messages by Radio Doubted," *The China Press*, April 23, 1926.

[44] "Waves Sent from Brain Are Puzzling," *Hartford Courant*, March 4, 1938.

[45] Quoted in La Vaque, "History of EEG," 7.

[46] "Paper Strips Tell Goings on in Brain," *Daily Boston Globe*, November 21, 1937.

[47] William L. Laurence, "Electricity in the Brain Records a Picture of Action of Thought," *New York Times*, April 14, 1935.

[48] Waldemar Kaempffert, "The New 'Electrical Thinking': Activity of the Brain Recorded on a Tape by the Delicate Electroencephalogram—Embryos Reared in Glass Vessels," *New York Times*, April 21, 1935.

[49] Ibid.

[50] Ibid.

[51] Waldemar Kaempffert, "Developments of the Week in Science," *New York Times*, November 21, 1937; and Kaempffert, "Science in the News," *New York Times*, October 6, 1940.

[52] "Plan to End Doubt If Cut-Off Heads Live," *The Sun*, October 15, 1939.

[53] "Record of 'Brain Waves' Admitted at Murder Trial," *Daily Boston Globe*, April 13, 1939.

[54] "Electric Waves from Brain Are Put on Screen," *New York Herald Tribune*, March 1, 1939.

[55] Ibid.

[56] Ibid.

[57] "Son's Brain Works Like Mother, Girls' More Like Fathers," *Austin Statesman*, February 16, 1938.

[58] Laurence, "Electricity."

[59] Today, this tendency reaches new extremes. Scientists and journalists often suggest that our brain chemistry, our synapses, or our brain morphology somehow reflects our identity. See, for example, Joseph E. LeDoux, *Synaptic Self: How Our Brains Become Who We Are* (New York: Penguin, 2003); and Sebastian Seung, "I am my connectome," TED, recorded July, 2010, https://www.ted.com/talks/sebastian_seung.

[60] "What the Scientists Are Doing," *New York Herald Tribune*, December 13, 1936.

[61] *For the Devil Commands,* directed by Edward Dmytryk (Columbia Pictures, 1941).

[62] Ibid.

[63] "Paper Strips."

[64] George Kreezer, "Intelligence Level and Occipital Alpha Rhythm in the Mongolian Type of Mental Deficiency," *American Journal of Psychology* 52 (1939): 503–532.

[65] "Electric Brain Currents Have Direct Tie to Intelligence Level, Cornell Study Shows," *New York Times*, December 17, 1939.

[66] Robert Potter, "Want a Baby? Then First Study Your Brain Waves," *The American Weekly,* July 12, 1942, 5.

[67] Sian Yong Tan and Angela Yip, "António Egas Moniz (1874–1955): Lobotomy Pioneer and Nobel Laureate," *Singapore Medical Journal* 55, no. 4 (2014): 175.

[68] Timothy W. Kneeland and Carol A.B. Warren, *Pushbutton Psychiatry: A Cultural History of Electric Shock Therapy in America* (New York: Routledge, 2016).

[69] Gerald G. Gross, "Diabolic Madmen Made Docile with New 'Shock' Treatments," *Washington Post*, March 7, 1938.

[70] William L. Laurence, "Man's Mind Traced by His Electricity," *New York Times*, April 23, 1937.

[71] George Windholz, "Pavlov on the conditioned reflex method and its limitations," *The American journal of Psychology* 108, no. 4 (1995): 575-588; Watson, "Psychology"; and William L. Heward and John O. Cooper, "Radical Behaviorism: A Productive and Needed Philosophy for Education," *Journal of Behavioral Education* 2, no. 4 (1992): 345–365.

Chapter 5. Waves Meet Computers

In 1951 three notable men of the day submitted their scalps for electrical analysis. Norbert Weiner, John von Neumann, and Albert Einstein underwent an EEG screenings to show, as *Life* magazine put it, "how a genius thinks."[1]

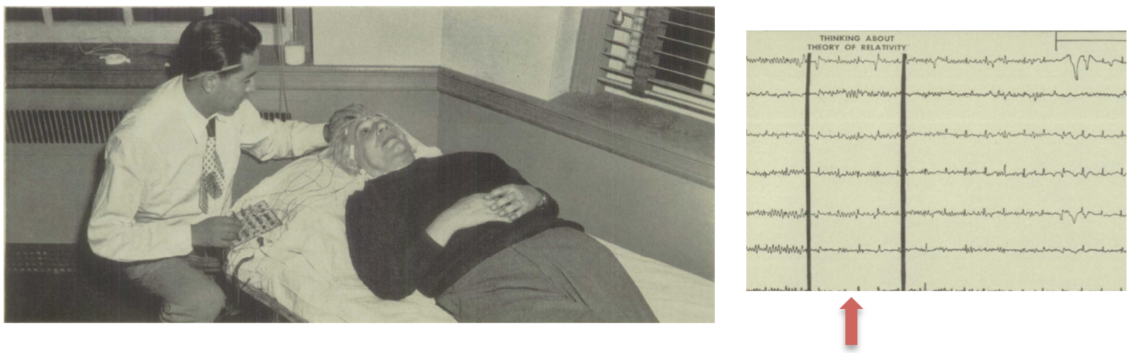

Figure 5. "Einstein's brain waves." Arrow points to time frame in which Einstein was, supposedly, contemplating the theory of relativity. Reprinted from "Einstein's Brain-Waves," *Life*, February 26, 1951, 40.

The experiment did not yield lasting insight into the physiological correlates of intelligence. Nonetheless, this spectacle of brilliant brains is multiply illustrative. It indicates that, by the middle of the twentieth century, EEG enjoyed an elevated and authoritative status. Further, the particular selection of geniuses for this exercise hints at key elements of the scientific and cultural zeitgeists. Weiner was the public face of cybernetics, a movement that framed organisms as feedback circuits and emphasized functional similarities among animals and machines; von Neumann was an early pioneer of electronic computers, redefining what machines can do (calculate) and how they do it (digitally). Einstein's particular breed of genius does not lend itself to brevity; but for the present purposes it is relevant that he seemed to disprove the existence of ether, while also pursuing a unified field theory that was decidedly wavy in nature.

All three "geniuses" owed their renown, in some respect, to the demands and fruits of war. In addition to its many atrocities, the Second World War brought the development of computing technology and, along with it, a host of new metaphors with which to think about communication, behavior, and brains. Simultaneously, wartime wounds and funds contributed to the refinement of EEG. In the postwar context, wavy representations of the brain complemented and competed with neural network models that depicted brain activity in binary terms.

Computing and theoretical neurobiology prioritize a distinctly non-wavy aesthetic: on/off, 0/1, binary, Boolean, bits. The continuous waves of EEG do not conform to this aesthetic. Still, the rise of digital discourse did not wholly replace waves, culturally or scientifically. Whereas discrete computational systems provide a mirror for the logical, calculating brain, *waves*, I argue, reflect a different aspect of mental life: the spiritual, intuitive, feeling brain.

Reflexive Reflections

> The idea of the reflex arc has upon the whole come nearer to meeting this demand for a general working hypothesis than any other single concept. It being admitted that the sensori-motor apparatus represents both the unit of nerve structure and the type of nerve function, the image of this relationship passed over into psychology, and became an organizing principle to hold together the multiplicity of fact.
>
> —John Dewey, "The Reflex Arc Concept in Psychology"[2]

Analogy between the nervous system and communications technology substantially predates the rise of electronic computing. However, until the 1940s, this discourse did not typically extend to *intra*-brain communication. That is, the brain was previously imagined as a communicating organ to the extent that it sent messages or signals to organs *exterior to itself:* the brain relays telegraph-like commands to the limbs; the brain transmits radio-like waves to a human or machine receiver; and so forth.

The concept of brain *cells* as communicating agents arrived belatedly—an understandable delay considering that the term *neuron* did not come into use until the 1890s. Indeed, through the turn of the twentieth century, scientists disagreed as to whether the brain consists of a continuous reticular network, or a collection of discrete cells.[3] The latter stance, known as "the neuron doctrine," asserts that brain cells interact via the exchange electrical or chemical signals—a view that eventually became scientific consensus and redefined the notion of *brain communication*.

The premise of signals emitted by *the brain* lends itself to construal of these emissions as corresponding to conscious thought.[4] Neuron-to-neuron communication, however, suggests information transfer at an infraconscious level. Put another way: intra-brain communication would be analogous to the currents that flow through circuits within a radio, rather than the EM frequencies broadcast by the radio. Unlike thought waves or radio waves, this type of internal communication does not seem to carry relatable messages. In this way, intra-brain signaling disassociates neural activity from phenomenal experience and enables a more functionalist view of the brain—a view that proved inspirational to cyberneticians.

Still, cybernetics cannot take full credit or blame for robotic depictions of the human subject. Long before the field likened brains to circuits, psychologists and physiologists deployed the language of *reflexes* to eschew mind and brain, respectively. Behaviorists modeled their subjects as aggregations of stimuli and responses—instinctive or conditioned reflexes. And neurophysiologists prioritized the analysis of *reflex arcs*, simple neural circuits involving (1) a sensory neuron that responds to external stimuli, and (2) a motor neuron that drives muscle response.[5] Such a circuit extends from the periphery (say, the leg), through the spinal cord, and back out to periphery again—brain none the wiser. Muscle reflexes thus provide both mechanism and metaphor for behavior devoid of subjective experience.

The ability to apply a reflex model at behavioral and cellular scales certainly enhanced the scientific currency of such an approach. But reflex models also succeeded for practical reasons: brains and minds are difficult to study. Scientists, of course, understood that the brain plays a role in behavior. However, they treated the organ like a more complicated version of the reflex arc: sensory signals travel up the spinal cord to the brain, which integrates said signals to produce the appropriate motor response. Accordingly, localizationists studying the brain tended to seek anatomical correlates of sensorimotor processes, rather than complex subjective experiences.

Until Hans Berger introduced EEG, mainstream electrophysiologists generally neglected nervous tissue above the shoulders. Lord Adrian of Oxford and Charles Sherrington of Cambridge serve as apt representatives of physiological orthodoxy through the 1930s. Early in the century, Sherrington defined the general structure of reflex circuits and outlined how signals from nerve fibers prompt muscles to relax or contract. Sherrington also coined the term *synapse,* referring to the connecting space and structures between two neurons, or between a neuron and a muscle cell.[6]

During the 1920s Adrian elaborated on Sherrington's work, using novel amplification techniques to study the electrical dynamics of a reflex arc with enhanced precision. In one of his most consequential experiments, Adrian monitored the relationship between stimulus strength and electrical output in a receptor (isolated from a frog muscle) sensitive to touch.[7] He found that variation in stimulus strength has no effect on the magnitude of the resultant electrical impulse. That is, strong and weak input stimuli created output waves of equal amplitude.

Adrian and Sherrington shared the 1932 Nobel Prize in Physiology or Medicine "for their discoveries regarding the functions of neurons."[8] In his Nobel lecture, Adrian concluded: "The nerve fiber is clearly a signaling mechanism of limited scope. It can only transmit a succession of brief explosive waves, and the message can only be varied by changes in the frequency and in the total number of these waves."[9] Depiction of impulses as a "signaling mechanism" naturally suggests analogy with communications technology. Equally important, however, is Adrian's emphasis on the *limitations* of nerve signals.

Adrian's work indicated that nerve fibers do not produce a wave spectrum of the EM variety; nor do they transmit a range of content across different frequencies like a radio. Rather, his research suggests that, in the nervous system, *a wave is a wave is a wave*; and either a neuron produces one or it does not. Put another way: nerve cells function in an *all-or-none* fashion.[10] Given this finding, it becomes less important to represent electrical activity as waves at all. Nervous impulses might as well take the shape of anonymous units that beep at varying paces—"spikes," in the neuro parlance. As I will show, the all-or-none characterization of nervous activity (which was not Adrian's finding alone), would prove central to cybernetic appropriation of neurobiology; but first, the field would have to expand its purview from the periphery to the brain proper.

At the time that Adrian delivered his Nobel speech he was ignorant of Berger's papers on EEG. After conducting his own alpha wave experiments two years later, Adrian reassessed some of his assumptions about nerve activity. Though he did not question the homogeneity of nerve impulses, Adrian did confront the role of the *brain* in mediating sensorimotor responses. Borck summarizes: "Electroencephalography undermined Sherrington's and Adrian's concept of higher nervous action as reflex integration…[T]he central nervous system was no longer a central telegraphy office processing incoming messages and outgoing commands, but a strikingly active source of intrinsic activity."[11]

Recall that during the 1920s some journalists characterized Adrian's single-fiber analyses as evidence of "brain waves"—part of a larger trend that framed nervous currents of any variety in such terms. By the 1930s, however, Adrian and others began to collapse cellular oscillations into all-or-none signals. Still, this shift hardly rendered "brain waves" obsolete: ripples continued to flow in the form of large-scale brain activity recorded by EEG. In the coming decades, EEG matured into a proper clinical tool; and the all-or-none model of neuronal behavior matured into the field of theoretical neurobiology.

Cells to Cyber

The reduction of impulse waves to all-or-none signals at first seems a technological regression: from radio back to Morse. However, this shift appears more forward-looking if one thinks of discrete signals not as dots and dashes, but as zeros and ones. That is not to say that binary models of nervous activity took their inspiration from electronic computers, which had yet to be invented; rather, during the 1930s and '40s computing and neurobiology coevolved, mutually contouring the discrete aesthetic of cybernetic consilience.

Central to this consilience was what Aspray describes as the "scientific conceptualization of information."[12] This conceptualization drew from 1940s work by Claude Shannon who, Aspray writes, aimed "to give specific technical definitions of concepts general enough to obtain in any situation where information is manipulated or transmitted."[13] Electrical signaling among neurons conveniently qualifies as such a situation; and an informational paradigm allows scientists to describe neuronal impulses as a form of communication, without suggesting that the interception of these signals might equate to mind reading. For Shannon and his followers treated information like a quantity rather than a message or mental experience. In this formulation, information obeys physical laws, but is not bound to any particular physical substrate: materialism without materiality, and communication without content.

That tiny cellular signals lack profound meaning sounds reasonable enough; yet, fashioning the entire brain as void of content is a tougher sell. That is: if one treats neuronal communication as a purely quantitative phenomenon, then at what level of brain activity do qualia emerge? This question is effectively an informational iteration of the "hard problem" of consciousness—the problem of defining the elusive relationship between biological matter and subjective experience. This kind of problem, however, becomes less prominent if one treats the brain not as an organ of consciousness, but of *calculation*. And an all-or-none view of nervous activity primes the brain for depiction as just such a machine.

In 1943, Warren McCulloch and Walter Pitts published, "A Logical Calculus of the Ideas Immanent in Nervous Activity," the essence of which is well summarized by the paper's opening sentence.[14] "Because of the 'all-or-none' character of nervous activity," the authors write, "neural events and the relations among them can be treated by means of propositional logic."[15] In the ensuing pages, the authors use logical syntax and Boolean algebra to transform neurons from messy biological tissue into docile digital units in abstract space. The paper effectively launched the field of theoretical neurobiology and established an analogical kinship between brains and computing machines—an affinity that continues to thrive.

In crafting their logical calculus, McCulloch and Pitts reference Sherrington's reflex arc, Whitehead and Russell's *Principia Mathematica,* and the Turing machine. As the authors transition from biological to theoretical conversation, neurons become "psychons" and interconnected psychons form "neural nets"—structures that aesthetically and functionally resemble electronic circuits. McCulloch and Pitts admit that psychons and nets simplify biological reality, yet they assert that their logic encapsulates the dynamics of actual, thinking brains. They conclude:

> The "all-or-none" law of these activities, and the conformity of their relations to those of the logic of propositions, insure that the relations of psychons are those of the two-valued logic of propositions. *Thus in psychology, introspective, behavioristic or physiological, the fundamental relations are those of two-valued logic*.[16]

Here, McCulloch and Pitts posit that all facets of cognition and behavior correspond to discrete functions. Though a nod to introspective psychology signifies a nontrivial departure from pure behaviorism, two-valued logic hardly resonates with genuine introspection.[17] Such logic confines thought to a series of binary calculations—a far cry from the fluidity of subjective experience. Specifically, this calculative framework neglects *emotions,* which register as neither binary, nor conventionally rational.

Though the language of digital logic fails to capture the subtleties of rich emotional states, it serves handily as a unifying discourse for biological and computational systems. The McCulloch-Pitts paper thus became a foundational work in cybernetics. During the same year that the pair published "Logical Calculus," Norbert Wiener, Arturo Rosenbleuth, and Julian Bigelow published "Behavior, Purpose and Teleology," which proved similarly foundational.[18] In the paper, Wiener *et al* impose high-tech trimmings on decades-old behaviorist dogma to describe machines and animals in terms of goal-directed reflexes. Central to cybernetics is the conflation of communication and control, and an emphasis on self-regulation. According to this view, communication serves as feedback that modifies behavior in service of some desired outcome.

Wiener and colleagues define *feed-back* as a process by which "the behavior of an object is controlled by the margin of error at which the object stands at a given time with reference to a relatively specific goal."[19] For example, an anti-aircraft servomechanism—the archetypal cybernetic machine—uses negative feedback to anticipate the future location of a plane and fires shots accordingly. From a cybernetic perspective, the most successful behavioral systems are "purposeful," a word used to describe actions that are "directed to the attainment of a goal-i.e., to a final condition in which the behaving object reaches."[20] This definition precludes more romantic ideas about human purpose, but obtains in a broad range of "behaving objects," placing the human, the servomechanism, and the dung beetle in a single framework.

By 1943, the recognition of functional similarity among animals and machines was not particularly groundbreaking. Nervous systems and communications systems already appeared as functional brethren due to a lengthy history of material and discursive exchange among engineers and biologists. It was not the Second World War, but the First that gave electrophysiologists like Adrian powerful amplification tools, initially developed for long distance communication; and even prior to Adrian's work, both researchers and journalists discussed nerves and telegraphy in similar terms.

Yet, whereas previous brain-machine dialogue involved informal discursive overlap and utilitarian material exchange, cybernetics comprised a deliberate effort towards disciplinary cross-pollination—an effort that took perhaps its most deliberate form at the Macy Conferences in New York. Transpiring between 1941 and 1960, this lecture series congregated a diverse group of researchers with the goal of enhancing cohesion across fields.[21] Though not exclusive to discussion of cybernetics, the conferences have become known for fostering that school of thought.

The novelty of cybernetics lay not in establishing a relationship between animals and machines, but in the recodification of how and why these systems work. According to cybernetics, purposeful organisms (biological or synthetic) use informational feedback to approximate a productive goal. Here, an apparent commutability among cellular and technological units disenchants us of biological exceptionalism, and redefines the *purpose* of human behavior and society. The work of McCulloch and Pitts complements goal-seeking behavior with a vision of digital brain cells. Inside and out, the human subject thus becomes a calculating machine.[22]

Under cybernetics, technological metaphor invades the brain and dominates behavior. *Homo sapiens* becomes accordingly robotic: he senses stimuli, executes motions, and he might even perform complex mental calculations. But, for *Homo technologicus,* feelings do not compute.

Still, cybernetics comprised only one facet of brain science—which is fortunate, considering that much of its research proceeded in the absence of actual brains. The development of EEG, by contrast, very much depended on contact with skulls, and thus with human beings.

EEG in War and Peace

At a London meeting of the International Neurology Congress in 1935, William Lennox of Boston presented a picture of disease in the brain. Specifically, he presented EEG charts showing the erratic oscillations that coincide with seizure in individuals with epilepsy.[23] Frederic Golla, a psychiatrist at Maudsley Hospital in London, was inspired by this work and eager to explore diagnostic applications of EEG. However, like most clinicians at the time, Golla lacked familiarity with the relevant technology. He therefore jumped at the opportunity to recruit W. Grey Walter, a young researcher from Adrian and Matthews's lab at Cambridge.[24]

In the early years of EEG experimentation, constructing and working with the new apparatus presented a challenge that deterred physiologists accustomed to simpler techniques. Walter, however, seemed to relish the technical aspects of research. Born in 1910, Walter was a baby of the radio age. He grew up playing with crystal sets and apparently never lost his enthusiasm for tinkering.[25] Walter's graduate work was equal parts neural circuits and electrical circuits; he obtained his MA in 1934—the same year that his mentors publically validated the Berger rhythm (*i.e.* alpha waves). By his mid-twenties, Walter was a skilled technologist, but not a physician; Golla was his inverse. Together, they rapidly expanded the role of EEG in medicine and beyond.

Whereas Berger's device had only two electrodes, Walter employed up to eight channels, distributing electrodes along a subject's scalp to analyze region-specific changes in neural rhythms.[26] Though EEG's forte is the detection of temporal dynamics, Walter recognized the benefits of attending to brain geography. Ongoing localization research yielded compelling evidence linking sensory and motor processes to specific cortical regions; and the ability to localize neurological malfunction was of obvious clinical value. With his multi-channel technique, Walter identified electrical patterns associated with the presence of brain tumors, introducing the terms "delta" (0.5 to 3.5 hertz) and "theta" (4 to 7 hertz) for these slower waves.

In 1939 Walter and Golla relocated to the Burden Neurological Institute in Bristol. In the following years, war catalyzed improvements in EEG techniques and technology: in order to rapidly evaluate soldiers with head wounds, Walter constructed devices that were mobile and easy to read. War also hastened the development of social infrastructure for clinical EEG, particularly in England, the United States, and Canada. Walter later recalled:

> The war period called for a rapid development of brain technique as a clinical accessory and for the sign and manufacture of better EEG equipment, the training of assistants and the formation of special societies—developments which probably would not have occurred until much later if physiological research had been uppermost…The first National EEG Society was formed primarily to make available our fund of knowledge to centres dealing with military casualties. At the first meeting of this group, held literally in the midst of the battle of London, criteria of electrical abnormality were agreed on and a glossary of terms was drawn up.[27]

Applications of EEG on the battlefield did not remain on the battlefield. Following the development of clinical training programs and the production of more reliable technology, EEG appeared in non-military settings, and eventually non-medical settings. Hayward writes: "As the [EEG] technology became more authoritative and respectable it began to be taken up outside the confines of the psychiatric hospital, being used as an artificial expert in cases of personality testing and deciding criminal responsibility."[28]

Wartime newspaper articles described the use of EEG to screen fighter pilots for epilepsy—a function that, however narrow, inspired suspicion that electrodes might decipher other mental features.[29] And as the visibility of EEG increased, the term "brain waves" became more firmly associated with the graphs it yields. During the 1940s, popular news outlets regularly reinforced the notion that brain waves betray something important about a person's thoughts or her character. For example, in 1941 *The Washington Post* announced: "Brain Waves Provide Key to Mind."[30] The author writes: "Insanity, mental troubles and psychoses present a confusion of wave forms like mixing all the earth's storms simultaneously over a small sea." The author acknowledges the challenges of gleaning meaning from EEG records, but also suggests that such records may offer insight into personality or behavior. He notes, for example, that the waves of an "alcoholic brain" possess "musical beauty," adding, "This alcoholic symmetry, however, is never a sign that the intoxicated person is about to burst into song."[31]

Elsewhere, reports of murderous brain waves and "brainprint bad boys" preserved the belief that EEG detects psychological or moral deviance.[32] Researchers and

Want a Baby? Then First Study Your Brain Waves

Some Day Brain Waves May Be Able to Tell What Makes a Criminal and Explain Why Some of the Worst Crooks Come From the Best and Most Moral Families.

Electrical Impulses From Little Gray Cells Which Tell If You Ought to Marry, Forecast Stomach Ulcers, Pick Good Drivers and Pilots—And May Answer the Question of Just How Long Our Minds Really Live AFTER Death

Figure 6. Brain waves in the news. Lower left caption: “Some Day Brain Waves May Be Able to Tell What Makes a Criminal and Explain Why Some of the Worst Crooks Come From the Best and Most Moral Families.” Lower right caption: “Electrical Impulses From Little Gray Cells Which Tell If You Ought to Marry, Forecast Stomach Ulcers, Pick Good Drivers and Pilots—And May Answer the Question of Just How Long Our Minds Really Live AFTER Death.” Reprinted from Robert Potter, “Want a Baby? Then First Study Your Brain Waves,” *The American Weekly*, July 12, 1942, 5.

journalists also continued to conjecture that certain brain waves might indicate great (or not-so-great) intelligence. And, in 1942, William Laurence reported on "the possibility of determining from brain waves the 'cerebral age' of an individual…thus offering the promise of an objective scientific method for determining the age for retirement."[33] Yet, despite ongoing brain wave applications and speculations, no one had explained why, in fact, the brain waves at all.

By the 1950s, scientists understood that a neuron's electrical dynamism depends on the movement of ions in and out of cell membranes.[34] However, even equipped with this knowledge, one would not necessarily predict the presence of large-scale oscillations in the brain, as detected by EEG. Single neuron emissions are not anywhere near strong enough to tickle electrodes on the other side of a skull. Thus, any signal detected by EEG must correspond to a huge population of cells firing *simultaneously*. Stereotyped brain waves indicate incredible neuronal synchrony; and there is no obvious reason why such synchrony should exist.

Shades of Grey Walter

Grey Walter believed that the brain's elegant electrical harmonies were no accident. Once relieved of war-related work, he thus directed his energy towards understanding brain waves at a more basic, evolutionary level. At about the same time, Walter fell in with a crew of cybernetically-minded gentlemen, including Ross Ashby, Horace Barlow and Alan Turing. In 1949 these thinkers and others formed the Ratio Club, Britain's counterpart to America's Macy Conferences—which is to say a hub for conversation and socializing around the topic of cybernetics and its many constituent disciplines.[35]

As I have described, cybernetics welcomed input from behaviorism, mathematics, engineering, and neurobiology; *waves,* however, did not typically feature in its grand syntheses. Brain waves challenge traditional cybernetic models for the same reason that Berger's work challenged the views of early twentieth century electrophysiologists: intrinsically generated waves do not jibe intuitively with input-output models of animals and machines.

Walter recognized the tension between his work in EEG and the feedback systems discussed in cyber-behaviorist literature. In his 1953 trade book, *The Living Brain,* Walter describes "two paths" in brain science: one starting with "Berger's discovery of electrical rhythms in the brain, the other with Pavlov's discovery that any bodily function can be made the basis of a conditioned reflex."[36] Walter believed that the future of brain research depended on a fruitful convergence of these two paths; and, being a career electroencephalographer as well a public cybernetician, he was well poised to guide this convergence. Though Walter's research certainly does not capture the entirety of EEG experimentation at midcentury, I focus on his contributions, in part, because his mutual attention to brain waves and cybernetics usefully integrates parallel efforts in neurobiological research.

A perennial tinkerer, Walter prodded the brain using gadgets more quirky than conventional EEG. In 1946 he fashioned an "electronic stroboscope" (*i.e.,* a strobe light) to stimulate the brain with flashes of light at intervals approximating the frequency of neural oscillations—a phenomenon he called "flicker." Walter observed that flicker exposure sometimes caused the to brain pulse in time with the stroboscope. To enhance this mirroring effect, Walter closed the feedback loop. That is, he constructed a cyborgian circuit in which the frequencies of the brain, as detected by EEG, modulated the frequency of the strobe light; in turn, the light stimulation would (ideally) lock the brain into a given rhythm. Walter summarizes: "to keep the flicker and the brain in time, a feedback system of automatic control was adopted."[37]

Walter's emphasis on feedback and control betrays his cybernetic influences. Yet, his circuit redefines "behavior" and "purpose" in ways that distinguish the apparatus from a standard servomechanism. The stroboscope-brain-EEG circuit does not target an outward behavioral goal, but rather aims to modify the internal rhythms of the brain. This goal reflects a more general inward turn in Walter's work; his postwar experiments lacked direct applications in medicine or industry, instead serving Walter's mission to develop a more cohesive model of the human brain and its waves.

Walter hoped that any correspondence between changing mental states and EEG frequencies might shed light on the physiological function of neural synchrony. His experiments thus strayed from a strict behaviorist paradigm in that they relied on *subjective* accounts from participants. In Walter's early flicker studies, some subjects reported strange experiences, including visual hallucinations.[38] According to Walter, these experiences tended to arise during stimulation at a rate of approximately ten flashes per second, or ten hertz—*i.e.,* the alpha rhythm. During flicker stimulation Walter also observed corresponding activity in the brain's occipital lobe.

Curious about the effect of flicker in non-visual brain regions, in 1951 Walter collaborated with engineer Harold Shipton to construct the *toposcope*—an apparatus that combines temporal and geographic views of the brain. Like standard EEG devices, a toposcope gathers data via electrodes placed along the scalp. However, Walter describes, "instead of being connected with pens, [the channels] lead the electrical activity of the brain tapped by the electrodes for display on the screens of small cathode-ray tubes."[39] As the machine's name suggests, this process yields a topographic view of electrical activity. Photographs of the toposcope at work document the regional distribution of electrical activity at a single moment, corresponding to a given stimulus, behavior, or subjective report (see Figure 7).

Much like brain scans today, toposcope images somewhat forgo temporality for geography; and, in the hands of another scientist, the tool might have spawned a new approach to localization research. Walter, however, devoted himself almost obsessively to brain rhythms and was not wooed by simple structure-function relationships. He did not want to know which brain regions were "on" or "off," but rather, which wavelengths dominate, when, and where.

Using the toposcope, Walter observed that, over time, flicker-induced alpha waves spread from the occipital lobe to brain regions not directly involved in visual processing. According to Walter's interpretation, "This meant that the stimulus of the flicker received in the visual projection area of the cortex was breaking bounds; its ripples were overflowing into other areas."[40] Walter was the first scientist to observe this sort of wave migration. Yet, his findings are in some ways familiar. The permeation of frequencies across geographic regions suggests wave transmission reminiscent of telegraphic—or telepathic—signals travelling across city limits. But what, exactly would it mean for one brain region to receive frequencies transmitted by another?

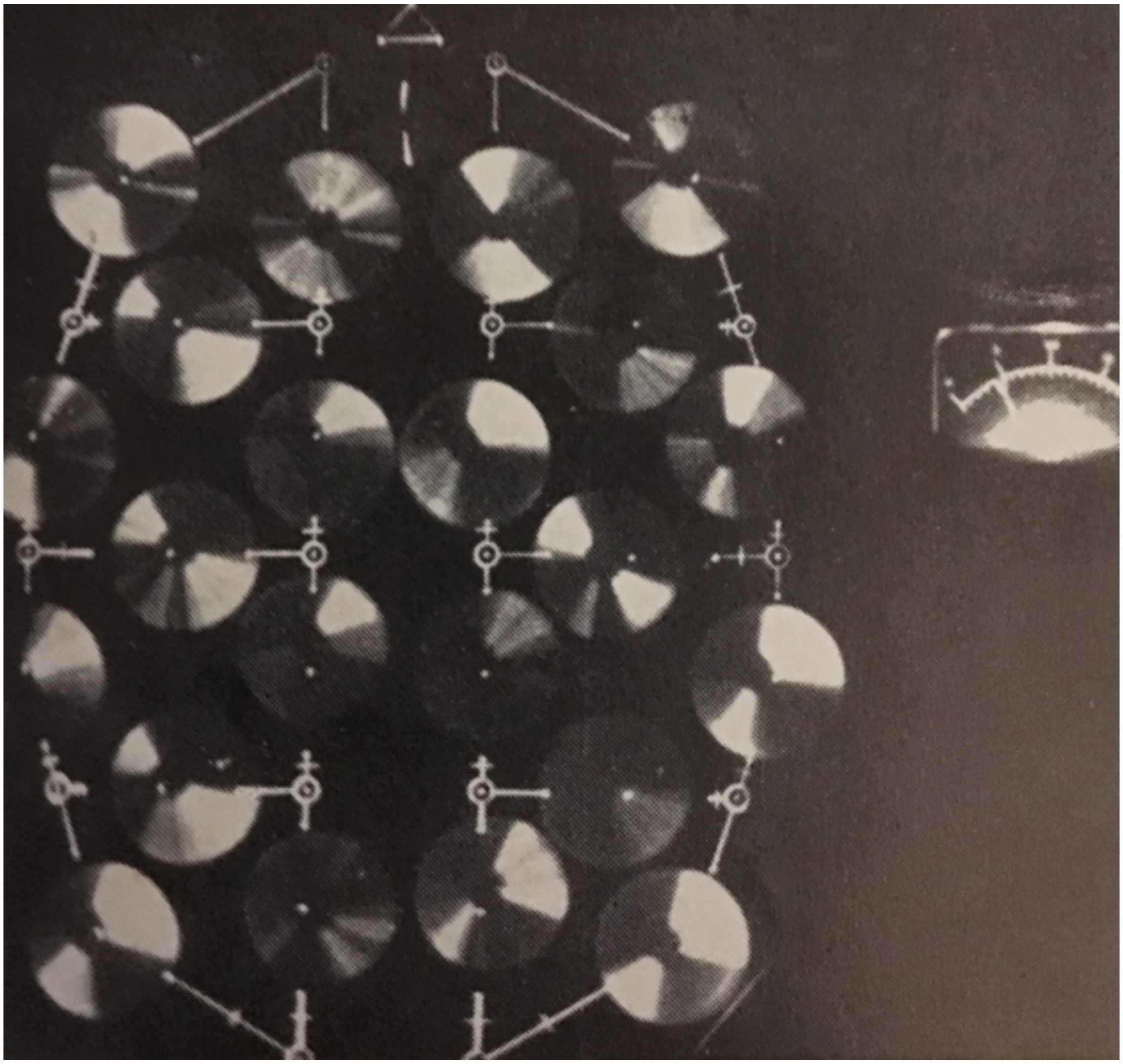

Figure 7. Photograph of toposcope recording. Original caption (excerpt): "Snapshots of the 'sparkling field of rhythmic flashing points.' Each of the tube screens, which forms a chart of the head seen from above with the nose at top, shows by the flashing sectors of its disc the activity of the corresponding area of the brain." Reprinted from Grey Walter, *The Living Brain*, 2nd ed. (New York: W. W. Norton, 1963), figure 6.

To better understand the implications of overflowing ripples, Walter compared toposcope records to temporally-linked subjective accounts. Summarizing reports from participants, he writes:

> The greatest variety of mental experiences are described, not by any means all of them unpleasant. Some have seen profuse patterns of many colours, sometimes

> stable, sometimes moving…Some describe feelings of swaying, of jumping, even of spinning and dizziness. Some people feel a tingling and pricking of the skin…Sometimes the sense of time is lost or disturbed.[41]

Walter's account of Flicker in *The Living Brain* prompted some members of the counterculture to seek out the mind-altering powers of alpha experimentation. During the early 1960s artist Brion Gysin and mathematician Ian Sommerville constructed their own flicker device, "The Dreamachine," which Gysin believed produced a natural "high" via alpha manipulation.[42] Later, Allen Ginsberg would write of the Dreamachine: "I looked into it – it sets up optical fields as religious and mandalic as the hallucinogenic drugs – it's like being able to have jeweled biblical designs and landscapes without taking chemicals."[43] The association between alpha and trippy experiences persisted among the counterculture throughout the 1960s and into the '70s, at which time the frequency obtained a spiritual, zen-like connotation (see Chapter 6).

Though Walter implicated alpha in extraordinary mental events, his explanation was more mechanical than spiritual or psychedelic. He hypothesized that the alpha rhythm represents, "a process of scanning—searching for a pattern—which relaxes when a pattern is found."[44] Walter believed that, in addition to scanning for patterns in the environment, alpha synchrony integrates information across the brain to create subjective cohesion.

According to this view, approximately every tenth of a second the brain aggregates all the information received during that alpha cycle. At a basic sensory level, this process would allow the visual system, for example, to compile stimuli detected over a .1-second period, thus yielding an organized visual scene. And because brain waves apparently transcend neuroanatomical boundaries, Walter believed that this synchrony might coordinate sensations and memories across multiple brain regions. Such crossmodality integration, he posited, would facilitate the sort of associative learning described in conditioning paradigms. [45] In sum, the combination of pattern recognition and multisensory association allowed Walter to insert brain waves into a behaviorist framework.[46]

Though more technical, Walter's premise of mental association via waves resembles the theory posited by David Hartley two centuries prior; and, in *The Living Brain*, Walter notes the prescience and "originality of [Hartley's] notions."[47] Walter was, in fact, quite aware of the wavy intellectual history to which he contributed. As such, he recognized the supernatural aura that tends to follow brain waves, and the technological ethos perpetuating telepathic fantasies. He writes:

> It has often been suggested by those seeking a material basis for otherwise unaccountable behaviour that the electrical activity of the brain might be the mechanism whereby information could be transmitted from brain to brain, and that the electrical sensitivity of the brain might be a means of communicating with some all-pervading influence…
>
> The familiarity of radio signaling around the world has popularized the notion that any signal once generated may be propagated indefinitely through the chasms of space, so that all events have an eternal quality in some attenuate but identifiable form. This is not even approximately true.[48]

Walter, like Berger before him, rejected telepathic conjecture on scientific grounds. "The size of the electrical disturbances which the brain creates are extremely small," he writes. "Their dominant frequencies are far below the range of radio channels, below even the scale of audible frequencies."[49]

Though Walter definitively disagreed with fantastic interpretations of EEG research, his posited association between the alpha frequency and strange subjective events ultimately contributed to the mystique of brain waves. Further, even as Walter attempted to quash telepathic dreams, his research fortified an association between one's identity and one's brain waves.[50] His writing and public statements throughout the 1950s and '60s reinforced early commentary on the uniqueness of individual neural frequencies and further explored the relationship between "brain prints" and personality.[51]

Walter believed that the shape of an individual's alpha waves influences that person's thinking style. He argued that the reduction of alpha during visual processing indicates that people with weak alpha waves think more visually, and that those with strong alpha waves think abstractly. Among visual thinkers, Walter proposed, the particular amplitude and frequency of alpha waves may determine how information flows through the brain, and thus how a person interprets a given situation. More than a matter of sensory processing, Walter posited that wave-driven cognitive styles might hold significant psychosocial implications. Hayward writes:

> [Walter] suggested that couples with a similar alpha rhythm would share a common approach to the problems of life, while those who differed greatly in their alpha rhythms and use of mental imagery would soon find themselves trapped in a loveless state of mutual incomprehension…Walter made great play of the EEG's newfound romantic utility, arguing in interviews with *Life Magazine* and the Brain's Trust that young couples should be routinely tested.[52]

Towards the end of his career (1968) Walter published an article titled "The Social Organ," which elaborated on his belief that contrasting "alpha-types" might explain differences of opinion in interpersonal affairs, or even international conflict. He writes:

> It may even be that serious crises between nations, where no territorial or material advantage can be gained by either side, have arisen because the negotiators have different types of imagery and can only talk at cross-purposes…Perhaps a diplomat should have his alpha-type endorsed on his passport.[53]

Walter saw EEG research, and brain research in general, as crucial to social cohesion. "If we cannot find time to study our brains as organs of social invention," he writes, "then we can by no means resolve the social tangle or extricate ourselves from the technical and political traps which we have so ingeniously set for one another."[54] Thus, while Walter took pains to debunk theories of thought transference, he, in his own way, framed the interception of brain waves as crucial to human interconnectedness. Further, though Walter embedded waves in a cybernetic framework, he preserved an association between brain rhythms and distinctly human pursuits—*i.e.,* love and war.

In 1970 Walter was involved in a scooter crash from which he never fully recovered. However, by the time of the accident, alpha had taken on a life of its own.[55] *The Living Brain* influenced future EEG researchers as well as members of the counterculture who appropriated alpha waves according to their own psychedelic principles (see Chapter 6). Walter's work appealed to thinkers hungry for introspection and keen on playful engagement with new technology. And a wavy framework jibed with projects in humanistic psychology that defined *purpose* in terms more elegant than goal-seeking behavior—that celebrated, rather than suppressed, cognitive diversity. For those hoping to escape oppressive functionalism and strict two-valued logic, brain waves provided an opportunity to view the brain and self in fluid terms.[56]

Giant Brains, Vanishing Brains

Following the 1946 debut of the first electronic digital computer, the press commonly referred to the machine as a "giant brain."[57] The Electronic Numerical Integrator and Computer—or ENIAC—used tens of thousands of vacuum tubes, resistors and diodes, weighed about thirty tons, and occupied the entirety of a not-small room.[58] Which is to say, it was by no mistake of appearance that ENIAC enjoyed comparison to cortices.

Computers earned an analogy to our most prized organ by virtue of their ability to quickly solve complex equations. Newspaper coverage of ENIAC and its progeny focused on the efficiency with which the machines attended to problems of military or industry, as well as the potential for these new devices to replace human workers (lest we assume this fear is new). Initially designed to perform ballistics calculations, ENIAC could not experience pleasure or pain, feel lust, or fear death. Of course it couldn't. Yet, these experiences are central to the lived reality a brain-carrying human. How did we so unflinchingly conclude that computational logic defines the brain's talent?

Prior to the introduction of ENIAC, behaviorists treated the nervous system like a machine void of interior experience. And the eventual praise of the computer's efficiency complemented the goal-seeking language of cybernetic literature. These discourses subjugate emotion in the name of logic, emphasizing not just behavior over feelings, but process over substance. Computers yielded the language of *programs, code,* and *software*—elegant symbolic architectures that distinguish themselves from clunky hardware and tend to marginalize the latter. Though the physicality of ENIAC was difficult to ignore, today our devices do not so aggressively assert their form. We often misplace our smartphones—an apt symbol of how easily we forget their materiality. The physical destruction of a computer needn't destroy its content because information resides safely in an almost-mystical cloud: hardware is interchangeable, subordinate to the discrete logic it supports.[59]

Given the metaphoric interplay of brains and computers, a de-emphasis of technological materiality may sway our view of biology. Consider the presently uncontroversial assertion that our brains *process information.* In this formulation, *information* appears materially untethered, and *process* alludes to vague mathematical transformations. Here, we enjoy the fruits of seeds planted by the likes of Shannon, McCulloch, Pitts and Wiener.

If brains, like computers, function via two-valued logic, then perhaps our bodies are as disposable as our devices. If only we could store our neural *information* on more durable material, mortality needn't define the human condition. Such implications of the human-machine analogy expose a conceptual thread that persists from the scientific spiritualism of the etheric era through EM enthusiasm and into the computer age. Each of these epochs provides its own seemingly scientific language in which to describe the brain's processes independent of its biological form.

According to an etheric view, electrochemical undulations within the brain transcend the skull via perturbation of an all-encompassing medium; and brain waves qua EM radiation seem to escape their tissue of origin in a comparable manner. The reduction of neuronal impulses to binary signals similarly detaches neural processes from biological matter as cognition gains entrée into abstract mathematical space. In this way, computational, data-driven models of the mind can fulfill the same desires for transcendence and universal connectivity satisfied by etheric views (see Chapter 9). Information, like ether, is everywhere and nowhere; it obeys physical laws but takes no detectable physical form; it is a difference that makes a difference by virtue of its dynamism.

Both two-valued logic and etheric waves denote *variation*—variation that somehow encodes information or meaning. Yet, whereas waves flow, digits assume a staccato pulse. This aesthetic distinction, I propose, corresponds to two distinct views of the human subject: whereas digitally inspired brain models prioritize a robotically rational subject, brain waves speak to a more humanistic sort of human.

Wave-Particle Duality

> We are faced with a new kind of difficulty. We have two contradictory pictures of reality; separately neither of them fully explains the phenomena of light, but together they do!
>
> How is it possible to combine these two pictures? How can we understand these two utterly different aspects of light?
>
> —Albert Einstein and Leopold Infeld, *The Evolution of Physics*[60]

Debates about the nature of light predate Isaac Newton, though the controversy of his time—waves versus corpuscles—was particularly contentious. Newton's corpuscular theory temporarily triumphed over wave hypotheses, only to be overturned when Young demonstrated that light consists of "Undulations of the luminiferous ether."[61] The wave-corpuscle debate eventually became a wave-particle debate, but its essential question remained the same: is light a continuous or discrete phenomenon? The twentieth century resolution—or dissolution—of this question perhaps points to the folly of framing continuity and discreteness in antagonistic terms.

Under certain experimental conditions light acts like a wave; under others, it appears particularly particularian. Duality at this fundamental level of nature can be perplexing—especially to the non-physicists among us. In other contexts, however, the mutual legitimacy of continuous and discrete models is more intuitive. For example, in the process of preparing an elegant home meal, my microwave oven is either on or off: apparently discrete states. The "on" state, however, involves the generation of EM radiation: continuous (micro)waves. If I would like to enjoy a glass of milk with my meal, I may consult its carton to determine whether it is fresh or spoiled. The expiration date suggests a moment of discrete and absolute state change; but anyone prone to smelling questionable milk understands that spoiledness comes in degrees.

In many cases, whether one sees waves or particles is a matter of perspective and pragmatism—an epistemological style. For the sake of convenience, a scientist asserts that a neuron "fires," alluding to an all-or-none phenomenon. But here, "all" denotes a lot: ion channels open in the cellular membrane, allowing some charged particles to move into the neuron, while others scurry out—an overall depolarization of the cell that occurs not instantaneously, but over space and time. A scientist specializing in voltage-gated ion channels may pay close attention to the details of depolarization, describing this phenomenon as a continuous process; a researcher primarily concerned with the timing of neuronal firing patterns, however, reduces depolarization to a discrete spike.

One selects an epistemological style according to relevance and efficiency: I assert that the microwave is *on* because the system should function the same way every time it is in this state, so the process requires no further elaboration. I state that the milk is fresh-*ish*, to convey that it is near its expiration date and perhaps unideal as a solo beverage, but passable as a coffee dressing. That is to say, waves and digits are both valuable modes of description. However, descriptions of the brain hold higher stakes than those of dairy products and kitchen appliances. For brain models carry subtle or overt implications about the nature and function of human subjects. The respective provenances of continuous and discrete brain models, I propose, inform the ways in which these epistemological aesthetics portray personhood.

Whereas digital brain models emerged alongside cybernetics and electronic computing, wavy models initially surfaced in the context of telepathy, ether, and psychical research. When Knowles first floated his theory of brain waves, he imagined that these oscillations might "convey sympathies of feeling beyond all words to tell—groanings of the spirit which cannot be uttered, visions of influences and impressions not elsehow communicable."[62] Into the twentieth century, wavy models remained associated with the communication of otherwise ineffable sentiments—despite a dearth of research confirming this view.

For example, in 1949 several newspapers circulated an interview with musician Raymond Scott, who stated: "Soon the scientists will get around to picking up the brain waves and channeling them directly into the minds of others. That's when we'll get the truly idealized conception of a composer's music."[63] And, following RCA's demonstration of color TV in 1953, the *Sun* published a story titled, "Next They'll Be Recording Brain Waves."[64] In the same way that EM technologies inspired early hopes for brain wave transmission, here television revives the belief that waves might communicate feelings beyond words. This sort of mind reading, the *Sun* explains,

> …would involve getting a tape recording of a person's brain vibrations which could be played off at the convenience of a second party. Such recording should save a lot of trouble and prevent much misunderstanding that now comes from the inability to find just the right words to express one's feelings.[65]

Though less poetic than Knowles's description, this account nonetheless promises a sort of translation of spiritual "groanings;" and Raymond Scott seems to suspect that brain waves will capture the platonic form of a composer's artistic vision. This is not the language of communication and control. It is a hope to access human experience at a profound level—a hope not just to transmit *information*, but to share aspects of subjectivity that elude standard forms of annotation. I do not mean to suggest that such hopes for brain waves were universal, but merely that brain waves discourse lends itself to imagining the transmission of experiences more uniquely human than digital dialogue.

The reduction of neuronal waves to neuronal spikes neglects the nuances of an electrical journey—the valiant rise and dramatic fall of cellular potential. In the case of cell depolarization, these details needn't be included in every scientific paper. However, this aesthetic reinforces a perspective on humans that elides non-binary experiences—emotional shades that defy on/off characterization. In an exclusively digital framework, the stream of consciousness becomes discrete logic; human expression transforms into "output" of militaristic precision; and individuality succumbs to homogenizing circuitry. Computational discourse prioritizes a very particular type of "thinking"—a logical, unemotional type; a masculine type. A wavy model of the brain thus serves as an enticing alternative to the austerity of two-valued logic.

Still, to view wavy and digital brains as mutually exclusive only perpetuates a binary style of thought. Here, we may take a tip from Einstein, who suggested that discrete and continuous models are not contradictory, but rather represent the same phenomena under different conditions. Adoption of such an approach in brain science is valuable at the level of electrophysiology and of psychology. The brain is simultaneously continuous and discrete, logical and emotional, rational and spiritual.

If uncertainty can find a role in physics, then surely *feeling* can comprise some aspect of rationality, and spirituality can interact with scientific thought. These components of cognition do not compete, but complement one another and, indeed, cannot be disentangled.

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[1] "Einstein's Brain Waves," *Life*, February 26, 1951, 40; and "Geniuses Aid Tests of Brain Processes," *New York Times*, February 24, 1951.

[2] John Dewey, "The Reflex Arc Concept in Psychology," *Psychological Review* 3, no. 4 (1896): 357.

[3] Ortwin Bock, "Cajal, Golgi, Nansen, Schäfer and the Neuron Doctrine," *Endeavour* 37, no. 4 (2013): 228–234.

[4] Indeed, the impulse to read EEG waves as mental messages may derive, in part, from an incorrect belief that such charts represent the brain's collective activity. In reality, the brain does not yield one cohesive stream of waves. That is, brain waves, as recorded by EEG, do not refer to some collective signal produced by the brain in its entirety. Electrodes detect electrical variations among some subset of neurons that sit beneath them. Thus, an EEG chart cannot reveal an encompassing summary of what the brain is doing, thinking, or saying.

[5] This description refers to a monosynaptic reflex arc—two neurons, connected by one synapse. However, polysynaptic circuits also exist; they involve several interneurons between the sensory and motor neurons.

[6] Charles S. Sherrington, *The Integrative Action of the Nervous System* (New Haven, CT: Yale University Press, 1906). Sherrington describes: "At the nexus between efferent neurone and the muscle cell, electrical organ, etc., which it innervates, it is generally admitted that there is not actual confluence of the two cells together, but that a surface separates them; and a surface of separation is physically a membrane." Sherrington, *Integrative Action,*16.

[7] Edgar D. Adrian, "The Impulses Produced by Sensory Nerve Endings," *The Journal of Physiology* 61, no. 1 (1926): 49–72.

[8] "The Nobel Prize in Physiology or Medicine 1932," Nobelprize.org, accessed January 26, 2018, http://www.nobelprize.org/nobel_prizes/medicine/laureates/1932/.

[9] Edgar D. Adrian, "Nobel Lecture: The Activity of the Nerve Fibres," Nobelprize.org, accessed February 11, 2017, http://www.nobelprize.org/nobel_prizes/medicine/laureates/1932/adrian-lecture.html.

[10] Adrian was not the first scientist to describe nerve impulses in all-or-none terms. In his Nobel lecture, Adrian references, among others, Francis Gotch and Keith Lucas, whose work hinted at this sort of "ungraded" response. Adrian, "Nobel Prize."

[11] Borck, "Recording the Brain," 371.

[12] Willaim F. Aspray, "The Scientific Conceptualization of Information: A Survey," *Annals of the History of Computing* 7, no. 2 (1985): 117–140.

[13] Ibid., 119

[14] Warren S. McCulloch and Walter Pitts, "A Logical Calculus of the Ideas Immanent in Nervous Activity," *The Bulletin of Mathematical Biophysics* 5, no. 4 (1943): 115–133.

[15] Ibid., 99

[16] Ibid., 114; italics mine.

[17] Kay argues that neural nets admitted a limited kind of introspective experience into experimental research. She writes: "the principal significance of the McCulloch-Pitts project inheres in its cognitive turn, in bringing the psyche back into the laboratory." Still, Kay qualifies, "it is not 'the mind' as an eternal and immutable object which McCulloch and Pitts brought into experimental quantitative research in the 1940s." Lily E. Kay, "From Logical Neurons to Poetic Embodiments of Mind: Warren S. McCulloch's Project in Neuroscience," *Science in Context* 14, no. 4 (2001): 592.

[18] Norbert Wiener, Arturo Rosenbleuth, and Julian Bigelow, "Behavior, Purpose and Teleology," *Philosophy of Science* 10, no. 1 (1943): 18–24.

[19] Ibid., 19.

[20] Ibid., 18

[21] Stuart A. Umpleby, "A History of the Cybernetics Movement in the United States," *Journal of the Washington Academy of Sciences* 91, no.2 (2005): 54–66.

[22] To be clear, Weiner and other cyberneticians did not deliberately forward a view of humans as *mere* machines and, in fact, they often offered opinions to the contrary. Hayles summarizes: "For Wiener, cybernetics was a means to extend liberal humanism, not subvert it. The point was less to show that man was a machine than to demonstrate that a machine could function like a man. Yet the cybernetic perspective had a certain inexorable logic that, especially when fed by wartime hysteria, also worked to undermine the very liberal subjectivity that Wiener wanted to preserve." *How We Became Posthuman: Virtual Bodies in Cybernetics, Literature, and Informatics* (Chicago: University of Chicago Press, 2008), Kindle edition, 7–8.

[23] Peter F. Bladin, "W. Grey Walter, Pioneer in the Electroencephalogram, Robotics, Cybernetics, Artificial Intelligence," *Journal of Clinical Neuroscience* 13, no. 2 (2006): 170–171.

[24] Ibid.; and Rhodri Hayward, "The Tortoise and the Love-Machine: Grey Walter and the Politics of Electroencephalography," *Science in Context* 14, no. 4 (2001): 615–641.

[25] Bladin, "W. Grey Walter," 172. While I won't belabor this point here, the *tinkering* aspect of Walter's work is nontrivial. It reflects the translation of amateur to expert practices, and of radio tinkering to electrophysiological tinkering.

[26] Grey Walter, *The Living Brain*, 2nd ed. (New York: W. W. Norton, 1963), 85–86.

[27] Ibid., 86. It was in this context that Walter developed the EEG frequency analyzer, "a device capable of decoding EEG records automatically, plainly displaying the frequencies and amplitudes every ten seconds, a kind of wave analysis, corresponding roughly to a Fourier transform." Walter, *Living Brain,* 86.

[28] Hayward continues: "Walter's own use of the EEG in the defense of an epileptic who had murdered a Brighton schoolgirl during a moment of seizure established the popular image of the EEG in the British press. It was depicted as a kind of truth machine or electric confessional that would reveal the occult workings of the human mind. It was a technology that materialized conscious life, transforming private mental states into public images – albeit public images whose interpretation required the hermeneutic expertise of the electroencephalographer." Hayward, "Tortoise," 620–621.

[29] Waldemar Kaempffert, "Science in the News: Brain Waves and Pilots," *New York Times*, October 6, 1940.

[30] Howard W. Blakeslee, "Brain Waves Provide Key to Mind," *Washington Post,* November 23, 1941.

[31] Ibid.

[32] "What Scientists Are Doing," *New York Herald Tribune*, April 2, 1950; and William S. Barton, "Everyday Science," *Los Angeles Times,* April 12, 1942.

[33] William L. Laurence, "Study Brain Waves for 'Cerebral Age,'" *New York Times*, May 13, 1943.

[34] Christof J. Schwiening, "A Brief Historical Perspective: Hodgkin and Huxley," *The Journal of Physiology* 590, no. 11 (2012): 2571–2575.

[35] Owen Holland and Phil Husbands, "The Origins of British Cybernetics: The Ratio Club," *Kybernetes* 40, no. 1/2 (2011): 110–123.

[36] Walter, *Living Brain,* 158.

[37] Ibid., 99.

[38] Walter also observed that, in epileptic subjects, flicker induces seizures—a result made famous by warnings preceding particularly intense light shows or movies.

[39] Walter, *Living Brain,* 62.

[40] Walter, *Living Brain,* 91.

[41] Ibid., 106–107.

[42] *Flicker*, directed by Nick Sheehan (National Film Board of Canada, 2008).

[43] Allen Ginsberg, "Letter to Timothy Leary," in *Chapel of Extreme Experience*, ed. John G. Geiger (New York: Soft Skull Press, 2003), 58, quoted in Bastiaan Christian Ter Meulen, Denes Tavy, and B. C. Jacobs, "From Stroboscope to Dream Machine: A History of Flicker-Induced Hallucinations," *European Neurology* 62, no. 5 (2009): 319.

[44] Walter, *Living Brain,* 109.

[45] To be clear: this theory has not become scientific consensus. However, as I discuss in Chapter 9, *some* twenty-first century researchers do believe that neural synchrony plays a role in learning and/or memory.

[46] In papers published during the 1960s, Walter elaborated on the link between learning and electrical patterns. See Grey Walter et al., "Contingent Negative Variation: An Electric Sign of Sensori-motor Association and Expectancy in the Human Brain," *Nature* 203 (1964): 380–384.

[47] Walter, *Living Brain,* 44.

[48] Ibid., 252–253.

[49] Ibid., 253.

[50] Walter objected to telepathy on the grounds that neural oscillations lack the EM stamina for faithful transmission. However, this objection leaves open the possibility of synthetic thought transmission (the weak view of brain waves). If, as Walter maintained, brain waves drive personality, then the appropriate technology could, in theory, amplify and transmit these signals, and thus facets of the self. I do not mean to suggest that Walter himself subscribed to such a view—only that his research left room for this sort of creative interpretation.

[51] Notably, Walter's reach was not limited to his colleagues, or even to readers of *The Living Brain.* Perhaps by virtue of growing up the son of two journalists, Walter often wrote for popular outlets and gave interviews to the press.

[52] Hayward, "Tortoise," 626.

[53] Grey Walter, "The Social Organ," *Impact of Science on Society* 18 (1968): 179–188.

[54] Ibid.

[55] After enjoying considerable popular success *The Living Brain* was reprinted in 1961, '63 and '68; Owen Holland, "Exploration and High Adventure: The Legacy of Grey Walter," *Philosophical Transactions: Mathematical, Physical and Engineering Sciences* 361, no.1811 (2003): 2092.

[56] As early as 1948, some identified the dehumanization implicit in cybernetic and behaviorist dogma. An op-ed in the *Wall Street Journal* reads: "Now the psychologists have come up with another science connected with man's stimulus-response mechanism. It has been labeled "cybernetics."…This business has dangers, and solid citizens should unite to prevent the spread of an invidious philosophy. Cybernetically speaking, who wants to work at his best speed all the time?" "Pepper and Salt," *Wall Street Journal*, July 2, 1948.

[57] "Giant 'Brain' Can Play Chess or Write Music," *Chicago Daily Tribune*, August 22, 1949; "New Giant 'Brain' Does Wizard Work," *New York Times*, August 25, 1947; and Herb Altsohull, "New Device Fitted with Giant 'Brain,'" *Hartford Courant,* August 22, 1949.

[58] Herman H. Goldstine and Adele Goldstine, "The Electronic Numerical Integrator and Computer (Eniac)," *Mathematical Tables and Other Aids to Computation* 2, no. 15 (1946): 97–110.

[59] Hayles has written extensively on the perceived liberation from materiality accompanying the informational age. She writes: "Information viewed as pattern and not tied to a particular instantiation is information free to travel across time and space… The great dream and promise of information is that it can be free from the material constraints that govern the mortal world." *Posthuman*, 13.

[60] Albert Einstein and Leopold Infeld, *The Evolution of Physics: The Growth of Ideas from Early Concepts to Relativity and Quanta* (New York: Simon and Schuster, 1938).

[61] Young, "Bakerian Lecture," 44.

[62] Knowles, "Brain-Waves."

[63] "Brain Wave Music Goal of Future, Says Author," *Austin Statesman,* September 8, 1949; "One Day You'll Be Able Just to 'Think' Music," *Washington Post*, August 21, 1949; Betty Prosser, "Sonatas by Thought," *The Sun*, September 4, 1949; and Key M. Lucy, "Front Views & Profiles," *Chicago Daily Tribune*, July 28, 1949.

[64] "Next They'll Be Recording Brain Waves," *The Sun*, December 5, 1953.

[65] Ibid.

Chapter 6. "Electronic Nirvana"

In November of 1957, Dwight Eisenhower suffered a minor stroke. The president made public appearances soon after the incident, ostensibly in good physical condition; yet, concerns about his health lingered. In March of 1958, as if to put these worries to rest, The *Baltimore Sun* announced: "IKE IS FULLY RECOVERED DOCTORS SAY: Result Of Cardiogram, Brain-Wave Tests Called Normal."[1] The *Hartford Courant* echoed: "Ike Pronounced Fully Recovered From His Stroke: Brain Wave Findings Are Normal."[2] Other newspapers concurrently ran similar assurances, citing EEG and EKG results as evidence of a clean bill of health—objective proof that the president was fit to serve.

These headlines serve as a telling reminder that, by the 1950s, brain waves functioned as more than a scientific or spiritual curiosity; they were understood, however vaguely, as a trusted metric of health. Just like a robust EKG signature denotes general physical vitality, a steadily waving brain seems to signify mental vigor. Of course, a psychiatrist could have spoken to the president to evaluate his mental wherewithal; and a cardiologist might have listened to Ike's heart, head on chest, to assess cardiac strength. Yet EEG and EKG exude technological authority, impressing certainty in a way that fallible human evaluation cannot. Lest the capability of machines be doubted, during the fifties loud pronouncements of innovation urged technological awe. Computer brains now performed calculations hitherto reserved for thinking minds; and hunks of metal began to explore corners of the galaxy untraversed by mere mortals.

In the year following his stroke, Eisenhower established NASA and the United States sent the first communications satellite into orbit. In December of 1958, the so-called "Talking Atlas" transmitted a personal message from Ike to Earth: "Through the marvels of scientific advance, my voice is coming to you from a satellite traveling in outer space," the broadcast relayed. "Through this unique means I convey to you and to all mankind America's wish for peace on earth and good will toward men everywhere."[3] Though Eisenhower's words communicated a genial Christmas greeting, his mode of delivery undermined universal good will towards men. Atlas announced to the world—and specifically to the Soviet Union—America's technological virility and a leg up in the ongoing space race. Thus, as Ike verbalized his wish for human peace, the rocket transmitted a subtext of technological war.

Atlas's dual messaging serves as an apt symbol for the impending clash between the military-industrial complex (MIC) and a peace-peddling counterculture. During the 1950s, backlash against the MIC and general social conservatism began to simmer, reaching a boiling point in the following decade. Disenchanted youth rejected the corporate engine and "dropped out" of institutions that, they believed, molded subscribers into robotic perpetuators of the status quo. Simultaneously, a number of psychologists grew frustrated with models of the brain that compared humans to anti-artillery servomechanisms. Hippies and humanists viewed themselves as more than machines; yet, technology itself was not the enemy. In the coming years, engagement with brain wave devices became an attractive way to embrace new science and technology, while recasting cybernetic circuits according to wavy, countercultural ideals.

Ground Control to Major Technological Innovation

Scientists on earth received signals from space decades prior to the launch of Atlas I. Beginning in the 1930s, astronomers made contact with the stars via giant antennae that intercepted EM waves of extraterrestrial origin. The antennae were towering structures that might be mistaken for extravagant radio stations—because that's more or less what they were. Midcentury reports describing "Radio Telescopes" and "Radio signals from freak stars" underscored the presence of familiar waves arriving from unfamiliar terrain.[4]

When Atlas and subsequent satellites went into orbit, they too relied on waves typically associated with audible entertainment. Satellite communication involves the amplification and transmission of radio waves to deliver messages across incredible distances with extraordinary speed. The basic governing principles of such transmission are not terribly different from that of standard 1950s broadcast technology—with the small caveat that frequencies happen to travel through outer space before arriving at their final destination.

By the late 1950s, radio was a near-ubiquitous domestic technology in the U.S.[5] Thus, descriptions of radio waves among the stars established EM continuity between living rooms and distant planets. One might (correctly) imagine that radio signals carrying the vocals of Elvis Presley would eventually reach distant corners of space—an electric interconnectedness that recalls Edward Hitchcock's vision of a "Telegraphic Universe," articulated a century earlier. Hitchcock writes: "There may be no spot in the whole universe where the knowledge of our most secret thoughts and purposes, as well as our most trivial outward act, may not be transmitted on the lightning's wing."[6]

Of course, neither radio telescopes nor early satellites detected secret thoughts floating about the galaxy. However, it did not take long for researchers and journalists to begin hypothesizing about the prospect of *brain waves in outer space*—a notion that is as exciting as it is ambiguous. As I have shown, innovation in wireless and wave-driven technology tends to inform speculation about the possibilities of brain wave transmission; and space communication was no exception.

In 1958 *The New York Herald Tribune* reported: "[a] group attached to the Army's great arsenal and ballistic missile development center...has advanced the idea that the brain wave amplification concept offers a possible means of communication between space ships."[7] *Tribune* editor Ansel Talbert describes projects from The Rand Development Laboratory as well as The Westinghouse Electric Company, the latter of which, Talbert reports, was potentially approaching, "a breakthrough in the understanding of brain-wave mechanics and their control in the atmosphere."[8] I highlight Talbert's article not because it faithfully represents the priorities of space research at the time, but because it demonstrates the ways in which rockets fueled fantasies about brain waves. "If carried to a successful conclusion," Talbert writes, "the projects certainly will fill in the gaps between practical working instruments...and more shadowy advances in studies in parapsychology dealing with 'extrasensory perception' [ESP] and mental telepathy."[9]

There is no evidence to suggest that the American space program devoted serious resources to investigating ESP; yet, that is not to say that brain waves and space science did not genuinely intersect. In 1964, NASA sponsored a symposium at which participants discussed the use of EEG to remotely monitor astronauts in flight—a hypothetical machine that would somehow jostle the pilot should EEG detect excessive drowsiness.[10] Meanwhile, experiments outside the space program showed that one needn't be an astronaut to send a brain into orbit. In 1963, a research team at the Burden Neurological Institute in Bristol recorded EEG data from a healthy female subject, and sent this signal via high-frequency carrier waves to the satellite Relay 1. Bouncing off the satellite, the carrier waves landed at the Mayo Clinic in Minneapolis, where a second research team received and interpreted the woman's oscillations.[11]

This brain wave space launch was covered by the *Chicago Tribune,* the *New York Times,* the *Baltimore Sun, Newsday,* and the *Boston Globe*, among other outlets.[12] The purpose of the experiment, according to the *Times,* was to "test the possibilities of speedy international diagnosis of brain disorders."[13] Yet, it is unlikely that the event's widespread popular attention reflects some universal frustration with established protocols for sending and receiving health records. The newsworthiness of Relay 1's accomplishment is much more basic, almost childlike in its simplicity. The exercise evokes a fantasy in which mental oscillations travel through the stratosphere. It suggests that the mind's vibrational energy not only transcends the body, but can leave the planet—a vision that resembles Reichenbach's nineteenth century theory of an "odic force" unifying cortex and cosmos. If brain waves can take extraterrestrial journeys, then perhaps the mind can escape the body to traverse the stars, if not the heavens.

Following the development of satellite communication, the practice of *telemetering* data garnered interest among earth-oriented scientists. Telemetering, in essence, refers to the transmission of data from its source to some remote location. During the sixties, a number of physiologists applied this technique—and this verbiage—

to the transmission of physiological information. For example, a 1964 article explains: “You can be warned in advance if twins or quintuplets are expected in your family. A telemetering device can detect heartbeats of unborn babies.”[14] And in 1967 researchers at Northwestern University devised a “brain wave helmet” that reportedly telemetered EEG data from the scalp of a halfback to remote analysts who scanned for evidence of neural disturbance suffered in the course of a game.[15] Telemetering is effectively synonymous with wireless transmission, but additionally evokes the notion of satellite telemetry, thereby situating biological data and interstellar data in a single waving universe.

The expanding purview of wireless at midcentury included not just the communication of data, but also the control of common objects. In 1956, advertisements for the provocatively named “Zenith Space Command” announced the first remote-controlled television, which functioned via the transmission of ultrasound waves.[16] During the sixties, commercial radio-controlled (R/C) toy cars became available, as did R/C dice that could fix a game of craps, and R/C garage doors.[17] California garages attracted the attention of the Federal Aviation Agency after door-opening waves were found to interfere with military aircraft communications—an accident that illuminated the entanglement of diverse EM signals.[18]

The appeal of remote controlled toys and appliances reflects more than general human lethargy; it points to the delight of manipulating objects at a distance. Remote control is both magical and scientific: it offers proof of agential, omnipresent waves, while approximating an illusion of telekinesis. When nineteenth century mediums commanded tables to levitate or instruments to play, a spectator might have attributed their powers to parlor trickery, or to a real “psychic force.” Somewhere in between, the remote control taps into EM forces and uses scientific tricks to animate the inanimate.

Still, opening a garage with the click of a button is nowhere near as exhilarating as controlling it with one’s mind. True telekinesis comes closest to actualization via brain-computer interfaces (BCIs) that respond to neural activity to maneuver objects in real or virtual space. I will return to this subject in Chapters 8 and 9, as BCIs are of growing interest among twenty-first century researchers and entrepreneurs. However, efforts towards brain-controlled technology were under way as early as the 1960s.

In 1964, physicist and air force scientist Edmond Dewan announced that he could turn on a light with his thoughts. To achieve this effect, Dewan fashioned a circuit that connected a lamp to an EEG device, the bulb illuminating only upon detection of alpha waves. Dewan purportedly trained subjects, including himself, to mentally modulate their neural frequencies, such that in “turning on” alpha, they turned on the lamp.[19]

In addition to EEG-aided telekinesis, Dewan reportedly established a form of telepathy by similar means. In a television interview with CBS News, Dewan claimed that his brain could compose Morse messages by generating “long and short bursts of alpha rhythm, in other words dots and dashes.”[20] A colleague would then read Dewan’s thoughts by decoding his EEG Morse in real time. From the available documentation of these experiments, there is no way to verify whether Dewan’s devices actually did what he claimed they did. Yet, even as ideas*,* the machines were decades ahead of their time. In interviews, Dewan commented that brain Morse held life-changing value for individuals unable to speak due to injury or disease.[21] Today, BCI researchers often verbalize a similar sentiment, proposing neurotechnologies that channel the brain’s electrical dynamics to restore limited speech or movement in otherwise "locked-in" individuals (see Chapter 8).

Of course, Dewan's devices do not represent the mainstream of brain wave research during the 1950's and '60s. Exciting accounts of mind-lamps and extraterrestrial brain waves notwithstanding, many EEG studies of the period could put a person to sleep—though, in all fairness, that was their intention.

Dream On, EEG On

For the first half of the twentieth century, sleep science was largely dominated by Freudian thought—an intriguing theory, but not a properly biological account of the snoozing cerebrum.[22] During the early 1950s, however, a group of researchers at the University of Chicago ventured to rouse sleep science from its psychoanalytic slumber.

In 1953, Nathaniel Kleitman and Eugene Aserinsky observed intermittent periods of rapid eye movement (REM) among subjects during sleep.[23] The team additionally found that subjects awoken during REM phases were more likely to remember vivid dreams.[24] In 1957, William Dement, a student of Kleitman, linked REM and dream states to specific EEG patterns, suggesting a relationship between brain rhythms and dreaming.[25] Together, this series of findings established a physiologically grounded approach to sleep and dream research.

Investigators at Chicago were not the first to apply electrodes to the scalps of sleepy subjects. However, whereas previous studies tended to compare the sleeping brain to the waking brain, Kleitman and colleagues used EEG to divide a night's sleep into distinct phases. During the late fifties and early sixties, the new science of sleep frequently appeared in the press, and so too did the relevant brain waves. Indeed, a large portion of popular brain wave discourse during this period pertained to the neural correlates of different sleep states. For example, a 1963 article in the *Tribune* outlines:

> Awake but resting with the eyes closed, the brain sends rhythmical waves out at from 8 to 13 cycles per second, making a characteristic rippling signature. These were called Alpha rhythms. In deep sleep...the waves are large and slow and have a frequency from 1/2 to 2 per second—the Delta rhythms.[26]

Improved techniques for evaluating sleep raised questions as to how one might sleep *better*—how to most efficiently use nighttime hours to enhance daytime productivity.[27] One account describes an EEG-based grading system for sleep: examined throughout the night, a subject receives four points for periods characterized by delta waves ("full unconsciousness"), one point for mere drowsiness, and so forth, with 356 points indicating a "perfect score."[28] Here, competition and performance standards penetrate the sanctity of dreams; even rest becomes work.

Not to be outdone in this apparent sleep race, during the 1950s soviet scientists began experimenting with a process called, "electrosleep," which purportedly promoted slumber via electrical stimulation of the scalp or eyelids (Figure 8). In some places this process is described as a more tame form of ECT, used to induce hypnotic relaxation in individuals with mental illness.[29] Elsewhere, it appears as a strategy to make sleep more efficient, condensing the requisite eight hours into a fraction of that time. In 1963 the *L.A. Times* reported that subjects using an "electrosone" felt fully rested after only two hours of sleep. According to reporter Cyril Solomon, an electrosone stimulates the brain "at approximately the same rate brain waves register on an electro-encephalogram... lulling you into a deep, natural sleep."[30] This research joined other anxious coverage of soviet brain wave technology and soviet science in general. One reporter warned, for example, that the “Reds” had plans to build devices that “generate artificial brain waves to influence mental activity.”[31]

Figure 8. The electrosleep apparatus. Reprinted from K. A. Achte, K. Kauko, and K. Seppälä, “On ‘Electrosleep’ Therapy,” *Psychiatric Quarterly* 42, no. 1 (1968): 20.

At the University of Chicago, EEG research was somewhat less foreboding; however, it wasn’t entirely limited to sleep. Joe Kamiya, a psychologist working across the street from the sleep lab, believed that brain rhythms could provide meaningful insight into the conscious experience of waking subjects. Borrowing Kleitman’s lab space and Dement's expertise in EEG, Kamiya began to investigate whether particular brain frequencies correspond to discernable subjective feelings.[32]

In a 1958 experiment, Kamiya attached electrodes to the scalp of a single subject—graduate student Richard Bach—and proceeded to intermittently ring a bell. After each ring, Kamiya asked Bach if his brain was currently producing alpha waves. Like anyone else, Bach was initially clueless as to the frequency of his neural oscillations. Kamiya thus offered his subject some feedback: after Bach took a guess as to the presence or absence of alpha, Kamiya responded with a simple "correct" or "incorrect." Over time, Bach's guesses became assertions. After a few days of training the subject reportedly recognized alpha with perfect accuracy.[33] To Kamiya, these results indicated that the alpha wave corresponds to a phenomenally accessible state—a finding that compelled him to further explore alpha awareness. If Bach learned to recognize the presence of alpha waves, Kamiya reasoned, then perhaps future subjects might learn to produce these waves on command.

Positive Feedback

> I was interested in the general area of self-perception, that is, the perception by persons of their own features, behavior, and body processes, including their feelings, emotions, thoughts, and memories... For me, such elements of private experience as feelings, images, thoughts, and hopes were a fundamental feature of human life… The apparent denial of their relevance for understanding behavior for the sake of scientific rigor seemed self-defeating.
>
> —Joe Kamiya, "The First Communications about Operant Conditioning"[34]

Earning his graduate degree in the early 1950s, Joe Kamiya was well versed in the behaviorist approach to psychology—an approach that he found both emotionally and intellectually stifling.[35] Kamiya hoped to incorporate private feelings and thoughts into empirical research and viewed EEG as means by which to achieve this goal. Rather than argue for unaided introspection, Kamiya planned to pair self report with brain wave analysis; he would exploit the seemingly objective authority of machines to empower subjective accounts of the mind.

Though motivated by an introspective impulse, Kamiya did not abandon behaviorism entirely. In fact, his investigation into the conscious control of alpha rhythms relied on distinctly behaviorist and cybernetic tactics. Building on his work with Bach, Kamiya developed a brain wave feedback paradigm that worked as follows: with electrodes firmly in place, a subject passively waits for her brain to produce alpha waves. Upon detection of electrical oscillations in the range of eight to thirteen hertz (*i.e.* alpha), an EEG apparatus emits an audible tone, informing the subject that she has hit her neural target. The tone is intended to function as a form of reinforcement that encourages the alpha state; and indeed, Kamiya found that, over a series of training sessions, some participants became quite adept at tuning their brains to the desired frequency.[36] This process can be thought of as a type of operant conditioning that both heightens awareness of a physiological process and enhances a subject's ability to modulate said process. That is to say, alpha training represents an early form of biofeedback—a burgeoning technique that gradually became an organized field of study over the course of the sixties and seventies.

Kamiya made notable strides in alpha research as early as 1958; however he did not formally publish on the topic until a decade later. When Kamiya and co-author Johann Stoyva finally submitted a paper to *Psychological Review* in 1968, they framed alpha training as an extension of dream studies and emphasized the use of conditioning strategies. They write:

> If a measurable physiological event(s) is associated with a discriminable mental event(s), then it will be possible to reinforce in the presence of the physiological event, and in so doing: *(a)* enable *S [subject]* to discriminate better whether the physiological event and the associated mental event are present, *(b)* perhaps, also, enable *S* to acquire some degree of control over the physiological event and the associated mental event.[37]

Kamiya and Stoyva clearly possess a strong command of the behaviorist idiom; yet their pursuit of "mental events" denotes subjective content conventionally off limits to its speakers. In the course of EEG feedback (now known as neurofeedback) electrical information seems to move from brain to machine in a way that feels inherently cybernetic. Yet, this particular breed of mind-machine communication serves not to control the external environment, but to confirm and affirm internal experiences. Neurofeedback simultaneously emulates and subverts the classic behaviorist model—a paradox achieved by recasting mental activity as a behavioral target.[38] Alpha represents both an electrical "output" of the brain and also an interior experience of the mind.

Defining the quality of this interior experience initially proved difficult. After Richard Bach became an exemplary alpha detector, Kamiya asked the man how he knew when his brain was producing the target waves. Kamiya wanted to understand, in effect: *what does alpha feel like?* At first, Bach could not provide an answer—he just knew.[39] Such an experience is understandable in Bach's case, and in biofeedback training more broadly. For, this type of learning entails enhanced sensitivity to visceral, embodied processes that might defy conventional verbal thought.

In biofeedback, a subject learns to associate a physiological state with a stimulus and to become better at recognizing that state. By flashing a light when a subject's blood pressure dips, for example, a subject (ideally) becomes aware of changes in blood pressure absent the light's guidance. Such awareness is distinct from a verbal stream of consciousness, but nonetheless comprises an aspect of conscious experience. In this sense, biofeedback turns behaviorism on its head: rather than marginalize feelings in the name of behavioral reflexes, operant conditioning here *expands* consciousness to include aspects of physiology otherwise beyond subjective awareness.

Though brain frequencies do not neatly translate to concise words or phrases, Kamiya eventually managed to obtain approximate descriptions of the alpha state. When asked about mental strategies for producing or maintaining alpha, study participants cited tactics such as "relaxation" and "letting go."[40] To Kamiya, these accounts suggested that the alpha frequency corresponds to subjective tranquility—and that, with practice, one might learn to induce this tranquility on command.[41]

Despite establishing a loose subjective correlate of the alpha frequency, Kamiya by no means framed his research as a form of mind reading. In fact, the tenets of neurofeedback are, in some ways, at odds with the impulse to use brain wave technology for decoding or transmitting mental content. An alpha monitor extracts waves from the cortex only to feed them back in—a tool not to know the minds of others, but of the self. Neurofeedback thus strays from the principles of cybernetics, broadcast technology, and remote control. Rather than direct waves outward to communicate with distant strangers or nearby machines, neurofeedback amplifies and celebrates waves as situated in the body, and as experienced by the mind.

The Age of ~~Aquarius~~ Alpha

In the early 1960s, Kamiya relocated from Chicago to the University of California, San Francisco (UCSF). There he benefitted from a community eager to expand minds and colleagues who valued introspective methods. During the sixties, Northern California was the epicenter of the Human Potential Movement (HPM), a cultural undertaking that involved the comingling of researchers dissatisfied with mainstream psychology and youth dissatisfied with mainstream culture—*i.e.,* Kamiya and his subject pool.[42] The HPM grew out of a revolution in humanistic psychology, led by Abraham Maslow and Carl Rogers (among others) during the 1950s.[43] The movement was a direct response to the limits of behaviorism, and to practices in psychiatry and psychosurgery that aimed to "correct" abnormal brains or to expose depraved ids.

Central to the HPM was Maslow's theory of *self-actualization*, which he defined as "the desire to become more and more what one is, to become everything that one is capable of becoming."[44] Maslow maintained that there exists no one *correct* way to think or behave, but simply room to become a better version of one's unique self—a view that spoke to a generation rebelling against prescribed social norms. Of course, for some members of the HPM, the quest "to become everything that one is capable of becoming" called for practices more extreme than clinical therapy and drugs a little stronger than empathy. The HPM permitted a number of methods for achieving self-actualization, including but not limited to: acid trips, meditation, gestalt, and *est*. Such practices spanned boundaries of social, scientific, and spiritual spheres, these worlds converging at research-recreation retreats like the Esalen Institute in Big Sur, California.[45]

Among the HPM's eclectic practices and people, Kamiya and alpha feedback fit right in. The notion of accessing one's brain rhythms—of unleashing the latent potency of alpha—aligned with the theme of human potential. Further, neurofeedback held an alluring resemblance to Eastern meditative practices recently appropriated by the counterculture.[46] Popular representations of Kamiya's work would exaggerate this resemblance to the point of gimmick; yet similarities between neurofeedback and meditation were not entirely manufactured. After all, even traditional EEG requires subjects to sit motionless, with little distraction—a protocol that possibly yields inner peace and definitely reduces signal interference.

The generation of *alpha* waves, specifically, demands a certain meditative quietude. As early as the 1930s, researchers understood that visual stimuli interrupt the alpha frequency.[47] Kamiya's experiments (and other research in the field) suggested that that even *imagining* visual scenes can obstruct alpha's flow. Kamiya describes:

> All those who had taken part in the [alpha feedback] experiment described various kinds of visual imagery or "seeing with the mind's eye" as occurring in the non-alpha state. The alpha state commonly was reported as "not thinking," "letting the mind wander," or "feeling the heart beat."[48]

In other words, alpha waves dominate when a subject shuts her eyes, but remains awake and thinks of nothing—a condition loosely describing meditation.

When Kamiya summarized his alpha experiments in *Psychology Today* (1968), he established an explicit connection between this research and spiritual practices, noting that subjective reports from study participants resembled "descriptions of Zen and Yoga meditation."[49] In the same article Kamiya also mentions that "seven practiced Zen meditators" participated in his study. These special subjects, writes Kamiya, "learned control of their alpha waves far more rapidly than did the average person."[50] This result seemed to corroborate a 1966 study (distinct from Kamiya's work) that indicated a superior ability to generate the alpha rhythm among Zen practitioners in Japan.[51] In both cases, alpha mastery was associated with spiritual mastery—an association that enchanted some members of the counterculture, and eventually mainstream culture.

Whereas the *Psychological Review* article cloaked alpha in protective behaviorist armor, Kamiya's concurrent piece in *Psychology Today* let alpha waves flow freely into the countercultural ethos. In the latter, Kamiya loosely maintains the framework of operant conditioning, but expounds on topics that would make the traditional behaviorist blush. Kamiya does not hesitate to deploy the c-word (consciousness) and associates neurofeedback with ideals and practices of the HPM. He alludes, for example, to "possible value in studies of alpha wave control during the LSD experience" and frames alpha itself as a sort of high. "People describe themselves as being tranquil, calm and alert when they are in the alpha state, and about half of our subjects report the alpha state as very pleasant," Kamiya writes. "Some of them asked us to repeat the tests so that they could experience once again the high alpha condition."[52]

Kamiya's combination of science, substances, and spirituality was a standard blend for the pages of *Psychology Today.* Like many of its subscribers, the magazine was fairly young and based in California; it was founded in 1967 by, as one account tells it, "a rogues' gallery of counterculture ex-college kids and self-described publishing geniuses."[53] In its early years the magazine presented an inspiringly fresh view of brain research. Contributing scientist-authors did not seek to diagnose or homogenize readers, but to offer assistance in the quest for self-actualization. I highlight these features not to give *Psychology Today* overwhelming credit for uniting scientific and social movements, but to underscore extant connections between the counterculture and humanistic research. The magazine was effectively a print incarnation of the HPM, evidencing that psychological research could, much like an acid trip, enhance introspection, expand consciousness, and, even while directing attention inward, encourage social harmony.[54]

Places like Esalen and publications like *Psychology Today* share qualities with other contexts in which brain waves and associated ideas historically thrived. Like pseudoscience spectacles or hobbyist magazines, the HPM opened scientific conversations to non-expert audiences. In such contexts, the boundaries of what constitutes science become somewhat relaxed, and research transforms from esoteric theories into something that nonscientists can *use*—practically, spiritually, or both. Mesmerism adapted theories of magnetism into a practice through which to heal the body and soul—a way to conceptualize religion according to empirical language. The HPM similarly offered a way to work on the soul and self via practices apparently corroborated by innovative research.

Psychology Today was the first popular publication to feature Kamiya's work; however, it was by no means the last. Between 1970 and 1971, alpha feedback appeared in the *New York Times,* the *Chicago Tribune, Look*, *Life,* and a number of local newspapers.[55] In the national spotlight, alpha maintained some of its countercultural edge, though by that time the line between counter- and mainstream culture was becoming increasingly hazy. A piece in *Life,* for example, borrows the language of Timothy Leary for its title, "Turning on With Alpha Waves," and notes that the technology, "is helping a lot of people to relax and a few even to sustain a mild alpha 'high.'"[56]

Figure 9. Photos of individuals building (left) and using (right) alpha brain wave monitors. Reprinted from “Turning On with Alpha Waves,” *Life*, August 21, 1970, 60-61.

It is difficult to estimate precisely how many people actually partook in EEG-aided meditation. But, according to the *New York Times,* by 1971 “a cult of alpha” had been established and Joe Kamiya was “something of a pop hero to kids who hoped to groove their way into an instant satori.”[57] In the same way that the scientific authority of humanistic psychology validated broader countercultural inclinations, the technological authority of EEG legitimized mind-expanding practices. The counterculture emitted a signal of self-discovery, and alpha’s feedback positively reinforced this behavior.

Good Vibrations

> Not long ago, the word “vibrations” entered American slang. “Vibes” are feelings that one person arouses in another by supposedly unobservable means. According to popular usage, one person sends vibes and others get them. The term is a metaphor for the communication of emotion. In another sense, vibes are more than a simple message, they’re an emotional climate, and like any emotional

> climate, particularly those evoked by first impressions, they tend to be categorized by receivers as beneficial or dangerous.
>
> —Ernst G. Beier, "Nonverbal Communication"[58]

Brain waves were not the only vibrations flowing through popular discourse during sixties and seventies. Concurrent with the rise of alpha feedback was the entrance of "vibes" into hip vernacular. Increased use of the term seems to reflect the collision of two etymological trajectories: musical vibrations and spiritual vibrations. Starting in the 1940s, "vibe" served as shorthand for a vibraphone or music therefrom, particularly in the context of jazz.[59] By the mid-sixties, *vibes* maintained the coolness of this musical connotation, but also referred to a less audible type of vibration—the sort of vibration that can neither be seen nor heard, but is nonetheless felt.

Vibes came to be understood as an emotional energy that radiates from an individual or a crowd. Though vibes appear a unique invention of the 1960s, we have seen this type of vibration before: invisible psychological and spiritual forces thrived during the etheric 1800s. Subscribers of mesmerism, spiritualism, and telepathy often imagined that humans (and perhaps animals) emit auras that are not detectable via common sensory organs, yet are somehow apprehensible by the psyche. William Crookes, for example, posited a "Psychic Force" that moves in "successive waves;" contemporaneously, Knowles proposed his theory of brain waves. Crookes's force and Knowles's waves were not interchangeable; yet, they reflect a common etheric worldview that fused the new science of EM vibrations with vitalism and older spiritual theories. The simultaneous rise of alpha enthusiasm and the use of "vibes," I contend, similarly points to a single waving ethos, but does not reflect a direct relationship between vibes and EEG.[60]

Though the pursuit of psychical research and associated phenomena eventually lost scientific credibility, colloquial references to interpersonal vibrations appear throughout the twentieth century. Positive or negative vibrations serve as a way to describe an intuition about a person or place; and in the 1960s, this sort of intuition was often framed in terms of *vibes.* Though they are not synonymous, vibes and alpha share a wave aesthetic and values embedded therein. I have previously associated this aesthetic with a prioritization of emotional fluidity over logical clarity—a prioritization consistent with the counterculture's preference for interpersonal awareness over soulless Boolean formulae and militaristic commands. The counterculture valued communication, but not the variety that aims to control; and they valued connections more profound than those comprising an electrical circuit.

Though vibes do, in a sense, convey meaning, they do not conform to the conventions of language. Indeed, vibes communicate what words cannot. In a society of disconnected bodies, vibes point to continuity and spiritual interconnectedness. From this perspective, vibes establish a wavy emotional ecosystem that unifies humankind. And from another perspective, vibes are vacuous hippie mumbo jumbo. In 1973, Henry Allen of the *Washington Post* wrote a column that satirically exposed these dueling views. "Every age needs something that explains everything," Allen writes. "At the moment, nothing does it nearly as well—or as often—as vibes." He continues:

> Vibes—short for "vibrations"—are the workingman's cosmic awareness, the psychic radiation that pulses out of everything from snakes to Walter Cronkite…Theologians call it God's will, captains of industry call it the protestant ethic, behaviorist psychologists call it conditioning, gamblers call it luck. It's vibes…Vibes explain everything, blame no one. Research is clearly called for.[61]

Though Allen's tone is mocking, he keenly identifies a sense of "cosmic awareness" that links the vibes of the 1970s to the etheric ripples of the 1870s. His examination of vibes also exposes distinctions between the counterculture's vibrational attitude and a cybernetic, cause-and-effect understanding of social and physical phenomena. Tongue in cheek, Allen indicts a generation that (in his view) did not accept responsibility for their actions and a government that similarly resisted accountability: "Vibes and responsibility don't mix," he writes.[62] Here, Allen captures a broader argument of the counter-counterculture: as liberating as a wavy, spiritual worldview may be, good vibes cannot resolve society's woes.

Zen and the Art of Alpha Maintenance

> Brainwave monitors that enabled one to tune in to hidden EEG waves was the new way to achieve a Zen state... I worked tirelessly to construct a custom brainwave monitor from Radio Shack transistors–a quest for a new technology that might empower the Quest. After a year of work, I attained my electronic nirvana. I could journey to the stars with my mind and a 9-volt battery!
>
> —Mitchell Waite, "How to Build a Brainwave Monitor"[63]

By the 1970s, clinical-grade EEG machines were far more complicated, and more expensive, than those of the 1930s. State-of-the-art devices collected several channels worth of data and incorporated analytic computing technology that enhanced the accuracy and speed of signal processing. Comparatively, a basic brain wave feedback monitor—a one- or two-channel apparatus that beeps in the presence of the desired frequency—was a rather simple and cheap piece of technology. An individual compelled to amplify inner alpha could feasibly build a personal monitor from components available at a common electronics store—provided that said individual possessed a certain level of technical competence.

Construction and maintenance of an alpha monitor, in fact, presented a familiar ritual to electronic hobbyists. The machines were finicky, demanding the ongoing attention of an old radio that struggles to find a signal. For some, technical hiccups might taint the serenity of alpha meditation. Yet tinkerers understand—and often enjoy—the nuances of caring for a temperamental radio. To the devoted hobbyist, electronic wires represent not (solely) circuits driving efficient communication and control, but a playground for personal diversion. Indeed, electronic hobby can be viewed as the technological analog of self-exploration. Just as the humanist rejects strictly functional models of the brain and prescribed social roles, the hobbyist engages a device in ways that upset its ordained function. For example, whereas the average consumer interacts with a radio to receive or send a signal (its ordained function), a hobbyist manipulates the radio's constituent parts to better understand how it works and perhaps amend its circuitry—mechanical mind expansion.

As I discussed in Chapter 3, hobbyist magazines proposed brain wave gadgets almost as soon as such publications existed. Editors like Hugo Gernsback welcomed accounts of unconventional, and even hypothetical, technologies; and the language of frequency modulation united neural and radio waves. Like *Psychology Today,* and like nineteenth century scientific spectacles, electronics magazines offered an opportunity to observe the forefront of science—and to perhaps look beyond it. In the 1970s, as in the 1920s, hobbyist magazines encouraged creative, technical thought; they provided a home for material and intellectual tinkering.

By 1972, the heyday of amateur radio had passed and the age of home-brewed computers had not quite arrived. Yet the hobbyist community was by no means inactive; and, according to one of its favored publications, amateur electricians still had a soft spot for brain waves. An editor's note in the December 1972 issue of *Popular Electronics* mentions "many requests from readers for articles on alpha brain waves"— requests that prompted the commission of two articles on the topic. Authored by Mitchell Waite, the articles outline how to master alpha, as a machine and as a mental state.[64]

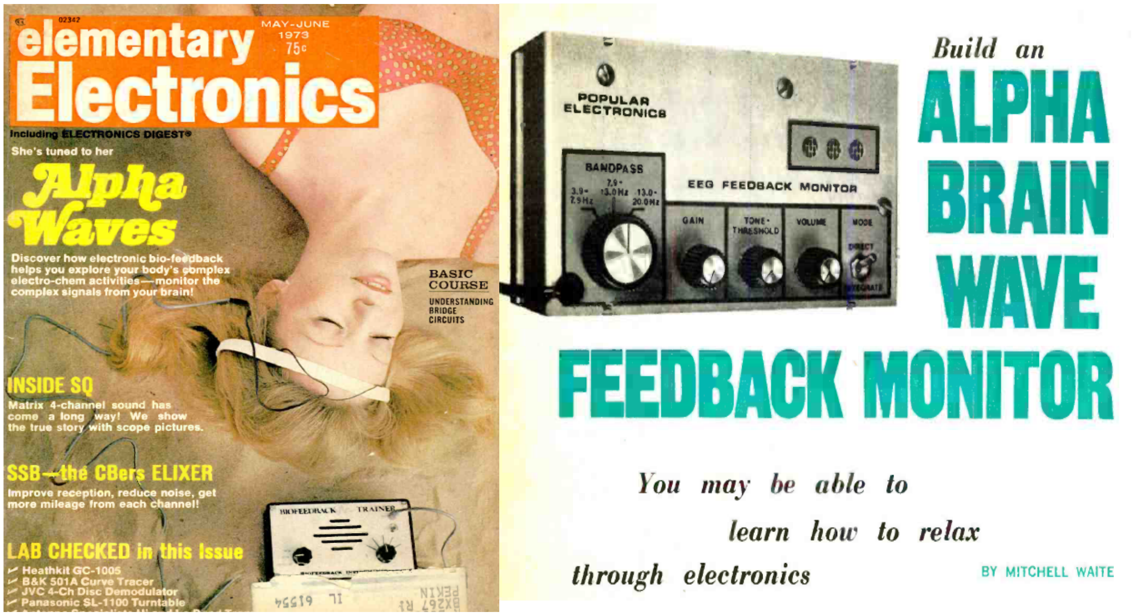

Figure 10. Alpha in electronics magazines. Left: Alpha waves make the cover of *Elementary Electronics*. Reprinted from *Elementary Electronics*, May–June 1973. Right: First page of Waite's second article. Reprinted from *Popular Electronics*, January 1973, 40.

Parallels between mind expansion and technical hobby come to a visible intersection in alpha feedback devices, particularly as described by Waite. The tinkerer must occupy a certain physical and psychological state to complete any electronics project; however, alpha construction explicitly incorporates subjectivity into technicality. Waite advises readers: "Notice the types of thoughts that block the alpha. After you are sure you are producing alpha, switch S2 to INTEGRATE and adjust the threshold/tone control so that, when the eyes are open, there is no tone."[65]

According to Waite, the monitor does not *work* unless the target wavelength corresponds to a target mental state. This subjective confirmation both connects the tinkerer to his device, and also denotes a clear distinction between the two: machines can guide the exploration of consciousness, but machines themselves cannot take subjective sojourns. Kamiya initially employed EEG technology to incorporate greater introspection into psychology; and amateur alpha projects functioned similarly. They encouraged hobbyists to *use* machines in pursuit of a uniquely human experience.

In their purest forms, both meditation and tinkering are self-justifying processes. The hobbyist fixes the radio not to sell the device for a profit, but to enjoy technicality itself; one does not seek enlightenment to receive some tangible prize, but to access an ineffable spiritual sate. Or as Waite, puts it, "[Biofeedback] does not offer an explicit reward for the correct response. The only reward is what comes from eventual mastering of the process."[66] The spiritual purity of alpha feedback, however, did not last long. Where Waite saw "electronic nirvana," others saw a business opportunity.

Selling Brain Waves

Kamiya did not patent alpha feedback technology. However, following the popularization of his research, copycat devices emerged.[67] A 1975 survey identifies 23 EEG manufacturers in the United States, with 16 machines meeting criteria for "popular-priced" at $250 or less.[68] These products ranged widely in quality and character. At $98 the MOE Biocouple came with a built-in frequency calibrator and LED feedback; the Psionics ETC, on the other hand, cost $200 and lacked both of these features—though, to be fair, the ETC did come with a pack of "Zen soda crackers," more commonly known as Saltines.[69] Though one can safely assume that no manufacturer retired on revenue from alpha monitors, 1974 litigation over royalties from the Aquarian Alphaphone (one of the better-known products) implies a belief that the devices were—or would become—profitable.[70]

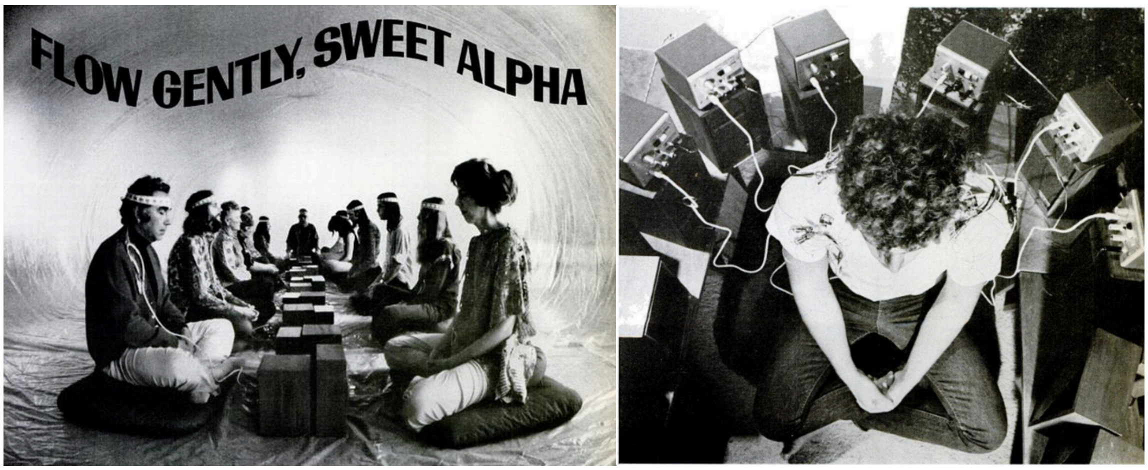

Figure 11. The alpha fad. Photos from a 1972 article in *Life*. The author writes: “In hopes of serenity, hopeful thousands study their own brain waves.” Reprinted from Jane Howard, “Flow Gently, Sweet Alpha,” *Life*, April 21, 1972, 63, 71.

To be clear, access to alpha monitors was far from ubiquitous. However, the notion of alpha-driven serenity nonetheless penetrated popular awareness via frequent reporting on the topic. By the mid-seventies alpha was, at least in some circles, a fad. In 1974 an *L.A. Times* reporter observed: “It’s an ‘in’ thing to worry about your Alpha brain waves—those associated with what might be called a state of ‘attentive relaxation.’”[71] Though newspaper coverage effectively spread the gospel of alpha, the simultaneous emergence of an alpha *market*, put a capitalist taint on technospirituality.

As alpha migrated beyond Northern California, the frequency remained associated with relaxation and introspection; however, transition into the mainstream somewhat distanced neurofeedback from other aspects of the counterculture. Proponents continued to refer to an alpha "high," yet the wave was frequently depicted as a safer alternative to narcotics, thus distinguishing alpha from the deviance of drug use. Further, alpha entrepreneurs often prioritized the *efficiency* of brain training—a kind of meditation not for mountain-dwelling monks, but for individuals subject to the demands of western society. In an interview with the *Chicago Tribune* a spokesperson for the Aquarian Alphaphone, Gene Estribou, commented: "People have always tried to achieve calm and relaxing 'highs' in which they can slow down and achieve peace and come to terms with themselves. But in a jet age, who's got the time to sit down for hours, just twiddling one's thumbs thinking of nothing?"[72]

Alpha proselytizers began to frame brain wave meditation as a tool to boost productivity—a momentary escape from the demands of capitalist society…to become a more valuable member of capitalist society. In 1972, as if to announce the corporate appropriation of neurofeedback, alpha waved right into McDonalds. That is, the company's headquarters in Oak Brook, Illinois installed an alpha feedback monitor, the goal of which was to enhance creativity among its top employees: fast food meets fast enlightenment.[73]

Over the course of the seventies, alpha became a monetizable product, independent of EEG technology. For-profit meditation groups increasingly used the language of brain waves, presumably to imbue their services with the authority of a yogi-scientist. Simultaneously, books about alpha training and other forms of biofeedback established a niche in the pop-psychology genre. Alpha also appeared in literature associated with various self-help schemes, particularly Silva Mind Control seminars and publications, which promised to make subscribers more effective in the world via a combination of brain wave coaching and ESP.[74]

After alpha's wave of fame subsided, traces of Kamiya's work—like influences of the counterculture more broadly—lingered. In popular science literature, alpha remained associated with relaxation; and biofeedback established itself as a lasting, if niche, therapeutic subfield. Further, the momentary trendiness of EEG somewhat destigmatized interaction with the machine. In her 1974 pop-psychology book, *New Body, New Mind*, leading biofeedback researcher Barbara Brown comments:

> Until the recent popular alpha bio-feedback fad, the subject of brain waves was of general intellectual interest and curiosity, but was a subject that caused considerable personal apprehension… Brain wave recording was always associated with serious physical problems. It meant search for brain damage, tumors and the kind of brain disorder with a poor diagnosis.[75]

Through biofeedback, EEG frequencies transformed from clinical metrics to a family of waves with distinct, likeable personalities. Though I have here focused on alpha—which, by far, received the most popular attention—other waves similarly established positive (and simplistic) reputations. In popular discourse, these reputations have remained more or less in place from the seventies through present day: Theta signifies creativity; Beta represents attention; Delta accompanies sleep; and Alpha indicates "attentive relaxation."

A Sea of Many Waves

Via association with meditative rituals, the brain waves of the 1970s maintained a spiritual tang—but one distinct from their telepathic origins. The waves of biofeedback depart from a view of waves qua medium for thought transmission. They are neither messages to be read, nor commands to manipulate muscles or lamps. Contrary to an impulse to remotely control foreign objects, biofeedback uses amplification technology to target a familiar subject—the self. The reported high of alpha suggests that cosmic connection arrives via exploration of inner, not outer space.

The years of the "alpha bio-feedback fad"—approximately 1968 through 1976—coincide with a historic climax in the volume of popular brain wave discourse.[76] This crest, however, does not solely reflect coverage of alpha waves as a strategy to achieve nirvana; rather, it reflects the sum of multiple conversations occurring in parallel. The counterculture, after all, did not have a monopoly on brain waves.

During the early 1970s The Advanced Research Projects Agency (ARPA) launched a series of studies investigating potential applications of EEG technology in the armed forces. Based at Stanford, the work transpired about an hour's drive from Kamiya's lab—yet the nature of this research was quite far from heart of the HPM. A 1973 report summarizing ARPA's project reads:

> The objective of this research is to test the feasibility of designing a close-coupled, two-way communication link between man and computer using biological information. The research plan is to conduct experiments to determine whether biological information from the central nervous system and muscles of portions of the vocal apparatus can be directly related to thought processes.[77]

Here, the proposed "link between man and computer" superficially resembles an alpha monitor. Yet, contrary to the brain waves of biofeedback, the report casts neural oscillations as a medium for communication and control; and contrary to the mission of the counterculture, ARPA's research was ultimately affiliated with violence. The team aimed to produce a machine that would monitor vigilance in fighter pilots, effectively creating more efficient war cyborgs.[78]

In case entering the military wasn't bad enough, EEG also appeared on the political stage when, in 1973, two congressmen used brain waves to forward an anti-abortion agenda. The pair argued that "Brain waves can be detected at about the sixth week of pregnancy," citing this evidence as proof that a fetus is a living, thinking person—an electric soul worth saving.[79] Elsewhere, experts proposed using EEG tests to evaluate hospitalized patients straddling death; according to this view, a patient is considered living as long as her brain produces reliable waves. However, this proposal faced backlash, as anti-abortionists cited a double standard: if brain waves prove life in an infirmed individual, why do they not prove life in a fetus?

The vast majority of actual EEG research throughout the sixties and seventies was neither politically controversial, nor spiritually inspired. As in decades past, EEG most often served as a tool for studying epilepsy and sleep disorders, and sometimes for identifying neural correlates of intelligence or personality.[80] EEG remained the only means by which to evaluate activity in the living human brain, and was thus employed to study a wide range of phenomena that lay at the intersection of psychology and physiology. For example, in 1972 a Stanford group used EEG to measure sexual arousal, suggesting that this technique might prove useful in identifying "deviants;" and in 1974 researchers in New York hypothesized that errant brain waves might underlie overeating in individuals with weight problems.[81]

Though no technology yet challenged EEG's dominance in imaging the active brain, during the sixties growing attention to brain *chemicals* added color to this picture. In some cases, the science of neurochemistry and brain waves was complementary. A clinician might, for example, use EEG to diagnose a mental illness, and then prescribe drugs to treat said illness. And in the popular press, articles about recreational chemicals—ranging from LSD to nicotine—sometimes referred to EEG results to confirm the (usually negative) effects of drugs on the brain. For example, according to a

1968 article in the *Chicago Tribune,* EEG tests among LSD users revealed that "there is so much electrical interference going on in the brains of drug users that incoming messages from the world cannot get thru."[82]

Though drug use among the counterculture represents a chemical revolution in its own right, the chemical turn in brain science remained in its infancy until the 1970s. Prior to that time, the development of psychopharmaceuticals was effectively a product of trial and error—chemical experimentation that wasn't too far off from the practices of narcotically-inclined youth. However, during the same years that alpha enjoyed its high, scientists achieved an increasingly sophisticated understanding of neurochemistry. And these advances, along with the development of novel neuroimaging techniques, would dramatically repaint the picture of brain science.

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like the ongoing normal fluctuations of some measure of their own physiological activity." Kamiya, "First Communications," 67.

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Method	Number of Reports (Possible for Each Category: 16)
Relaxation	7
Awareness of inhalations and exhalations	4
Letting go	3
Floating	3
Feeling of pleasure, security	3
Sensual warmth	3
Not focusing	2
Awareness "in back"	2
No idea	4

Table 1. How Subjects Reported They Controlled EEG Alpha: A Coding of Their Spontaneous Remarks. Reprinted from Nowlis and Kamiya, "Control," 482.

The two studies included 34 subjects—combined—and were, empirically speaking, less than impressive. However, these papers were published after the *Psychology Today* article—wherein Kamiya claims to "have tested over 100 people." Thus, though Kamiya's scientific publications might have given scholarly critics ample opportunity to question his work, they likely had little impact on the popular appeal of alpha feedback.

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[54] Owen Lipstein, "Yesterday, Today & Tomorrow: A Conversation with Nicholas Charney," *Psychology Today* 25, no. 3 (1992): 20. For example, the first issue of *Psychology Today* featured an article by Stanley Milgram. Therein, the controversial psychologist summarizes his Small World experiments. Closing with words that would appeal to the magazine's young readers, Milgram writes: "While many studies in social science show how the individual is alienated and cut off from the rest of society, this study demonstrates that, in some sense, we are all bound together in a tightly knit social fabric." "The Small-World Problem," *Psychology Today* 1, no. 1 (1967): 67.

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[60] The term "flow," coined by Mihaly Csikszentmihalyi, also came into circulation during the mid-seventies. I am not implying a direct relationship between alpha monitors and Csikszentmihalyi's work; I only mean to highlight a contemporaneous area of psychological research that prioritized subjective experience…and one that had a certain waviness about it.

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Chapter 7. Waves 'n' Stuff

Neuroeconomics. Neurolinguistics. Neurophilosophy. Neuroaesthetics. Today, brain science permeates facets of the social sciences and humanities historically beyond biology's purview—a disciplinary diaspora that is met alternately with enthusiasm and disdain. The latter response reflects a mix of academic territoriality and well-founded skepticism, particularly regarding reductive claims associated with fMRI studies and other "brain-mapping" techniques. These bright brain portraits have become the unofficial mascots of Neuroscience and serve as easy targets for neuro-detractors. Essayist Arthur Krystal, for example, bemoans: "Where once the philosophical, political, and aesthetic nature of ideas was the sole source of their appeal, that appeal now seems to derive from something far more tangible and local…Instead of grappling with the gods, we seem to be more interested in the topography of Mt. Olympus."[1]

EEG research, like brain mapping, sometimes inserts scientism where it may not seem to belong—say, into meditative rituals. Yet critics quick to mourn the invasion of neuroscience into sacred humanistic space don't often wage war against brain waves. Certainly, outlandish EEG claims will face scholarly suspicion; but this area of brain science does not suffer the public anti-reductionist wrath endured by newer imaging technologies. For while brain wave models ultimately offer a materialist theory of the mind, they do not seem bound by identifiable matter: abstract signals appear an incomplete physical reduction. Whereas a wave may represent undulations of ether, electromagnetism, or the spirit, brain maps prioritize unambiguous physical *stuff*—brain regions made of neurons, which exchange specific chemicals.

Cartographic and chemical views of the brain came to prominence during the last quarter of the twentieth century—coinciding with a rise in the prominence of neuroscience as a field. When the Society for Neuroscience (SfN) held its first annual meeting in 1971, the event drew just shy of 1,400 scientists. By contrast, organizers reported a total of 31,250 attendees at the group's 2014 conference.[2] Though an imperfect metric of the discipline's growth, these statistics accurately reflect expansion within neuroscience, as well as increased cultural visibility of the field. In the early seventies the term "neuroscience" rarely appeared in the popular press; by 2000 the field was trendy, sometimes controversial, and effectively synonymous with the vivid maps yielded by fMRI and similar technologies.[3]

Though brain waves remain the protagonist of this story, it would be misleading to depict neural oscillations as central to brain culture or pop culture during neuroscience's formative years. Thus, in this chapter I outline the development of the geographic and chemical models that remain closely associated with the discipline today. Such a discussion will not lead us completely astray: a closer look at brain portraits and neurotransmitters elucidates the cultural niche of brain waves in the new millennium.

Brain Stuff

When neurons became doctrine at the beginning of the twentieth century, many scientists suspected that discrete cells communicate with one another electrically. Existing research overwhelmingly confirmed that muscle contraction corresponds to fluctuating electric potentials.[4] Given this evidence, it seemed reasonable to assume that inter-cell messaging consists of electric signals that leap across synapses, akin to a sort of biological spark gap. This assumption, however, was not universal.

During the early 1900s, a handful of researchers observed that select chemicals excite muscles in a manner similar to electrical stimulation. Specifically, multiple studies showed that muscles flinch when exposed to a hormone isolated from the adrenal gland. In 1904 Thomas R. Elliott posited that this substance, adrenalin, "might then be the chemical stimulant liberated on each occasion when the impulse arrives at the periphery."[5] According to this view, the propagation of signals *within* nerve fibers indeed takes electrical form, but *cell-to-cell* interaction requires a chemical liaison.

The chemical theory of synaptic signaling initially endured considerable pushback. However, in 1921 German scientist Otto Loewi performed a now-canonical experiment that challenged an exclusively electrical model of the nervous system. Loewi showed that electrical stimulation of a frog's vagus nerve prompts the secretion of a unique substance. Further, he demonstrated that a frog's heart rate relaxes when exposed to said substance. Loewi concluded that it is not electricity proper, but the secreted chemical that mediates heart rate. This chemical is now known as acetylcholine (ACh); but Loewi, in his native German, originally termed the substance "*vagusstoff.*"[6]

In English, *stoff* translates to "material," "substance," or simply "stuff." Loewi's name for ACh—effectively "vagus stuff"—is therefore not particularly creative. However, the term importantly betrays an ontological contrast between electrical and chemical theories of neurotransmission—a contrast between process and substance, or signals and stuff. That is, whereas electricity often appears as dematerialized dynamics, chemicals present as palpable particles with mass, volume, and structure.

In the most general terms, electricity connotes a change or movement of charge; thus, it is inherently a *process.* Electricity is not a piece of *stoff* that one may store in a pocket, purse, or vial. Of course, nervous electricity is not made of nothing: when a cell depolarizes, charged particles (*i.e.* bits of matter) move across cell membranes. Yet, we often treat electricity like a vague, intangible energy—an invisible power resembling imponderable etheric forces of yore. And, to a certain extent, neuroscientific methods reinforce electrical dematerialization. Electrodes detect changes in potential over time: voltages rise and fall; neurons spike at varying rates. Electrical "messages" are thus defined by their temporal features, rather than the matter—the *stoff*—underlying these changes.

As compared to electricity, a chemical like ACh appears quite tangible. A distinct type of stuff, the chemical can be isolated, analyzed, sniffed, and stored. Still, embrace of a chemical model of mind did not follow immediately from Loewi's work. For, his findings pertained narrowly to the heart, implicating chemicals in the modulation of unthinking visceral organs, but not of the brain or of skeletal muscles. Even after Loewi and Henry Dale received the 1936 Nobel Prize in Physiology and Medicine "for their discoveries relating to chemical transmission of nerve impulses," conservative adherents to an electrical view were not willing to extrapolate these findings to the nervous system at large.[7] Chemical innervation of skeletal muscles remained a contentious topic; and a chemical model of the brain was effectively off the table.[8]

Proponents of chemical neurotransmission butted heads with electrical traditionalists from the 1920s through midcentury—a conflict sometimes referred to as a war of "Soups" and "Sparks."[9] Research increasingly supported a chemical view (the Soups); however, holdouts in the Sparks camp maintained, among other things, that chemicals move too slowly to govern cognition and behavior with the requisite efficiency.

The objection that chemicals can't keep up with the speed of thought is reasonable enough—chemical transmission really is slower than electrical transmission. However, this objection may also reflect a less empirical attachment to electrical theories. Electricity is associated with the rapidity of telegraphy and the potency of lightning. As such, it achieves a magical, technological status. Both ghost and machine, electricity presents as a sort of vital force without the embarrassment of overtly spiritual language. Electricity, like the mind, seems somehow *more* than physiology—more resilient, more dynamic, more special. Brain chemicals, on the other hand, represent simple organic matter—*stoff* that is subject to the limitations of biology.

By the 1950s, the vast majority of researchers acknowledged the existence of chemical signaling in the peripheral nervous system. Yet, they were slow to explore these dynamics in the brain proper. As Valenstein highlights, the belated investigation of brain chemistry was peculiar considering the growing use of psychoactive medications.[10] During the 1950s pharmaceutical companies marketed the first drugs explicitly indicated for the treatment of depression—namely, imipramine and iproniazid.[11] These drugs emerged alongside the tranquilizer, meprobamate, also known as Miltown or "Mother's little helper."[12] Concurrently, recreational drug use among the counterculture represented another breed of pharmacological experimentation. Thus, independent of the esoteric battle of Soups and Sparks, it was known that chemical *stoff* interacts with subjective experience.

Still, knowing that chemicals influence the mind or brain does not amount to a scientific model of neurotransmission. During the 1960s and '70s, however, improved cellular labeling and microscopy techniques began to illuminate how particular bits of stuff might move from one neuron to another, and the cellular changes that follow.[13] Specifically, fluorescence microscopy allowed researcher to visualize monoamines—a subset of brain chemicals—within the bodies of neurons.[14] By the late sixties, resistance to a chemical view of the brain had diminished in the face of mounting evidence, and the word "neurotransmitter" began to appear with increasing frequency in scientific papers.[15]

A neurotransmitter is any chemical released by one neuron that moves across a synapse to reach a receptor on a second neuron.[16] To the uninitiated, the term might seem a peculiar choice. Typically, a "transmitter" denotes a device that transmits something, often through the air; a radio, for example, is a transmitter of EM waves. By comparison, *chemical* neurotransmission appears a rather old-fashioned mode of communication. Chemicals do not zip along as waves through EM fields; rather, their movement depends on a series of cellular processes that prompts a neuron to empty a packet of chemicals into the synapse. A relatively slow means of transmission, chemical messaging registers as more tangible than its electrical counterpart. The process resembles the handoff of a precious package—the contents of which somehow change the demeanor of receptive cells.

By the mid '70s, systematic study of neurotransmitters was not only active, but in vogue. Researchers identified an array of molecules that participate in neuronal signaling; and news about various brain chemicals began to penetrate popular discourse. In 1977, the *New York Times* reported: "until a year or two ago the brain seemed to be dominated by just a few neurotransmitters...Today scientists count at least 25 neurotransmitters, and more are being discovered each week."[17] The report perhaps exaggerates the actual pace of neurotransmitter discovery, but it captures the spirit of progress in this area of research.

In the end, the Soups triumphed over the Sparks. However, this victory does not imply that electricity plays no role in the nervous system. Biologically speaking, chemical and electrical signals are entangled; and a cohesive understanding of the nervous system requires attention to both of these aspects of physiology.[18] Culturally speaking, neurotransmitters fill a niche that brain waves cannot: for better or worse, they represent a departure from the view that brains work like electric machines.

Chemical People

> Perhaps the most interesting overall finding about the brain is that most of the early mechanical versions of how it operates have now been completely abandoned. The brain used to be described in terms of the prevailing technology—a spinning wheel, a radio station, a telephone system, a computer, even a hologram. None of these portraits lasted very long because the brain proved to be so much more complex than the latest manmade machine. The new view is that nothing in technology can match the brain even metaphorically. The brain seems to be comparable to society itself.
>
> —Lee Edson, "4,000 Scientists in California Find the Universe in the Brain"[19]

I have argued that, historically, theories of brain waves benefitted from analogies between the nervous system and communications technology. A resemblance to radio waves, for example, stirred fantasies that brain waves might transmit messages to distant locations—locations much more remote than, say, the other side of a synapse. I have also argued, however, that comparisons between our brains and our tools are not always complimentary. Analogy between the psyche and a servomechanism, for instance, robs the brain of emotional nuance. Thus, though neurotransmitters do not inspire the sort of telepathic dreams associated with neural oscillations, their distance from the realm of electrical technology may, in some respects, be an asset.

Chemical investigations of the nervous system call attention to the material aspects of neurophysiology that distinguish nerves from wires. Whereas computers and brains both convey electrical signals, neurons alone trade in biologically synthesized *stoff;* and by late 1960s, this may have been a welcome distinction—a way to preserve the brain's humanity as technology encroached on domains hitherto reserved for people. And, indeed, as researchers and journalists made increasingly specific claims about the role of various neurotransmitters, they did not paint these chemicals as cold signals within a servomechanism. Rather, they commonly linked chemicals to uniquely human *feelings.*

That brain chemistry interacts with emotion is now common, if vague, knowledge. As Leo and Lacasse show, the "chemical imbalance" theory of mental illness has considerable popular currency—despite inconsistent scientific evidence. They write:

> In the world of American popular culture, the current view of mental illness depicts someone walking down the street, and everything is fine, life is good. Then all of a sudden, out of the blue, a chemical imbalance emerges. At the root of every twisted thought lurks a twisted molecule—so the thinking goes.[20]

France, Lysaker and Robinson attribute the emergence of the modern chemical imbalance theory to a series of scientific events that took places during the 1950s and '60s. Namely, they cite "important discoveries such as the efficacy of chlorpromazine for psychosis; findings that monoamines exist within the central nervous system (CNS) and act as neurotransmitters; and an early understanding of monoamine synthesis, storage, release, and deactivation."[21]

Neurotransmitter research did not introduce the notion that substances can influence one's subjective state; certainly, millennia of alcohol consumption would offer ample evidence to corroborate such a hypothesis. However, emerging studies reframed chemicals not merely as something prescribed to "crazy" people or imbibed to alter consciousness, but rather as *stoff* native to the brain. By the late 1970s, new research—and popular coverage thereof—represented brain chemistry as a component of normal psychological function.

For example, a 1977 *Wall Street Journal* article defines neurotransmitters as "chemical messengers that the brain's many billions of nerve cells, or neurons, use to communicate with one another."[22] In this case, the dynamics of neurotransmitters appear perfectly congruous with mental health. Still, the author adds, "In severe mental disorders, this process seems to go awry."[23] Here, the author depicts neurotransmitters as both crucial to brain function *and* as a source of emotional distress—establishing material continuity between "crazy" and "normal." In the following years, journalists increasingly framed brain chemicals as endogenous matter, responsible for a spectrum of emotions, including both common feelings and disturbing disorders. For example, in June of 1980, the *Chicago Tribune* announced: "Brain makes drugs for 'feeling good.'"[24] In October of the same year, the *Sun* ran the headline, "Emotional Depression: A Matter of Chemistry?;" and in December, the *Courant* asserted, "Imbalance Is Called Cause Of One Kind Of Depression.[25]

At the time, coverage of brain chemistry often explicitly emphasized the physical—as opposed to mental—origins of psychological disturbance. For example, quoted in the *Sun* article, psychiatrist Maurice Rappaport states: "There are many physical problems that will masquerade as mental or emotional problems...And the person often doesn't know he has the physical problem...He thinks it's mental."[26] Rappaport likens depression to diabetes, the tenuous balance of neurotransmitters being analogous to that of insulin. By framing depression and anxiety as physical ailments, chemical models reduce the stigma of psychiatric illness. The assurance that an affliction belongs to the body transfers blame and shame from an individual her *stoff*. And, appealingly, chemical defects appear correctable: if psychological problems arise from a chemical imbalance, then one can, in theory, fix such problems via some chemical intervention.

Reading Rappaport's account of brain chemistry, one might come to the conclusion that researchers of the 1980s were the first thinkers to posit a relationship between mind and brain—the first to suggest that phenomenal experience arises from biological processes. Of course, that is not the case: some sort of relationship between brain tissue and the psyche had been assumed for centuries. And, as recently as the 1970s, EEG studies suggested a link between alpha waves and mental serenity. Yet, brain wave research, however scientific, does not register as a *physical* explanation in the manner of a neurochemical model; because, again, brain waves do not present as *stoff*. Further, the framework of neural frequencies lacks a taxonomy of diverse physical *things* that might absorb responsibility for the diversity of human emotions.

Whereas the materiality of electricity does not vary across cells, different neuron types secrete different neurotransmitters—bits of *stoff* defined by their chemical structure. Thus, it becomes possible to imagine that each emotional state corresponds neatly to a particular molecule. In this way, the chemical imbalance theory achieves greater specificity than a broad equation of mind and brain. It is consistent with a view that *you are your brain matter*, but additionally affiliates a spectrum of emotions with a spectrum of chemicals. And indeed, since the 1980s a number of neurotransmitters have made names for themselves: oxytocin is the "love chemical," dopamine denotes pleasure, serotonin staves off depression, and so forth. These chemical connotations arrive both from simplistic science journalism, and from pharmaceutical ads that link psychiatric illness to an excess or dearth of particular neurotransmitters.[27] In this framework, psychoactive pills serve as a palpable proxy for the chemicals that they interact with or mimic: one holds a Prozac tablet, for example, and imagines it as a bundle of serotonin that will restore balance of brain and mind.

In some respects, the quest for chemical-mental stasis resembles the restoration of magnetic stasis offered by mesmeric healers. However, whereas a theory of animal magnetism (or an odic force, or brain waves) identifies some unifying energy that transcends the body, chemical models depict the brain as a self-contained ecosystem. As such, associated theories of imbalance prioritize internal, as versus cosmic, harmony. They suggest that peaceful existence depends not on successful interpersonal communication, but on successful cellular communication. Indeed, a chemical view appears strikingly closed, as compared to etheric or electromagnetically inspired models of the brain. Confined to synapses, chemicals cannot participate in the perceived continuity of a wavily entangled universe.

Brain waves flowed out of a culture oscillating between scientific and spiritual worldviews. In this context, mesmeric healing could be understood as both body-saving and soul-saving—a way to correct imbalance within the body via a force that is more than bodily matter. Like mesmerism, early brain waves theories mirrored EM language, while conjuring something that resembled an immaterial spirit. In both cases, EM energies appear a more rational language than discussion of souls; and associated rituals exude greater rigor than standard prayer. Yet, these practices don't quite reach the level of modern western medicine. For mesmeric healing practices—and even alpha meditation—do not involve interventions that act directly on bodily *stoff*.

By contrast, the reduction of psychology to neurotransmitters places feelings within a completely material, medicalized framework.[28] Chemicals appear more concrete, more knowable and changeable than fleeting electric signals. Yet, this tangibility comes at the cost of mobility: neurotransmitters participate in hyperlocal exchange, moving from one cell to another across a microscopic gap. Such targeted signaling is incongruous with the notion that the goings on of the brain might ripple out from the cortex and into the ether or outer space. The embrace of *stoff* tethers mind to matter, moods to chemicals, and neurology to geography.

Reclaiming Territory

> Since the time of Leonardo da Vinci, gross anatomical detail has been shown better in the drawings produced by medical artists than by any other technique, including photography. It is likely that for the first time in history this will no longer be true.
>
> —Harold B. Hawkins and Dorothy C. Cinti, "It Draws Out Body Mysteries"[29]

The Prozac consumer accepts that chemicals alter her temperament, while also assuming that they do not replace her identity entirely. On or off psychoactive medications, we prefer to imagine that a stable self persists through various concentrations of chemicals. In seeking some essential identity, one may nominate a soul or other immaterial character that is impervious to material intervention. Alternatively, one may point to the enduring shape of the brain qua fatty, lobed organ. If one takes neurotransmitters to represent the moods that *I* experience, then the brain's macroscopic form—its enduring structures—may represent the biological *I* that perseveres through waves of chemicals, electricity, and emotion.

The belief that *I am my brain* imbues the physical nuances of this organ with the utmost importance. If an entire person fits within a three-pound blob, then it serves to reason that the shape of said blob might reveal something about the shape of one's character; and, given the breadth and complexity of functions a brain must perform, every nook and cranny—or sulcus and gyrus—becomes a possible clue into a person's nature. The success of phrenology points to the attractiveness of such a proposal. Phrenology, of course, fell out of favor by the end of the nineteenth century; yet, the field's demise did not mark the end of brain mapping.

During the first half of the twentieth century researchers continued to navigate cortical territories via lesion studies and electrical stimulation of the cortex. Such research was largely limited to the identification of sites associated with basic sensory and motor functions. However, work by Wilder Penfield and others around midcentury suggested that more complex mental capacities, such as memory, might also hold regional correlates.[30] Still, this work did not amount to the brain mapping industry of present day—in part because localizationists of the time lacked imaging technology to bring their geographic findings to life. That is, though scientists intermittently found new links between brain areas and mental functions, they largely expressed these insights via sketches—a visual language that is sometimes compelling, but which lacks the authority and dazzle of machine-acquired images.

Anyone with a camera and a strong stomach can take a picture of a dead brain. Obtaining images of a live, thinking brain, however, proves rather challenging. Coyly hidden in their skulls, functioning brains don't regularly appear for photo ops. Thus, for half a century EEG was the default technique for measuring human neural activity. The associated images failed to capture the brain's seductive physique, but nonetheless offered hints as to what the organ was up to. Brain waves, in turn, became a common, and very particular, way to "see" the brain.

Though Grey Walter's toposcope and similar techniques nod at brain geography, standard EEG artifacts bear no resemblance to the brain's three-dimensional structure: wavy scribbles do not depict the brain in portraiture. Spurning any attempt at realism, waves paint an abstract, oscillating picture—which reveals its own aesthetic truth. EEG images highlight temporal features of the brain that evade techniques devoted to structural verisimilitude. And, isolated from the brain's materiality, waves are open to creative interpretation in a way that realist depictions of anatomy are not.

Still, the dominance of EEG as a neuroimaging method does not reflect a cultural preference for the abstract. Rather, it is the product of a practical inconvenience: the brain is a reluctant subject of portraiture. Though standard X-ray handily detects a crack in the femur or a bullet lodged in the gut, the technique does not recognize the nuances of soft tissue like that which constitutes the cortex.

Undeterred by initial failures to photograph the brain, early radiologists made special accommodations for the organ, introducing a technique called pneumoencephalography (PEG) in 1919. PEG requires a spinal tap that drains the skull of its cerebrospinal fluid.[31] A clinician then pumps oxygen (or sometimes helium) into the skull, which makes the brain more amenable to X-ray imaging. Unsurprisingly, PEG often produced troubling side effects, including intense vomiting and headaches.[32] Despite this unpleasantness, and despite rather poor image resolution, PEG remained in use through midcentury—largely due to a dearth of alternatives until the development of brain scintigraphy during the 1950s.

Also known as scintoencephalography, scintigraphy yields two-dimensional images of the brain via a gamma-sensitive camera that captures the movement of radioactive isotopes.[33] PEG and scintigraphy were largely confined to diagnostic use and were helpful in identifying the location of brain lesions. However, they did not produce captivating images.

During the second half of twentieth century, advances in computing technology contributed to the refinement of multiple neuroimaging techniques, particularly computed tomography (CT) and magnetic resonance imaging (MRI). Introduced commercially in 1970, CT scanners acquire a large number of X-ray images from various angles, to depict internal structures in three dimensions. CT was not developed specifically for seeing the brain; and early pictures of the organ were fuzzy.[34] However, as computer memory increased throughout the seventies, so did the clarity of CT brain scans. The technology received considerable attention in the popular press, though coverage did not regularly feature actual brain images. Further, the benefits of CT were often qualified by questions as to whether the cost of a scanner was worth the benefits: early machines were priced in the range of $500,000—at the time an unprecedented sum for a piece of medical equipment.[35] When MRI technology arrived on the imaging market the following decade, however, CT would appear relatively cheap.

First used in the late 1970s, MRI is based on the principle of nuclear magnetic resonance (NMR), a phenomenon characterized by the interaction between atomic nuclei and local EM radiation. A 1984 *Hartford Courant* article summarizes the technology as follows:

> If radio frequency waves somewhere between the AM and FM bands on the radio dial are then applied to the body, the hydrogen protons become excited and change their orientation. When the radio frequency pulse is removed, they relax and return to their original orientation. The time it takes them to return to their normal state is detected by an antenna and subsequently processed by a computer.
>
> The end result is an astonishing image of the body in any place, produced harmlessly.[36]

More than an impressively succinct overview, the above passage elucidates an important role for EM waves in MRI procedures. Yet, the passage also makes clear that any waviness is a means to more picturesque ends. Where radio frequencies were once an object of fascination in their own right, they here become a mechanism facilitating the production of an "astonishing image."

Just as few couch-dwellers consider the means by which moving images reach their TV monitors, the lay public viewing new MRI or CT scans did not necessarily appreciate the work required to construct these pictures. Kevles writes:

> Most people knew that CT scans were produced by X-rays, but few understood that the X-rays in CT scanners do not make any initial picture, much less an image on film…The system works in two ways: it can reveal an anatomical slice by mathematically reconstructing the data the computer has received, and it can take a weak image and clean it up—the equivalent of retouching a photograph.[37]

MRI and CT images are appealing because they approximate a photorealistic rendering of the brain. However, the ostensible accuracy of these anatomical stills elides their means of production—thus neglecting both the waves involved in their manufacture and the electrical waves of the brain itself.

Superficially, brain scans yield a more faithful representation of the organ than do EEG charts. After all, an MRI image *looks* like what one expects to see were one to crack open a skull. However, scans capture the "real" brain only insofar as one assumes the organ's crucial features to be located in space, rather than time. That is, the belief that a high fidelity MRI image accurately depicts the brain reflects an ontological stance in favor of substance over process, or geography over temporality. Of course, such a stance is not extraordinary: humans are accustomed to understanding objects according to physical shape. Indeed, even the brain's electrical dynamics only become comprehensible when they assume a visual, often wavy, form.

Still, standard EEG artifacts do not take the shape of lobes, sulci, or gyri. They neither look like a brain, nor do they purport to be a brain. Conversely, brain scans closely adhere to the organ's visual appearance, suggesting a faithful representation of the brain qua physical object. In turn, the permeation of brain scan imagery has come to inform cultural understanding of what brains *are*: color-coded maps with neatly defined regions that correspond to similarly neat functions.

EEG was not entirely immune to this geographic turn. In 1979, Frank M. Duffy and colleagues introduced an adaptation of quantitative EEG (qEEG) called "Brain Electrical Activity Mapping," or BEAM. Rather than chart electrical crests and valleys over time, qEEG isolates the relative strength of various frequencies (alpha, theta, *etc*.) during a given time period and represents this data as bar graphs or, in the case of BEAM, as brain maps. Explaining their technique, Duffy and colleagues write: "Data dimensionality is reduced and visibility increased by computer-controlled topographic mapping and display of data as color television images."[38]

In the case of BEAM, EEG data becomes glowing pixels within the outline of a skull, the intensity of each dot corresponding to the strength of a particular wavelength in a particular brain region. Here, neural frequencies adhere to the modern human's preferred epistemological aesthetic: data oriented spatially, and on a TV. BEAM and similar techniques allow researchers to quickly survey the regional distribution of a given neural frequency and to *see* the intersection of temporal and spatial variables. The maps allude to the brain's oscillations, yet do not represent them in wavy form. Put another way: in a geographic model, even brain waves no longer look like waves.

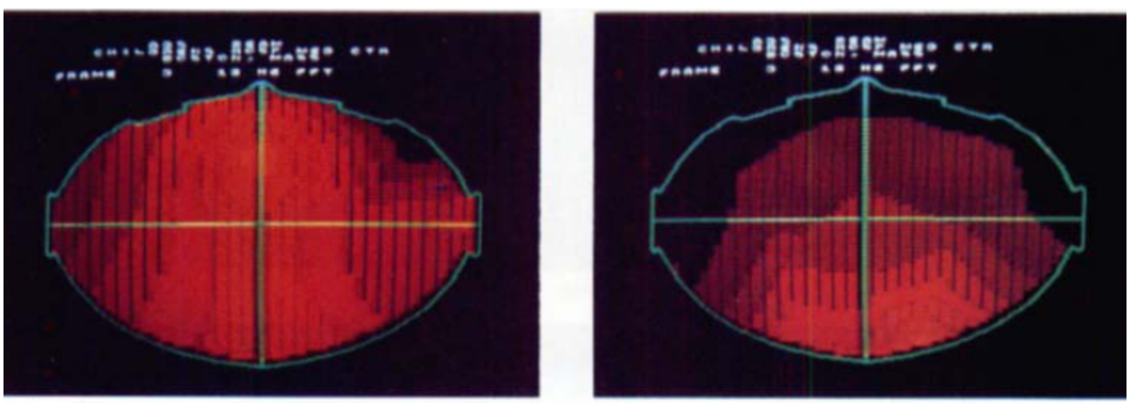

Figure 12. Example of BEAM spectral plot. Image shows alpha wave distribution in the "eyes open" (left) and "eyes closed" (right) conditions. Reprinted from Frank M. Duffy, James L. Burchfiel, and Cesare T. Lombroso, "Brain Electrical Activity Mapping (BEAM): A Method for Extending the Clinical Utility of EEG and Evoked Potential Data," *Annals of Neurology* 5, no. 4 (1979): 313.

Still, it is unlikely that projects like BEAM significantly altered popular connotations of brain waves. During the 1970s and '80s EEG maps barely penetrated popular discourse, garnering relatively little attention, as compared to CT and MRI. At the time, even these latter technologies did not inspire the sort of conversations associated with such machines today: initial discussion was largely limited to their diagnostic potential, forensic applications, and their cost. Brain map mania did not arrive in full until the development of *functional* imaging technologies, namely, positron emission tomography (PET), single photon emission computed tomography (SPECT) and fMRI.

What's Your Function?

> It bears emphasis that there are lots of things other than looking for functional loci that brain scientists do for a living; and that they use lots of experimental techniques other than neural imaging to do them. But it's functional localisation by neural imaging for which the *Times* is especially enthusiastic…It particularly likes those polychrome maps that show a place in the brain that's red when you're thinking about one thing and green when you're thinking about something else. (Disappointingly, I gather it's not that the brain turns red or green depending on what you're thinking about; the colours are computer generated to summarise the levels of neural activity that the experiments discover.) Well, to come to the point, I wonder why the *Times* cares. I wonder why anybody cares.
>
> —Jerry Fodor, "Diary: Why the Brain?"[39]

On July 17, 1990 President George H. W. Bush announced that the U.S. had entered the "Decade of the Brain." The purpose of this proclamation, Bush stated, was to "enhance public awareness of the benefits to be derived from brain research."[40] By the new millennium, brain science would indeed achieve a new level of public visibility—though not directly as a result of presidential decree. A dramatic increase in the awareness of neuroscience arrived, in part, via functional imaging technologies that rendered the brain, literally, more visible than ever before.

Broadly speaking, functional neuroimaging refers to the measurement of some aspect of neurophysiology while a subject performs a cognitive or behavioral task. By documenting correlations between task performance and regional activity, researchers attempt to establish the "function" of various brain areas. Introduced commercially in the early 1980s, cerebral PET represents the first neuroimaging technique to yield the multicolored maps now associated with the term "brain scan."[41] This approach is similar to CT, but uses radiolabeled molecules to track metabolic processes in the active brain.

During the early nineties, PET was joined by fMRI.[42] The latter approach tracks the distribution of oxygenated blood over time, with the assumption that fresh blood moves towards active brain regions. By calculating areas of increased blood flow during the performance of a target behavior, researchers can thus (in theory) deduce the neural regions responsible for said behavior.

PET and fMRI allowed researchers to make claims regarding the function of different brain structures, and to present aesthetically compelling images to support these claims. In the early and mid-nineties, this research translated into headlines like, "Biologists Find Site Of Working Memory," "Feeling Cheerful? Thank Brain's Left Lobe," and "Scanner Pinpoints Sites of Thought as People See or Speak."[43] By the end of the brain's decade, scientific and journalistic claims became more creative. For example, in February of 1999 the *New York Times* described fMRI research that had apparently identified "parts of the brain aroused by beauty."[44] Such simplistic structure-function statements have come to serve as neuroimaging's greatest asset and greatest source of critique. For, an assertion that beauty confines itself to a dimple in the cortex is as fascinating as it is facile.

Sometimes referred to as "the new phrenology," functional imaging attracts critiques from both within the neuroscience community and without.[45] Detractors argue, among other things, that complex cognitive processes recruit neurons distributed across the brain and thus cannot be attributed to bound anatomical regions; they also argue that a map does not amount to a proper *explanation* of a particular mental phenomenon.[46] I will not rehash the criticisms of fMRI and PET in full, both because it is redundant and because excessive fMRI bashing fails to capture the larger scientific moment of which brain mapping partook.

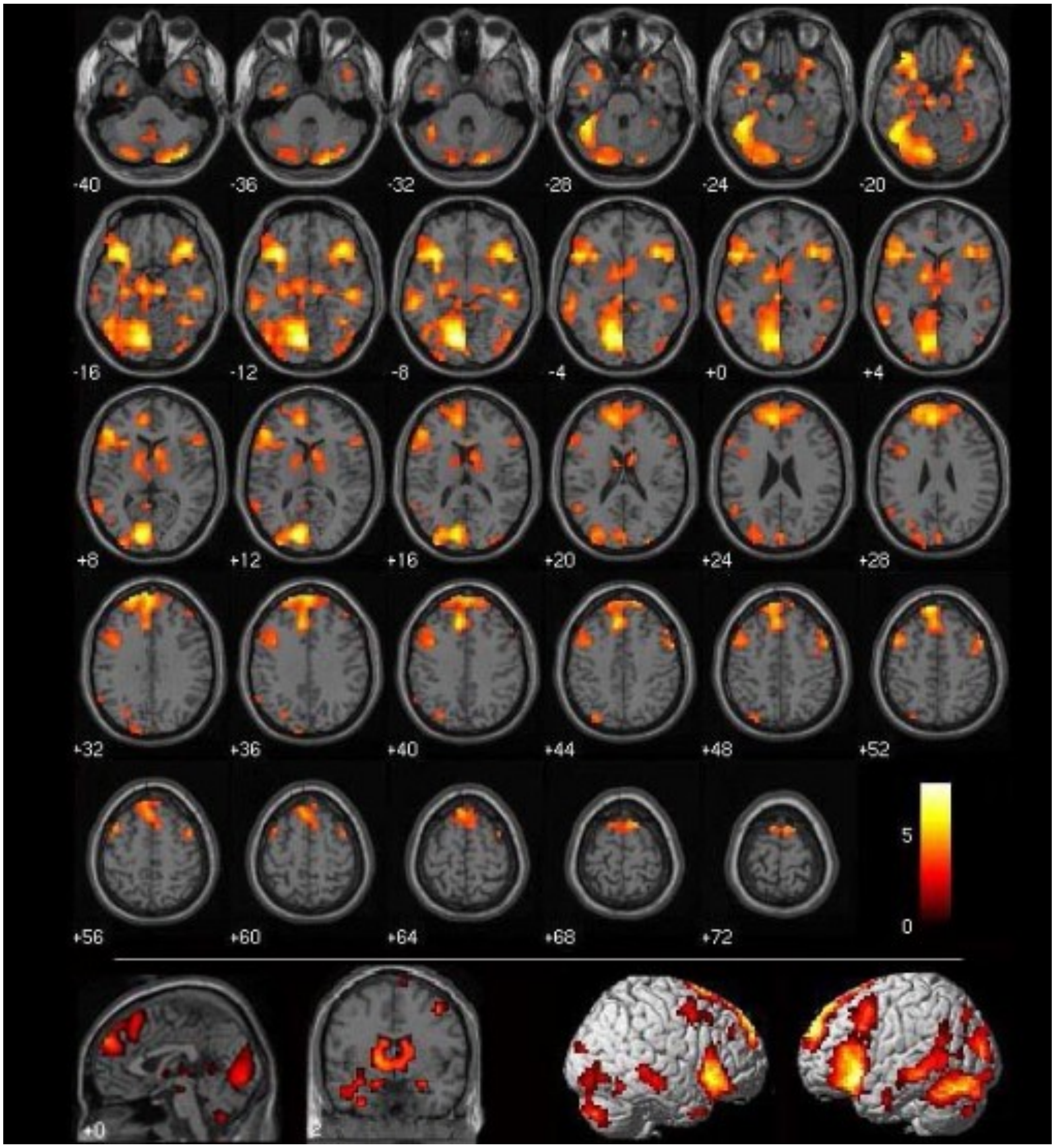

Figure 13. Imaging morality with fMRI. Original caption: “This image shows differences in brain activity between people who judge an act wrong and others who say it’s not wrong.” Reprinted from Elizabeth Landau, “How Your Brain Makes Moral Judgments,” CNN, March 27, 2014, http://www.cnn.com/2014/03/26/health/brain-moral-

judgments/index.html. Original study: Jana Schaich Borg, "Neural Basis of Moral Verdict and Moral Deliberation," *Social Neuroscience* 6, no. 4 (2011): 398–413.

Although the 1990s brought Technicolor brains into widespread circulation, these pictures are merely the cover art for a bigger story—a story of seductive reduction in which people become *stoff*. The same year that Bush announced the Decade of the Brain, the National Institutes of Health officially launched the Human Genome Project; and in the following years, discourse surrounding psychiatric medications—particularly, Prozac—surged.[47]

Genetic, neurochemical, and geographic models present distinct, but not necessarily competing, views of the human subject; in different ways, these three views transform personality into biology. The attribution of feelings to chemicals, and of chemical constitution to genes is intellectually neat and emotionally appealing: by blaming the brain, genes, or neurotransmitters, one is relieved of moral and social culpability. Geographic and chemical models nominate some form of matter as the substrate of self and emotions: brain region X controls mental function Y; chemical A mediates emotion B.

To a certain extent, early brain wave discourse offered similarly coarse reductions of personhood. However, the explanatory scope of brain waves was relatively limited. Despite ongoing efforts to associate neural frequencies with mental or moral aberrance, scientists failed to establish reliable links between particular waves and distinct psychiatric conditions or personality quirks (though research to this effect continues). Ultimately, waves cannot compete with chemicals and maps in the game of psychological reduction. But then, the appeal of brain waves never depended on an ability to explain away the mind via matter.

Whereas newer brain models attempt to locate emotions in chemicals and mental functions in brain regions, wavy models suggest that the mind is not confined to *stoff* at all. Brain wave theories satisfy a rational, materialist impulse, while drawing attention away from matter proper. They do not deny the existence of a chemical organ; however neither do they prioritize that kind of *stoff*. Instead, brain wave theories emphasize electrical, temporal patterns. And, as we have seen, this framework permits fantasies in which the brain's oscillations reach far beyond cells, synapses, and skulls—a trick that neurotransmitters and brain lobes appear unable to perform.

Thus, though chemical and cartographic views of the brain made a distinct splash upon their entrance into popular culture, they did not wholly displace the waves that preceded them. Scientifically, these models can coexist because they measure the brain in two distinct ways, which prove useful under different experimental conditions. Culturally, these models can coexist because they serve two distinct functions. Maps and chemicals assure that the intimidating complexity of the mind can be explained in terms of simple, physical *stoff*. And brain waves assure that the beautiful complexity of the mind transcends simple, physical *stoff*.

"New Technology, New Tensions"

During the final two decades of the twentieth century, the volume of popular brain wave discourse decreased relative to its peak in the mid-seventies. This discursive dip, however, does not reflect a decline in actual EEG research.[48] As the field of neuroscience expanded, electrophysiology more or less expanded to scale. In particular, research into event related potentials (ERPs) grew considerably, exposing new relationships between cognition and the brain's electrical dynamics.

Broadly speaking, an ERP refers to an electrical change in the brain, on the scale of milliseconds, that corresponds to a specific mental or behavioral event.[49] Though sometimes referred to as brain waves, ERPs are distinct from the neural oscillations previously associated with the term. Whereas the likes of alpha and theta represent ongoing, endogenous pulses in the brain, an ERP is an isolated electrical blip (a single wave on a graph), provoked by particular environ/mental conditions. For example, the P300 (P3) wave has been linked to conscious recognition or categorization of a stimulus.[50] As its name suggest, P3 tends to occur approximately 300 milliseconds after stimulus presentation, though this timing varies slightly with age and other variables.

Researchers observed ERPs associated with basic sensory stimulation relatively early in the history of EEG; however, Grey Walter established the first ERP with a *cognitive* correlate in 1964.[51] Building on this work, Samuel Sutton, Margery Braren, and Joseph Zubi identified P3 the following year.[52] Researchers later classified additional ERPs types, including the N400 wave (N4)—a voltage fluctuation occurring approximately 400 milliseconds after exposure to an intellectually meaningful or surprising stimulus.[53] Marta Kutas and Steven Hillyard discovered the N4 response in a 1980 experiment, which showed that N4 follows the presentation of an unexpected word that drastically alters or confuses the meaning of a sentence (*e.g.,* "I take my coffee with cream and *monkeys*").[54]

The discovery of N4, coupled with novel applications of ERP science, brought new attention to this research area. Like other brain waves, ERPs do not amount to a transcript of conscious thought. However, ERPs can, in a limited way, hint at an individual's cognitive state; they can, for instance, reveal a subject's interest in or attention to a stimulus. Research suggesting as much served as sufficient impetus for journalists to, once again, link brain waves to mental content, stirring hopes and fears that EEG might enable a form of mind reading. For example, a 1980 *New York Times* article about P3 and N4 waves bears the headline, "Signals Allow Scientists to Eavesdrop on Mind." The article asserts: "Computers isolate specific thoughts among brain waves."[55] Here, the author distinguishes ERPs from older, apparently less remarkable, brain waves. He writes:

> Although the conventional EEG is valuable for detecting epilepsy and major aberrations, such as brain tumors, it does not reveal specific mental reactions. Even the much-publicized alpha waves…do not reveal the specific focus of attention. That is what the evoked potentials do.[56]

In 1984, the *Washington Post* suggested that ERP eavesdropping might be useful beyond the lab. In an article titled "Technology Could Let Bosses Read Minds," author Michel Schrage describes ongoing P3 research at the Westinghouse Corporation. He writes: "it is now possible to envision a marketable product that could instantaneously assess whether employees are concentrating on their jobs by analyzing their brain waves as they work."[57] In addition to ruining the good vibes associated with brain waves of the 1970s, this new connotation of the term introduced a novel cast of wavy characters that were seemingly unrelated to established frequencies (*e.g.,* alpha, delta, *etc*). Schrage explains:

> One brain wave pattern, the "n200," has been linked to the speed of information processing in the cerebral cortex. A wave known as the "n400" has been identified with various aspects of linguistic processing. However, it has been the "p300" wave that most researchers believe gives extremely reliable measures of the individual's mental workload.[58]

Three years following the *Post's* piece, the prospect of mind-reading bosses gained new traction. In October of 1987, the congressional Office of Technology Assessment (OTA) issued a report titled, "The Electronic Supervisor: New Technology, New Tensions."[59] The document addresses various types of "electronic monitoring systems [that] automatically record statistics about the work of employees."[60] Among the Orwellian tactics described are devices that track time spent on the telephone and that monitor employee keystrokes. However, the report's most dramatic technologies (and tensions) fall under a section devoted to "Brain Wave Research" in which the authors outline several workplace applications for EEG, including:

- predicting whether a person is at risk if certain diseases, such as Alzheimer's disease or alcoholism;
- determining whether a person is concentrating and predicting the speed of mental response to stimuli;
- determining recognition of persons, places, and objects;
- testing for knowledge of a specific subject;
- detecting lies[61]

Several popular news outlets covered "The Electronic Supervisor," raising understandable concerns about the prospect of employee brain monitoring.[62] And, in their report, the OTA itself acknowledges that such practices might pose a threat to "personal dignity and privacy."[63] Here, mind reading transforms from an intimate spiritual connection into a worrisome form of surveillance.

At the same time that ERP technology threatened mental privacy, research in this area inspired hope for the development of revolutionary therapeutic tools.[64] Progress in electrophysiology, coupled with advances in computing, led to the introduction of early BCIs—machines that monitor electrical dynamics in the brain and feed this data into a digital device. Via such technology, individuals with paralysis may regain the ability to communicate, or even to drive the motion of a prosthetic limb. For such individuals, a brain-controlled machine represents a life-changing innovation. For the able-bodied population, the development of such devices is less urgent, but nonetheless enticing. For BCIs create an illusion of mind control, thus offering an experience of “real” telekinesis (see Chapter 8).

In 1997, the *L.A. Times* reported that Hidenori Onishi had invented “the world's first brain-wave remote control aimed at a broad consumer market.”[65] Onishi’s work, like most BCI research at the time, primarily targeted improved quality of life among paralyzed individuals. However, popular accounts of his work and similar projects suggested broader applications for brain control technology. For example, the *L.A. Times* ran the headline, “Scientist Uses His Brain to Turn On TV.” And the Associated Press described: “A Japanese company plans to market a device that activates household appliances at the flicker of a brain wave.”[66]

Figure 14. Prototype of Hidenori Onishi's "brain-wave remote control." Reprinted from Associated Press, "Japan: Company to Market Mind Control Operating System," AP Archive, November 15, 1997, http://www.aparchive.com/metadata/youtube/83a7280cb856e08360a86acaf836cb53.

I will discuss early and contemporary use of BCIs at length in the following chapters. However, I highlight this technology here to elucidate an emerging niche for brain waves in an era of maps and chemicals. As the twentieth century drew to a close, brain waves were increasingly presented a mode of communication between humans and machines. While neurochemistry and neurocartography represented a return to biologically situated *stoff,* electrical waves became a dynamic liaison between physiology and technology.

Waves among *Stoff*

As scientists construct increasingly detailed pictures of the brain, waves appear perhaps less pretty, less informative, and certainly less colorful than these portraits. Still, what EEG lacks in spatial resolution it more than makes up for in temporal resolution: EEG captures brain changes at a pace that embarrasses fancy fMRI machines. Further, EEG is far more affordable and mobile than other brain imaging technologies. A scanner that costs a million dollars and weighs several tons is confined to the basement of its host institution. Relatively small and cheap, an EEG machine can inhabit a biofeedback practice, an advertising firm, an airplane, or a living room; and this physical mobility breeds a particular kind of cultural mobility. Literally and figuratively, EEG transcends the lab, thus entangling its artifacts with ideas and people not traditionally associated with brain research.

Whereas chemical and anatomical models underscore biological uniqueness, brain waves suggest an electric link between mind and machine. BCIs extend this link beyond metaphor, opening lines of communication between biology and technology. As I will show in the coming chapters, the twenty-first century has brought a variety of toys and tools that purportedly translate neuronal activity into digital conversations in virtual space. Thus, although brain scans serve as an attractive way to *view* the brain, electrical techniques remain a practical way to *use* the brain—to connect the brain physically to inorganic circuits, and to connect it conceptually to forces beyond the body.

Chemicals cannot escape the brain; and the brain cannot escape the skull. Waves, on the other hand, are not weighed down by the physical limitations of common matter. Inherently mobile and unbound to a particular material form, brain waves speak to a suspicion that we are more than biological tissue. They sustain hope that some aspect of the self transcends a subject's corporeal instantiation, if not to reach a higher plane of existence, then at least to deliver the content of the brain to some external destination. One cannot extract a piece of brain matter or a vial of neurochemicals to transfer thoughts: removing brain *stoff* will damage the organ of origin. Brain waves, however, denote not a substance, but a signal. And signals are intended to be sent.

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[16] Purves et al. define neurotransmitter more extensively. They write:

> Three primary criteria have been used over the years to confirm that a molecule acts as a neurotransmitter at a given chemical synapse.
>
> 1. *The substance must be present within the presynaptic neuron…*
>
> 2. *The substance must be released in response to presynaptic depolarization, and the release must be Ca^{2+}-dependent*. Another essential criterion for identifying a neurotransmitter is to demonstrate that it is released from the presynaptic neuron in response to presynaptic electrical activity, and that this release requires Ca^{2+} influx into the presynaptic terminal…
>
> 3. *Specific receptors for the substance must be present on the postsynaptic cell.* A neurotransmitter cannot act on its target unless specific receptors for the transmitter are present in the postsynaptic membrane.

"What Defines a Neurotransmitter?" in *Neuroscience,* 2nd ed., ed. Dale Purves et al. (Sunderland, MA: Sinauer, 2001), https://www.ncbi.nlm.nih.gov/books/NBK10957;

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[18] In brief: an action potential travels down the length of a neuron; upon reaching the end of the neuron (the axon terminal), an electrical changes prompts the release of chemical neurotransmitters which travel across the synapse to excite, inhibit, or modulate a second cell, which may or may not generate its own action potential. Thus, chemical transmission follows from electrical transmission and vice versa.

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Chapter 8. Unlocking Skulls

> Until recently, the dream of being able to control one's environment through thoughts had been in the realm of science fiction. However, the advance of technology has brought a new reality: Today, humans can use the electrical signals from brain activity to interact with, influence, or change their environments.
>
> —Jerry J. Shih, Dean J. Krusienski, and Jonathan R. Wolpaw, "Brain-Computer Interfaces in Medicine"[1]

Communication typically connotes the movement of ideas, messages, or information; but communication also tends to require the movement of *bodies.* Normally, ideas cannot leap from brain to brain without the intervention of muscles, say, in the fingers or the lips. The prospect of sending messages via brain waves ostensibly obviates this aspect of transmission. When Knowles proposed his theory, he described an exchange of subjective experience without overt movement—thus dissociating communication and muscled action.

Knowles's theory took inspiration from telegraphy, which, in its own way, entailed a reduction in physical labor. With the telegraph users could move messages across great distances, without moving bodies the same distance. Today, we take this convenience as given. Yet, even with access to rapid digital tools, communication remains an embodied process. The modern communicator regularly swipes, taps, and types—a fingertip triathlon of minimal caloric output, yet one that recruits muscles nonetheless. These small movements serve as subtle reminders that communication requires more than a brain: thinking alone does not suffice for interpersonal connection. The dream of disembodied discourse thus remains largely unfulfilled—for now.

In recent decades, researchers and technologists have developed BCIs that seem to convey messages directly from our cortices to our devices. Broadly speaking, a BCI is a piece of technology that detects changes in the brain and uses this data to manipulate real or virtual environments. Connected to a BCI, one may, for example, open an email and "type" a response via thought alone. Often described in the popular press as responding to a subject's brain waves, BCIs revive Knowles's vision of decorporealized communication.

Yet, thinking itself requires bodily engagement: though associated with phenomenology, the brain remains biology. In this sense, BCIs fail to make good on a promise of complete corporeal transcendence. The appeal of this technology—and of brain waves more broadly—thus relies on an alluring but fictional premise of matter-less messaging.

More than an alternate form of transmission, BCIs and brain waves promise to convey a different type of signal. They propose access to the mind's musings at their source—suggesting more pure or more true contact with the brain, mind, or soul. Unlike lips, brains do not lie. Still, as we have seen, detection of the brain's waves is only half the battle: discerning the significance of these oscillations is hardly straightforward. Brain waves hold no inherent *meaning*. Thus now, as ever, the brain's electrical dynamics remain subject to cultural interpretation.

Brain Control

According to a typical definition, a "BCI is a computer-based system that acquires brain signals, analyzes them, and translates them into commands that are relayed to an output device to carry out a desired action."[2] Here, "desired action" connotes any form of communication or control—BCIs are output agnostic. If connected to the appropriate extension, your brain's emissions can, in theory, send a text message or launch a missile, without your lifting a finger.

The difficulty of constructing an effective BCI lies in acquiring a signal that reliably corresponds to the user's intent. It is easy enough to make a word processor produce a "Q" every time an electrode detects a particular brain rhythm. However, generating said brain rhythm on command is less easy; and consciously conjuring a distinct frequency for every letter of the alphabet is effectively impossible. Engineer Jacques Vidal—who coined the term BCI—identified this challenge while conducting a series of feasibility studies during the early 1970s. In a 1973 paper, Vidal asserts that the standard brain waves (*e.g.,* alpha, beta) don't lend themselves to productive dialogue with a computer. Vidal suggests that, instead, BCIs should respond to discrete electrical fluctuations, akin to ERPs (discussed in Chapter 7). He writes: "All meaningful EEG phenomena should be viewed as a complex structure of elementary wavelets, similar in nature to components of evoked responses."[3]

Though Vidal's early research did not yield a working interface, his feasibility studies offered useful guidance for forthcoming investigations. He advised, for example, that future studies "must involve the subject in an interactive or 'game playing' situation that offers reward for performance and, therefore, constitutes a form of operant conditioning."[4] This point highlights a crucial facet of BCI development, then and now. Vidal recognized that effective brain-computer interaction requires more than some electrodes on the scalp. The participating brain, he urged, must learn to work *with* the machine, ideally via some sort of biofeedback "game." As a simple example, consider a

BCI that allows the subject to control a computer cursor via neural oscillations. A brain thinking something to the effect of "*Move up, cursor!*" receives positive feedback if and when the cursor happens to moves on up. In this way, the brain learns to "speak" in a language that the computer can recognize. Today, this sort of feedback remains essential to successful BCIs.

In the years following Vidal's feasibility studies, the press began to speculate about commercial use of BCIs. In 1976 the *L.A. Times* ran a story on Vidal's work under the headline, "Scientist Hooks Mind to Computer: Machines Controlled by Brainwaves?"[5] Therein, the author predicts that "man's brainwaves will be useful for controlling machines someday." In citing particular applications of BCI technology, the author mentions "controls inside an airplane cockpit which could be operated by the pilot's brainwaves if his arms and legs were immobilized."[6]

This article requires a moment's attention—not because it was particularly influential, but because it captures a distinct trend in brain wave discourse. Namely, it describes harnessing neural oscillations, not for interpersonal connection, but for technological control. Considering that computers of Vidal's day were not the communications tools they are today, brain-computer interaction did not necessarily represent a social endeavor. As machines become more intelligent and connected, interfacing with our devices may be thought of as a kind of cyborgian telepathy—mental conversations with or through a computer. However, during the early stages of BCI development, their application was much more telekinetic in nature—a means to manipulate machines.

Specifically, mind-controlled aircrafts—or even spacecrafts—were a surprisingly common theme among BCI commentators. It is almost as if imagining one seemingly fantastic achievement of technoscience rendered the rest of scientific fancy fair play. And brain-crafts were not solely the product of journalistic extrapolation. In his 1973 paper, Vidal himself asks: "[Can] observable electrical brain signals be put to work as carriers of information in man-computer communication or for the purpose of controlling such external apparatus as prosthetic devices or spaceships?"[7] To date, a genuine brain-controlled plane or space shuttle has yet to be built. However, ongoing interest in EEG technology from DARPA, the U.S. Air force and NASA intermittently encourages suspicions that such a feat of engineering may be feasible.

The fantasy of brain-controlled planes soared into popular culture via the 1982 film *Firefox* (based on a 1977 novel by the same name).[8] In the film, Clint Eastwood plays a pilot who steals a mind-mediated Soviet fighter jet. A secondary character in the film bemoans American misjudgment of Soviet technological prowess, explaining, "some three years ago, our theoretical weapons strategists stood before NATO command to explain...that it would take the Soviets a minimum of ten years to develop a Mach Five aircraft with thought-controlled weapons systems… we were wrong."[9]

Whereas characters in *Firefox* underestimate BCI science, many in the real world tend overestimate—or at least overstate—accomplishments in the field. For example, in 1995 the *New York Times* ran a story titled, "How Brain Waves Can Fly a Plane," which reported on experiments by the Wright-Patterson Aeronautical Systems Center. At the time, no one was actually directing planes with thoughts: the experiments in question were trials of a BCI flight *simulator,* which yielded limited success. Despite its headline, the bulk of the *Times* article discusses not brain planes, but rather "new techniques in electroencephalography [that] may soon make it possible for a totally disabled person to communicate by directly controlling the faint electromagnetic signals emitted by his or her brain."[10]

Via telekinetic sensationalism, news of brain-controlled machines can attract a wide range of readers. The majority of actual BCI research, however, pertains to a much narrower audience. The most impressive strides in brain control do not serve individuals enamored of the prospect of abandoning embodiment; rather, they address the needs of a population *involuntarily* relieved of muscled labor—paralyzed, or so-called "locked-in" individuals.

Unlocked

When Edmond Dewan presented his system of "brainwave Morse code" in the 1960s he effectively invented a BCI before a name for such systems existed (see Chapter 6). According to the *Boston Globe*, Dewan spelled out the message "I CAN TALK" at a rate of twenty-five seconds per character, via consciously controlled bursts of the alpha rhythm. The *Globe* noted that the technology "could have a bearing on one of the most tragic and frustrating medical situations conceivable: total paralysis."[11] In interviews Dewan reiterated the therapeutic potential of his invention, though there is no evidence that he tested the device in paralyzed individuals.

Dewan is largely overlooked in histories of BCI technology, perhaps because his invention predates the field, or perhaps because he did not submit his findings for peer review. However, even if Dewan's system of brain Morse did not live up to his claims, the physicist deserves recognition for anticipating a serious future for brain wave devices.

Contrary to prior efforts in "brain radio" or "thought recorders," Dewan importantly identified a genuine medical application for brain-mediated technology.

The term "locked in" refers to those suffering from complete paralysis and is apt on multiple levels. It evokes the psychological isolation experienced when one lacks the ability to communicate—thoughts *locked inside* the realm of the phenomenal. Underlying this psychological imprisonment are physiological processes, similarly impeded. The electrochemical activity in the brain remains more or less normal; however impulses generated there cannot reach the relevant muscles. Akin to cutting the cords of an old telephone line, calls cannot exit the proverbial house, leaving any pleas for help unanswered. Inhabitants of the locked edifice remain alive and active, but outsiders are ignorant of the nature of their suffering, wants, needs, and ideas.

Medical BCIs aim to create an alternative route of communication with the locked-in individual. To be clear, BCIs cannot re-connect nervous phone lines; they do not allow an individual to clearly and eloquently convey every thought as it arises. Rather, these technologies detect changes in brain physiology that are, with training, subject to conscious control. Through feedback, the subject learns to modulate her brain in ways that the interface can detect.[12] Slowly, the subject establishes a sort of code through which to communicate with or control her environment. It is as if, from within the house, a person turns the lights on and off to deliver encrypted messages to those outside. This form of communication is unideal, for sure, but it represents a vast improvement from the agony of complete isolation.

Despite Dewan's contribution in 1964, substantial progress in the field of medical BCIs did not arrive until over two decades later. One of the earliest projects to show promise came from the laboratory of Emmanuel Donchin, an early leader in ERP research at the University of Illinois at Urbana-Champaign. In the mid-eighties Lawrence Farwell joined Donchin's lab as a graduate student; and soon after, Farwell recalls, a terrible accident inspired a BCI breakthrough. "A kid fell off a silo," Farwell told me in a phone interview, "and he was paralyzed from the eyeballs down...we thought he was awake in there but we didn't know."[13] In fact, no one knew whether the young man "was awake in there"—but Farwell and Donchin were in a position to find out.

"I was doing research on P300, and we were getting signals out of people's heads without them responding with any movement of their body—without any speech or movement of their hands," said Farwell. "So we thought…[we] can develop a system to communicate from a brain to a computer and then to a speech synthesizer so a person could talk."[14]

Specializing in P3 research, Donchin's lab was well equipped to further pursue such a system. Recall that the P300 wave is an electrical fluctuation that occurs approximately 300 milliseconds after the presentation of a stimulus—and that it tends to indicate stimulus recognition or categorization.[15] Donchin and Farwell built on this premise to develop a new form of brain reading. Their 1988 experiment worked loosely as follows: a subject attempting to "write" a five-letter word begins by thinking of a target letter—the first character in the word. The subject then views a matrix of letters on a computer screen; when her target letter flashes, this stimulus should elicit a P3 wave in the subject's brain, establishing the first letter of the word. The subject then imagines the word's second character, and so on.[16]

Yielding about two and a half letters per minute, Donchin and Farwell's method wasn't the picture of efficiency; and their initial subject pool did not include the fellow from the silo accident, but instead consisted entirely of able-bodied volunteers. Nonetheless, the research offered unique hope for communication with those otherwise locked in their skulls. And beyond the paralyzed community, this early BCI established a precedent for a new level of human-computer intimacy.

A 1993 *New York Times* article discussing Donchin and Farwell's ongoing research bore the title "Computers Taking Wish as their Command."[17] The same year, the *Chicago Tribune* proclaimed, "Just think! A mind-reading computer," with the subhead "It's simply a matter of decoding brain waves."[18] Coverage of Donchin and Farwell's research, like coverage of BCIs today, stirred spectacular visions of mind-controlled technology and disembodied communication. The *Tribune* imagined, for example, "machines that people talk to by simply thinking…rather than by typing on a keyboard or dragging a mouse."[19]

As I will discuss in the following chapter, popular speculation about consumer grade brain-typing gadgets has increased in recent years. Now, as then, it is difficult to discern whether this excitement reflects a desire to *use* brain-mediated devices for more efficient social exchange—or whether a direct link from mind to machine represents an end in itself.[20] In the case of paralyzed individuals, however, the desire for specifically *human* interaction appears more urgent than enhanced engagement with technology. For those robbed of organic communication tools, the BCI enables re-connection with society.

Though unlocking brains represents a lofty goal, the strategy by which to achieve as much is not entirely obvious. A researcher must determine, for example, where to place electrodes and the *type* of neural oscillations to which the computer should respond. By the 1980s researchers had identified an assortment of brain rhythms and ERP components that might effectively deliver commands from brain to machine. At the same time that Donchin and Farwell focused on P3, neurologist Jonathan Wolpaw (of the Wadsworth Center in Albany, New York) developed a BCI that selectively responded to *mu* waves.

Oscillating between seven and thirteen Hertz, mu waves resemble the famous alpha rhythm. However, whereas alpha waves are often associated with activity in the occipital lobe (the back of the head), mu waves are typically observed in the motor cortex (the top of the head).[21] And whereas alpha decreases in the presence of visual stimulation, attenuation of mu tends to correspond to the execution or observation of motor tasks.[22] For this reason, mu monitoring is an intuitive candidate for the translation of neural oscillations into real or virtual motion. And, indeed, during the late 1980s and early '90s Wolpaw created a BCI that selectively responded to mu activity to drive the motion of a computer cursor: depending on the amplitude of the waves, the cursor would move either up or down.[23]

By 2004 Wolpaw's group achieved two-dimensional BCI control—the ability to move a computer cursor both up-and-down and side-to-side according to neuro-electrical activity.[24] Wolpaw currently remains active in the field of BCIs—though said field has become substantially more populous than it was during the eighties. I will not venture to summarize the entirety of today's medical BCIs industry, however the group BrainGate warrants mention. Since the early 2000s, this multi-institutional team has developed a series of BCIs and brain-machine interfaces (BMIs) via work with individuals with tetraplegia.[25]

The term BMI refers specifically to interfaces that manipulate some piece of physical machinery (such as a prosthetic leg), rather than objects on a computer screen. Though this sort of re-embodiment remains a goal for BrainGate and other research teams, the development of agile limb prosthetics has proven difficult; current devices move awkwardly, just barely able feed a subject via robotic arm. Efforts to achieve fluid movement in virtual space, however, have been more successful. Consider the following summary from a 2006 BrainGate trial on a subject ("MN") with spinal cord injury:

> Continuous computer cursor control could be used to provide many valuable new outputs for a person with paralysis to carry out *activities of daily living*… MN used a simplified computer interface to open simulated e-mail and to draw an approximately circular figure using a paint program. Using the neural cursor coupled to a simple hardware interface, he adjusted the volume, channel and power to his television. He was also able to play video games such as Neural Pong.[26]

The translation of neural activity into on-screen action lacks the theatrics of an "I can walk again!" moment; but this application of BCI technology may provide as much practical benefit as a robotic arm. For, even among the able-bodied, many "activities of daily living*"* have been relocated to virtual space. In this sense, a person capable of efficiently controlling her computer screen may lead a somewhat normal life—an accomplishment that underscores the bizarre state of contemporary normalcy.

In the twenty-first century it is easy to feel as though computers are taking up an increasing amount of brain space; and for BrainGate subjects, this sentiment applies quite literally. Unlike standard EEG techniques, which are noninvasive, advanced medical BCIs use electrodes that sit directly on the surface of the cortex—so-called "brain chips."

And in 2017 BrainGate researchers described the application of an intracortical recording technique that involved implanting electrodes 1.5 millimeters *below* the brain's surface.[27] This approach yields more precise neuronal data and better output control than less invasive methods. However this advantage comes with a serious drawback: brain chips require open skull surgery—not something for a healthy tech enthusiast looking for a new toy. Understandably, this type of procedure is presently reserved for those with paralysis, or extreme forms of epilepsy.

Though very few people currently have electrodes inside their skull, BrainGate subjects serve as an apt metaphor for the broader contemporary codependence of brains and machines. Through feedback, an individual with tetraplegia trains her brain to speak in an electrical language that the computer can recognize. More subtly, the rest of us also learn to alter our discourse in ways that conform to the constraints of various digital platforms and interfaces. We have become so accustomed to internet exchange that messages confined to a single computer come to feel "locked in." Thus, we manipulate our communiqués with the hope that they are clicked, shared, and liked by other members of the technosphere; and this feedback slowly contours what we say and how we say it.

"The Truth Will Out"

When Donchin and Farwell first experimented with P3-mediated communication, they used what psychologists refer to as an *oddball paradigm.* This method involves the identification of a rare target stimulus among other (non-target) stimuli; following detection of the target, subjects' brains typically produce a P3 wave. So, for example, if a subject is scanning a screen for the letter *B*, her brain will produce a P3 wave when the *B* appears; and the more rare the target stimuli, the larger and more reliable the P3 response.

Donchin and Farwell explain: “[T]he events that belong in the rare category elicit a large p300. The amplitude of the p300 is inversely proportional to the probability of the eliciting event-category and directly proportional to the relevance of the event to the subject's task.”[28] Though the preceding quote accurately describes the pair’s approach to brain typing, it does not come from their 1988 paper on the subject. Rather, it is an excerpt from their 1991 article, “The Truth Will Out: Interrogative Polygraphy (‘Lie Detection’) With Event-Related Brain Potentials.”[29]

Indeed, in some cases information may be locked in a brain, not because a subject is unable to communicate, but because she is *unwilling* to do so. A piece of neurotechnology that betrays secrets of a guilty mind has obvious—if ethically murky—forensic value: the ability to read guilt among neural oscillations all but obviates a written confession. Still, like others forms of lie detection, “interrogative polygraphy” is imperfect; and, like other brain wave interventions, it does not amount to mind reading.

Donchin and Farwell’s lie detection technique uses the same oddball paradigm as their brain-writing experiment: since the brain produces a P3 wave upon presentation of a rare target stimulus, they reasoned, the brain should act similarly upon presentation of a stimulus related to rare knowledge of a crime. To test this hypothesis, Donchin and Farwell asked subjects to participate in “one of two different mock espionage scenarios.”[30] The following day, the same subjects completed a discrimination task, identifying target stimuli among non-targets. Embedded in these stimuli were “probes” somehow relevant to the espionage task of the previous day. Donchin and Farwell predicted that when a subject possessed “guilty knowledge,” the probes would elicit a P3 response; and, according to their 1991 paper, results of a 20-subject experiment confirmed this hypothesis.[31]

Though Donchin and Farwell's paper suggests a forensic future for P3, it also details limitations of the work and describes a need for additional research. Following the study, Donchin apparently did not pursue the topic further, though he remained active in the field of electrophysiology and continued to focus on the P3 wave. In fact, Donchin's curriculum vitae reads as a testament to the diversity of P3 research from the 1970s through the twenty-first century. The titles of his papers range, for example, from "Absolute pitch and the P300" to "The P300 as an Electrophysiological Probe of Alcohol Expectancy."[32]

Larry Farwell's career has been somewhat less diverse, though ambitious in its own right. After publishing "The Truth Will Out" he focused almost exclusively on refining and publicizing the efficacy of brain wave lie detection. According to Farwell, almost immediately after releasing results of the interrogative polygraphy study, he was approached by the F.B.I. and the C.I.A. "They found *me,*" Farwell commented.[33] He received contracts from both government agencies to further test his P3 interrogation system, which he dubbed "Brain Fingerprinting."

ERP polygraphy does not represent the first attempt to weed out bad guys by virtue of their neural oscillations. In the 1930s and '40s, select truth-seekers believed that EEG might help identify deviants and madmen via brain wave abnormalities; and even the notion of criminal "brain prints" was not a completely novel suggestion. Recall that, in 1935, William Laurence of the *New York Times* wrote: "[brain waves] may be said almost to resemble finger-prints, so that in the future it is not impossible to expect that the criminologist may add brain-prints to his methods of identification."[34] Whereas Laurence imagines perpetrators identified via the uniqueness of their brain waves, Farwell links his technology to fingerprinting more obliquely: "With the original [finger printing]...you're matching the prints on the fingers with the prints at the crime scene," he said. "With Brain Fingerprinting we're matching information from the crime scene with information stored in the brain."[35]

EEG lie detection faces significant critiques from both the scientific and legal communities.[36] Though the technique has not been universally dismissed, it is rarely admitted as evidence in court. Still, Farwell maintains that brain fingerprinting may be of use outside traditional legal settings—say, for example, in F.B.I. interrogations. When I asked Farwell if the government was currently using his technology, he told me that such information was classified. Though he cannot confirm how or whether the three-letter agencies have implemented his product, Farwell has a list of potential applications at the ready. In 2015, he (self-)published a white paper titled, "Brain Fingerprinting in Counterterrorism: The Key to Investigating the San Bernardino and Paris Terrorist Attacks, Bringing Terrorist Masterminds to Justice, Preventing Future Attacks, and Responding to the Migrant Crisis."[37] Farwell's website reiterates: "Brain Fingerprinting technology can detect trained terrorists, bomb makers, members of a terrorist cell, etc., even before they strike."[38]

Depending on one's perspective, border brain wave screenings offer a promising or dystopian new strategy for national security. Farwell maintains that he does not sell his product to actors with suspect motives, such as foreign governments seeking to persecute dissenters. Yet, companies offering copycat technologies may be less discerning.

For example, Brainwave Science, LLC claims that its neural interrogation technique can be of service in the contexts of border security, counterterrorism, and human trafficking.[39] The company provides no scientific data to support these claims; and though it purports to use the Brain Fingerprinting method, Farwell has distanced himself from the group and does not endorse their work. In late 2016, Brainwave made fleeting national news when several outlets reported that then-nominee for U.S. National Security Advisor, Michael Flynn, was an advisor to the company. Brainwave Science, like Flynn himself, turned out to be somewhat shady. According to the *Chicago Tribune,* "One of Brainwave's two-member board of directors was Sabu Kota, an Indian-born software engineer who pleaded guilty in 1996 to selling stolen biotech material to an FBI agent posing as a Soviet spy."[40]

The details of the Flynn scandal, and the Kota scandal, are beyond the purview of the current discussion. Yet, that their suspect venture took the name *Brainwave Science* is telling. Here and elsewhere the term "brain wave" functions as a discursive sleight of hand: it resonates as empirical and familiar in a way that elides the nebulousness of the term's referent. A nonscientist learning that a "terrorist" was identified via his brain waves may not consider the fact she doesn't know what, in fact, a brain wave *is.* This may be particularly true of a citizen—or a legislator—who is inclined towards better-safe-than-sorry security policies.

It is unlikely that Brain Fingerprinting will become a standard interrogation tool among F.B.I. agents or other law enforcement officials in the near future. Still, the prospect of government technology that extracts the "truth" from a brain is enough to ruffle even the casual conspiracy theorist. Further, this high stakes application elucidates the broader seduction of brain waves: they connote the authority of brain science married to the mysterious charm of a wave. Undulations from the scalp, we assume, must relay *something* about the information stored in the brain, or about the person to whom said brain belongs. This assumption, which is logical enough, underlies myriad varieties of *Brainwave Science*.

Feedback's Comeback

Bizarrely, Flynn was not the only Trump appointee mixed up with questionable brain wave technology. Betsy DeVos, the current Secretary of Education, invested millions of dollars in the biofeedback firm, Neurocore, and was on its board until her appointment.[41] Like a number of comparable companies, Neurocore might be interpreted as an innovative venture that helps people with mental illness, or as one that exploits the obscure allure of brain waves to turn a profit.

Contemporary biofeedback clinicians apply the same basic principles as alpha practitioners of the 1970s: a subject wears an EEG cap and attends to a stimulus that confirms if and when her brain achieves some target frequency, or combination of frequencies. However, newer biofeedback apparatuses hardly resemble Joe Kamiya's alpha monitors. Rather than respond to a simple auditory tone, subjects today might watch a virtual wizard race on a broomstick, the speed of which changes according to EEG input. As the subject learns to control her broomstick she, in theory, also trains her brain to produce the desired waves.[42] By reinforcing the right neural frequencies, proponents claim, feedback games can remedy a number of psychological woes.

Though current research suggests that neurofeedback can improve symptoms of select psychological conditions, feedback firms often overstate the technique's efficacy and exaggerate the diversity of brain ailments that benefit from this intervention.[43] For example, Neurocore's website advertises "Med-Free Neurofeedback Treatment For ADHD, Anxiety, Depression, Overall Brain Balance & More."[44] Here and elsewhere, an emphasis on *non*-pharmacologic therapy recalls 1970s endorsements of alpha training. Just as alpha may have appealed to individuals seeking a drug-free high, modern biofeedback companies target consumers looking for "med-free" mental health.

In the previous chapter I discussed potentially attractive features of a "chemical imbalance" model of mental illness. Chemicals, I suggested, register as a tangible and *fixable* source of psychological dysfunction. Via reduction to material *stoff,* a complex emotional condition becomes a concrete medical problem: an unideal concentration of chemicals simply calls for consumption of additional chemicals. Yet, for some patient-consumers, the introduction of foreign *stoff* to the body represents something unnatural, and thus, undesirable. Chemicals, after all, tend to come with side effects. By contrast, biofeedback does not require the ingestion of synthetic matter. Like a mesmeric healer or an alpha yogi, the likes of Neurocore promise an improved you by optimizing the dynamics of the body's vital, electric energy—no pills necessary.

Biofeedback may be particularly attractive to parents of children with attention disorders who are reluctant to feed their kids amphetamines at age eight. Indeed, when awareness of attention deficit disorder (ADD) grew during the early 1990s, so did discourse on biofeedback therapies to treat this condition.[45] This work indirectly revived links between brain waves and social or mental aberrance. For example, in 1992 an *L.A. Times* article on "ADD children," reported that,

> Their EEG patterns generally have an excess of the slower theta waves associated with daydreaming, and a shortage of the beta waves associated with concentration

> … By increasing the beta waves and normalizing theta waves, the EEG treatment can increase the youngster's ability to focus and concentrate, which can lead to improvements in classroom performance, achievement test scores, IQs, as well as their social and behavioral skills.[46]

A diagnosis of ADD does not bear a social stigma equivalent to categorizing someone as a moral deviant; however, in a culture obsessed with productivity, mental sluggishness represents an unacceptable deviance in its own right. Accordingly, modern biofeedback and "brain training" firms often market their interventions not just to those with diagnosed learning disabilities, but to anyone hoping to gain a competitive edge in the game of thinking. Biofeedback has been proposed for improving mental acuity in a variety of contexts, ranging from the workplace to the golf course.[47]

Modern brain wave proselytizers invoke an updated vocabulary to market new products: biofeedback becomes "neurofeedback," human potential takes the name "brain fitness," and scalp electrodes fall into hip categories like "biosensors" and "wearables."[48] The associated hardware has also received a millennial makeover. Consumers can now purchase chic, at-home EEG sets—lightweight headbands that relay neural information to a smartphone or tablet via Bluetooth technology (see Figure 15). The user receives feedback regarding her neural status either via visual cues on her screen, or via audio cues from her headphones. This sort of technology does not require—or benefit from—the expertise of a biofeedback clinician; instead, an accompanying app allows the user to independently track "progress" over days, weeks, and months of training.

The ability to assess one's neural oscillations falls into a broader trend of self-surveillance, known as the "quantified self" movement. According to the *Economist,* participants in this movement believe "that gathering and analysing data about their everyday activities can help them improve their lives."[49] For the dabbler, quantification might involve tracking steps with a FitBit or similar device; and for extreme practitioners, a quantified life could demand records of every calorie that enters the body, as well as the form and character of feces that exit therefrom.[50] Excrement analysis may, understandably, deter some would-be quantifiers.[51] Brain analysis, on the other hand, has a wider appeal (not to mention, a nicer smell).

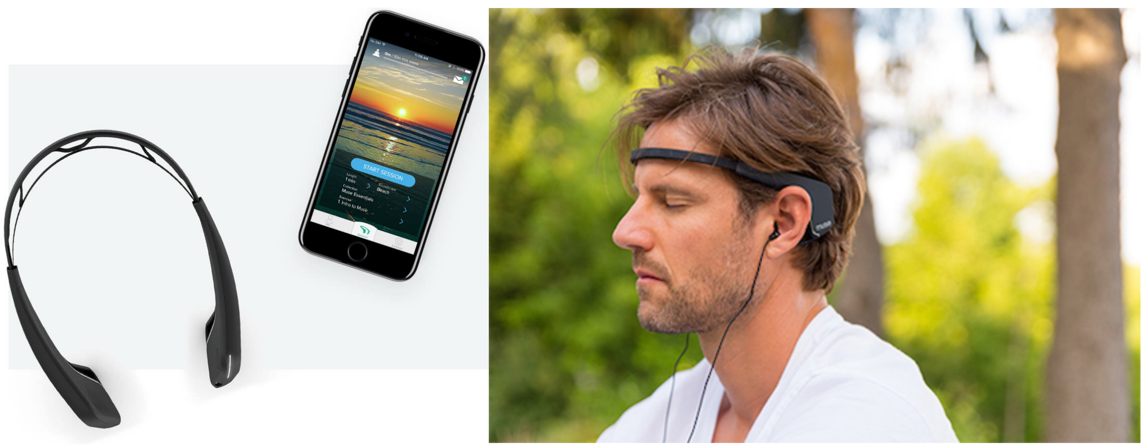

Figure 15. Marketing graphics for Muse. Reprinted from "How Does Muse Work?," Muse™ The Brain-Sensing Headband, accessed January 26, 2018, http://www.choosemuse.com/how-does-muse-work/.

A consumer interested in brain quantification can choose from a number of wearables that purport to help users track, and perhaps amend, their neural habits. "Neuroon Open," for example, is a $120 headband that, according to one online magazine, "can be used for effective sleeping, smart waking, deep meditation, polyphasic sleep, and lucid dreaming." Leaving alone what "smart waking" might entail, the author also claims that "The EEG can be used to monitor brain waves, allowing you to get a precise reading of your sleep habits and needs, [and] also allowing you to meditate by playing out audio cues to lull your brain into the correct meditative state."[52]

Like the assortment of alpha monitors that emerged in the early 1970s, modern EEG headbands range in quality and rarely come with scientific evidence to support their manufacturers' claims. And, like the original alpha machines, new consumer EEG devices are often marketed as tools for expedited meditation. For example, Muse, "the brain sensing headband," uses the tagline, "Muse makes meditation easy.™"[53] Perhaps heavy-handedly, Muse relays feedback via the sound of water waves: violently crashing water (supposedly) indicates that the user is distracted or agitated; more serene-sounding waves denote relaxation.

Muse and companies like it capitalize on the convergence of two trends in popular technoscience: quantifying the self and scientized meditation. The latter is often framed as a pursuit of "mindfulness," defined as "awareness and nonjudgmental acceptance of one's moment-to-moment experience."[54] Many mindful techniques resemble older meditative practices. Today, however, researchers dress up these rituals with terms like "mindfulness-based stress reduction" (MBSR) or "mindfulness-based cognitive therapy" (MBCT)—language that seems to transform meditation into a valid therapeutic option.[55] In turn, scientific literature on MBSR and MBCT allows companies like Muse to make authoritative statements about the value of their product. One of the larger and more prominent manufactures in the genre, Muse does not claim that the device proper actually yields any benefit. Instead, marketing materials highlight the value of meditation itself. The Muse website states, for example: "Meditation has been scientifically shown to reduce symptoms associated with stress, depression and anxiety as well as improve focus, performance and quality of life."[56]

Of course, users do not need a Bluetooth-equipped neurogadget to sit still and breathe. However, the ability to digitally track progress may appeal to self-quantifiers and other outcomes-oriented consumers. In the same way that the language of brain waves historically provided "scientific" validation for spiritual beliefs, here, brain wave technology seems to boost the legitimacy and value of meditation. Working on one's soul resonates as a spiritual—and perhaps time-wasting—practice. By contrast, working towards the optimization of EEG metrics on a smart device seems tech-savvy and productive.

Whether consumer neurofeedback technologies confer genuine psychological benefits remains unclear. One critique of such "EEG" products points to the fact that many of these devices may not offer EEG at all.[57] That is, the data obtained from some consumer machines may denote electrical fluctuations in forehead muscles, rather than the brain—thus technically qualifying the process as electro*myo*graphy (E*M*G). To the self-quantifier, EMG may offer valuable data; and forehead relaxation may indeed aid meditation. However, companies rarely advertise their products as forehead sensors. "Muscle waves" simply don't inspire the imagination in the manner of *brain waves.*

Even if Muse and similar devices turn out to be muscle wave headbands—even if any "brain sensing" is an illusion—the increasing ease of obtaining electrical data from the scalp marks a new era in the history of brain waves. By streaming biological metrics from the head to a smart device, consumer BCIs *appear* to entangle the brain's dynamism with the rest of our digital data. Biofeedback becomes "gamified," blurring the lines between therapy and recreation, between health and self-improvement, and between physiological space and virtual space.

Brain Play

In 2009, the company NeuroSky released the first mass-market BCI *toy*. The product, called Mindflex, resulted from a partnership with Mattel and promised the sort juvenile diversion one might expect from such a company.[58] An early review from *Gizmodo* reads:

> The object of the game is simple. You must manipulate the vertical movement of [a] ball using the power of your thoughts. The headband detects the intensity of your brainwaves—the harder your concentrate, the higher the fan in the unit will elevate the ball.[59]

Also in 2009, Uncle Milton released a similar toy with themed trimmings, called the "Star Wars Force Trainer." The product, which is currently available for sale online ($85 to $130), allows users to imagine that, like Luke Skywalker, they can control objects with some fantastic force of will.[60]

Figure 16. Brain toys. Left: Neurosky Mindflex. Reprinted from Neurosky Store (website), accessed January 20, 2018, https://store.neurosky.com/. Right: Star Wars Force Trainer. Reprinted from "Star War Science-Force Trainer," Amazon, accessed January 20, 2018, https://www.amazon.com/Star-Wars-Science-Force-Trainer/dp/B001UZHASY.

As both games effectively involve moving a ball, they are not the picture of recreational sophistication. Yet the thrill of products like Mindflex lies not the rules of the game, but in the manner in which it is played. Capitalizing on the excitement of mind control, the NeuroSky online store states: "You'll feel like a character in a science fiction movie as you strap on the headset… you feel like you've mastered the art of telekinesis."[61] Again, some experts surmise that Mindflex is actually an EMG device — but then, MuscleFlex sounds like a different sort of game.[62]

Neurosky's competitors include the company Emotiv, which sells multiple electrosensitive gadgets and identifies a variety of applications for its products. Their website states: "EMOTIV's Mental Commands algorithm recognizes trained thoughts that can be assigned to control virtual and real objects just by thinking."[63] In addition to brain games, Emotiv highlights their tools' more serious, professional functionality. Specifically, the company suggests that Emotiv devices can perform high tech market research: using an EEG headband, an advertising agency might track brain changes to determine when an ad piques the interest of a would-be buyer. Emotiv is not alone in recognizing a corporate future for EEG. Researchers in both academia and industry have suggested that neural oscillations can be a valuable metric in evaluating consumer response to commercials and associated products.[64]

In a 2010 paper, a group of researchers working in this area wrote: "We believe that methodologies based on measuring brain waves activity [will] soon significantly enrich marketing research portfolio[s] and help marketers to go beyond verbal declarations of their consumers."[65] Like Brain Fingerprinting, efforts in "neuromarketing" reflect a hope that brain waves will betray information more valuable or true than spoken and written communication—secrets that the mind knows, but that lips will not reveal. Cheap and portable, commercial BCIs allow researchers to collect EEG data in contexts where brain measurements would otherwise prove difficult—including, but not limited to marketing studies. Emotiv has been used, for example, to evaluate brain rhythms during different stages of a poker game, and to detect drowsiness in drivers.[66]

Emotiv's more elaborate device, the Epoc, boasts fourteen channels and costs about $800; for reference, lower-range devices have one to five channels and typically run from $100 to $300. With the enhancement of at-home devices, potential applications for data collection and "brain control" become virtually limitless. As Edmond Dewan commented in 1964, "Once you have a switch that can turn on and off you can plug anything you wish into it."[67] That is, once a consumer EEG headset can recognize defined electrical features in the brain, a skilled programmer can assign this "input" to any range of technological outputs. To this end, Emotiv and other companies encourage consumer innovation. In addition to pre-packaged products, some BCI manufacturers host a forum for amateur programmers—modern-day electric hobbyists—to develop novel software that makes use of the company's hardware and the body's electricity.[68]

Forecasts about near-future neurotechnology anticipate diverse applications of consumer BCIs, including brain-responsive computer games, mobile devices, and drones.[69] Yet, even with improving EEG software and hardware, currently available "mind-controlled" products typically fail to perform at a level superior (or even equivalent) to their hand-controlled counterparts. Simple brain-mediated video games, for example, respond unreliably to neural commands. So why should BCIs represent the cutting edge of technotainment?

The prospect of mind control offers a form of escapism more profound than puerile games. It promises release from corporeal incarceration into digital ether. Traditional video games depict computer avatars as unshackled to physiology; though the human player controls the avatar, her power is undermined by the fact that she exerts this control via clumsy body-fingers. A screen tap, however slight, implicitly confirms that the gamer, unlike her avatar, must answer to mortifying biological demands: eating, sleeping, defecating, and so forth. BCI-mediated play ostensibly rectifies this asymmetry, as both the player and her avatar seem to exist out of body.

Unlike the wire-laden apparatuses typically found in a laboratory, consumer BCIs relay data wirelessly from headband to machine. In doing so, these devices produce an illusion of genuinely sending one's brain waves through space. They thus manufacture a reality in which brainpower alone suffices to communicate with and control the environment. Like a mesmeric show or a spiritualist séance, mind control games offer an experience of "real" magic. And, like elusive forces of the nineteenth century, the power of neurotechnology often becomes most vivid through extravagant shows of scientific spectacle.

At the 2010 Olympic Games in Vancouver, for example, the company InterAxon debuted a giant light installation that was, supposedly, controlled by brain waves.[70] Covering the exhibit, *Wired* describes: "[An EEG] headset measures the brain's electrical output and reacts to alpha waves, associated with relaxation, and beta waves, which indicate concentration. As users relax or focus their thoughts, the computer sends a message to the site they are viewing."[71] Such an event can be captivating, even if utterly purposeless. Practically speaking, no one *needs* to control light displays via neurons; but the sensation of telekinetic power provides a kind of wish fulfillment—a real experience of manipulating the physical universe according to mental whim.

In another dramatic display of psychic force, the artist Lisa Park brought new meaning to the term "brain waves" through her 2013 exhibit, "Eunoia." In this piece of performance art, Park used a NeuroSky headset to convey her brain data to speakers, which were seated beneath bowls of water that rippled and splashed as the speakers emitted noise: brain waves, to sound waves, to water waves.[72] In videos of the event, Park sits serenely, apparently commanding the water to ripple via intense concentration. At first, she resembles some sort of medium or demigod. Only a small headpiece betrays that her "powers" rely on technology.

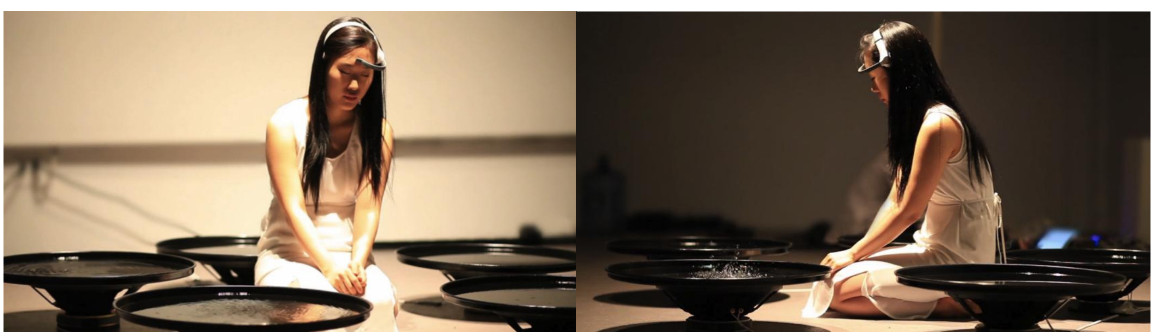

Figure 17. Lisa Park performing "Eunoia." Reprinted from Olivia Chow, "Artist Manipulates Water with the Power of Her Mind," Vice, June 10, 2013, https://creators.vice.com/en_us/article/vvygzm /eunoia-seeking-enlightenment-by-tracking-brainwaves.

Out of Body

At present, touch screens and keyboards offer sufficiently direct interface between brains and technology. However, as computer speeds accelerate, deficiencies of this tactic become increasingly apparent. Like telegraphs before them, computers humiliate the body's lethargy. As neurologist Anthony Ritaccio puts it, "obviously the way we communicate with computers is rather comical. The way we interact with this blazing fast machine is to poke at it with a finger."[73] Comically menacing, each poke reiterates the poker's mortality: *fingers, flesh, death.*

BCIs appear to liberate neuronal discourse from the constraints of physiology, transposing mental activity from organic to technologic space. And though BCIs may be the first device class to offer a more level playing field, they reflect the continuation of a lack-of-arms race initiated by earlier tools. Kittler writes:

> [W]hen Samuel Morse patented his electric cable telegraph in 1840, he introduced a communications technology whose speed of light far outpaced all forms of manual communication…What therefore became part of the wish list were writing instruments that could coincide with the operating speed of nervous pathways.[74]

Incredible advancements in communications technology, it seems, do not sate the hunger for expedited discourse, but merely whet the appetite for future innovation.

BCI optimists suggest that our brains will be able to send text messages—or more sophisticated communiqués—within the decade (see Chapter 9). And though such projections are likely overly ambitious, they represent the next logical step in communicative efficiency. With telegraphy, the incredible convenience of moving messages without moving one's body obviated the immersion in nature required by foot-on-soil transmission. With BCIs, the convenience of moving messages directly from brain to computer represents a similar retreat from the natural landscape that is the body.

In both instances, technologies purporting to expand the reaches of the self ironically contract and compress embodied action. As our messages move further, faster, we occupy a shrinking circumference of physical space: mobile technology, immobile bodies.

Knowles's original theory suggested that telepathic oscillations might allow a person to intimately commune with a loved one in a physically isolated location. Today, sending messages across incredible distances is an assumed facet of modern life. However, speedy messaging does not guarantee the sort intimacy Knowles had in mind—*i.e.,* "sympathies of feeling beyond all words to tell—groanings of the spirit which cannot be uttered, visions of influences and impressions not elsehow communicable."[75] Even as communications tools begin to encroach upon the skull, they remain a long way from capturing the spirit. The ability to technologically extract messages from the cortex does not guarantee greater sympathy between brains; and, in fact, it may yield the opposite effect.

From the telegraph through the iPhone, advancements in communications technology have inspired hope for enhanced human connection; in the process however, humans have also become desperately connected to their machines. That is, though novel tools offer opportunities for interpersonal interaction, the tools themselves are not passive conduits. And, in some cases, devices may hinder genuine human intimacy: one need only consult the frustrated parent imposing a "no cellphones" rule at dinner to understand the potential obtrusiveness of technology.

As gadgets grow smart, they become as much tools for escaping sociality as encouraging it. We feel compelled to stay "connected." But to whom? Or perhaps more accurately: to what? In the digital age, being "connected" connotes intimacy with a piece of technology, only *sometimes* in service of genuine social exchange. It should not be surprising, then, that in the twenty-first century fantasies about brain waves tend to involve neural oscillations that flow not towards other brains, but towards devices.

Perhaps consumer BCIs will ultimately facilitate a deeper understanding of our fellow humans. Conceivably, transmission of brain data could enable communication about experiences ineffable via conventional language. Alternatively, a more direct attachment to virtual worlds may estrange us from the truly ineffable experience of embodied interaction.

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Chapter 9. Wave Goodbye

In April of 2017 a 65-year-old Australian man, Philip Rhoades, wrote an open letter to Tesla CEO Elon Musk. Seeking a peculiar partnership with the billionaire, Mr. Rhoades explained:

> In addition to my own health issues, the planet also has rapidly increasing environmental health problems - with the potential for Abrupt Climate Change and concomitant, large-scale ecological collapses. For these reasons *I am convinced that I need to become a virtual person (via mind uploading)* sooner rather than later - and lots of other people should too – "Rage, rage against the dying of the light."![1]

Also known as "Cloud Man," Rhoades may come off as a bit kooky—particularly considering that he counts "signs of cognitive decline" among his reasons for wanting to go virtual. Yet, Rhoades did not invent the idea of "mind uploading," a notion that has floated around science fiction literature since the 1950s, and that now appears in academic literature under the name "whole brain emulation" (WBE).[2] In 2008, futurists Anders Sandberg and Nick Bostrom developed a "road map" on WBE, which treats the topic at length and with utter seriousness. The authors write:

> The basic idea is to take a particular brain, scan its structure in detail, and construct a software model of it that is so faithful to the original that, when run on appropriate hardware, it will behave in essentially the same way as the original brain.[3]

Bostrom and Sandberg assert: "WBE represents a formidable engineering and research problem."[4] And though they contend that scientists may one day solve said problem, they don't believe that such a day will come particularly soon. In this sense, Rhoades's appeal to Musk is in vain, if not insane. His letter continues:

> A successful result would be that I would get to explore the Universe for as long as I found life interesting and exciting and, with the help of my virtual self, you [Musk] would have a much better chance of successfully colonizing Mars. Your

> current SpaceX and Tesla projects are part of the bigger picture and your new "Neural Lace" development is a very big part of it.[5]

Rhoades's allusion to "Neural Lace" indicates familiarity with Musk's latest investment—a company called Neuralink that promises exceptionally precise measurement of the brain's electrical dynamics. Rhoades, apparently, hopes that such a technology will not only record his brain data, but also instantiate his consciousness in virtual space, and in outer space. To say the least, Rhoades overestimates the state of the science. However, between whimsical misbeliefs, Rhoades points to very real issues in twenty-first century technology and society. Namely, his letter identifies a future of increasingly vivid virtual realities and increasingly dismal ecological realities.

Whereas the imagined futures of earlier generations comprised flying cars and world peace, today "the future" evokes environmental devastation and perhaps a new world war. It should not be surprising, then, that some individuals look to virtual worlds and interplanetary travel to escape this depressing destiny. As the planet endures "health issues" and society evidences "signs of cognitive decline," the desire to upload the mind to elsewhere doesn't seem so crazy.

Of course, disappointment with life on earth is not new. For millennia, those unimpressed with mundane existence have maintained hope for something better in the next life. Today, as ever, religious individuals may find comfort in scripture: earthly or bodily demise seems less tragic if heaven waits. For the less overtly religious among us, a belief in technological reincarnation may offer a similar sort of comfort. Yes, our brains are doomed to perish, but brain *waves* or brain *data* just might survive degradable tissue.

Information of all varieties now spawns duplicates that reside on a resilient cloud. Given as much, it seems unfair that the content of the mind should lack an analogous backup plan. Current proposals for WBE, or less extreme varieties of brain-machine interaction, construct a reality in which brain data flows to a haven safer than our skulls. Though some features of mind uploading take inspiration from twenty-first century technology, the desire to transmit neural dynamics elsewhere is hardly a new invention. Indeed, as projections for near-future neurotechnology straddle realms of science and fiction, they occupy a liminal space where brain waves have always felt quite at home.

Science and Fiction

> The point frequently has been made that private dreams are systematic in content and impulse. Dreams and fantasies created, exchanged, and reworked in the public forum are systematic as well. They develop their own traditions in the conversation society has with itself about what it is and ought to be. Such dreams are never pure fantasy, perhaps, since their point of departure is a perceived reality. They reflect conditions people know and live in, and real social stakes.
>
> –Carolyn Marvin, *When Old Technologies Were New*[6]

Knowles's theory of brain waves depended on contemporary misunderstandings of the universe. In particular, the belief that waves travel unaided from brain to brain grew from an assumption of all-pervading ether. In the century and a half since Knowles first proposed his theory, Western technoscience has, to state the obvious, advanced tremendously. Given the scientific knowledge accumulated since 1869, one might presume that modern society has no place for the fantastic ideas that captivated Knowles, Crookes, Wallace, Lodge, and other scientific spiritualists. Yet, advances in technoscience do not stifle fantasy—they fuel it.

Recall that Knowles's theory did not gain traction upon its original publication in 1869, but rather upon its *re*-publication thirty years later. This delayed reception corresponds to the development of radiotelegraphy, which exemplified the kind of wavy, wireless transmission proposed by Knowles. In this instance, a new technological ethos did not suppress spiritual beliefs, but instead yielded an authoritative language through which to convey them. Though scientific research *seems* to place limits on what is possible, this effect is more in style than in content. Even after researchers disproved the existence of ether, a belief in brain waves persisted according to newer scientific motifs: perhaps neural oscillations travel via radio waves, or perhaps via Bluetooth. As the technical details of thought transmission evolve, the basic premise remains unchanged.

For thinkers inclined to believe in miracles, new developments in science and technology offer concrete targets on which to pin tenuous dreams; and this phenomenon applies beyond brain waves. Consider, for example, the individual diagnosed with a terminal illness: rather than accepting death, the patient may prefer to believe that some new experimental treatment will deliver a cure. Similarly, scientists studying presently incurable diseases do not accept these conditions as hopeless. Their careers, in fact, depend on an assumption that forthcoming technology and research will eventually yield a therapeutic breakthrough. Though a universal end to cancer may appear a more reasonable desire than telepathic communication, efforts towards both ends have a long history of failure. And, in both cases, new scientific advances perennially revive hope. Perhaps forthcoming gene therapies will exterminate treatment-resistant disease; perhaps new neurogadgets will finally liberate the mind from the skull.

In Mr. Rhoades's case, a hope for transcendence arises not *despite* the limits of modern technoscience, but *because* of the ways in which novel technologies regularly expand those limits. Like a desperate cancer patient, Rhoades skimmed the available literature for some glimpse of promise; and, as his letter suggests, he found his "experimental therapy" in the tweets and technologies of Elon Musk.

Among the one hundred richest people in the world, Musk is part eccentric billionaire, part genuine innovator.[7] He is prone to grand proclamations regarding self-driving cars, hyperloops, the colonization of Mars, and recently, techno-telepathy. When Musk writes or speaks about his projects, the realistic blurs into the fantastic, and near-future plans comingle with far-future dreams. In this respect, Musk faithfully carries on the legacy of his company's eponym, Nikola Tesla, who often forecasted dramatic developments in EM technology. For example, in 1904 Tesla predicted that, in the future,

> A cheap and simple device, which might be carried in one's pocket, will accurately record the world's news or such special messages as may be intended for it. Thus the entire earth will be converted into a huge brain as it were, capable of response in every one of its parts.[8]

In the same interview, Tesla also refers to his ongoing research into a system of wireless energy transmission—a pursuit to which he devoted considerable time and resources.

Today, pocket-sized devices that "record the world's news" are commonplace. Wireless energy transmission, however, remains fantasy. If Tesla, with intimate knowledge of EM technology, saw the two inventions as similarly plausible, outsiders certainly might misgauge the line between science fiction and technological reality. After all, telepathic brain waves don't sound terribly far off from an earth "converted into a huge brain." That is to say, wireless science at the turn of the twentieth century expanded the realm of the possible for thinkers both with and without technological expertise.

Further, speculation from prominent innovators can create public confusion regarding the current state of technology, and the boundaries of reality. Leaders like Tesla and Musk describe worlds that do not exist, yet they speak with a confidence and authority beyond that of the novelist. Musk does not discuss the colonization of Mars in the context of a *story,* but rather via comments regarding logistical parameters of the requisite rockets. And when he mentions the prospect of telepathy, he does so not as an off-hand conjecture, but as an act of publicity for his latest business venture, Neuralink.

According to Musk, Neuralink will eventually produce a *neural lace*—an electrosensitive, biocompatible mesh that enters the skull via syringe. A functional neural lace would relay cortical data to some external receiver, thus theoretically facilitating brain-to-machine or brain-to-brain exchange. Though originally a sci-fi concept concocted by author Iain M. Banks, a genuine neural lace is now in early stages of development.[9] In 2016 a Harvard group led by Charles Lieber announced the application of "a chronic *in vivo* recording and stimulation platform based on flexible mesh electronics."[10] In Lieber's experiments, the device successfully collected neuronal data for months at a time, albeit in mice.

Musk's public comments regarding Neuralink read as an amalgamation of Lieber's research and Banks's fictional world—a world in which implants allow human minds to communicate with one another and with technological systems. Like brain wavers of past centuries, Musk describes his still-hypothetical technology in telepathic terms. He does not go so far as to mention "groanings of the spirit," but he comes close. In a lengthy 2017 interview Musk frames his proposed product with respect to more conventional forms of communication. He states:

> There are a bunch of concepts in your head that then your brain has to try to compress into this incredibly low data rate called speech or typing… If you have two brain interfaces, you could actually do an uncompressed direct conceptual communication with another person. If I were to communicate a concept to you, you would essentially engage in consensual telepathy. You wouldn't need to verbalize unless you want to add a little flair to the conversation or something… [T]he conversation would be [a] conceptual interaction.[11]

Here, Musk depicts concepts as existing independent of language—a stance that, in itself, could spark a philosophical debate and should not be taken as given. Conveniently sidestepping how one might experience wordless conceptual exchange, Musk explains that this sort of communication is "on a level that's difficult to conceive of right now."[12]

From a different source, Musk's claims would read as wildly implausible; and maybe they are. But given his track record—Musk's company really does build rockets—such assertions attract more attention and more credence than an obscure individual rambling about telepathy. Musk does not use the language of brain waves to articulate his ideas, but rather employs more current terminology. In 2018, *spontaneous telepathy via undulations in ether* may sound a bit ridiculous. But *uncompressed conceptual interactions via an injectable neural lace*? Well, that sounds like science. Again, scientific progress alters the discursive trimmings of cultural desires—but it does not limit their content.

Both among experts and laypersons, forecasts about future technology require a compromise between practicality and fantasy—an ability to imagine what might be, based on what *is*. In some cases, such exercises of the imagination yield a new generation of technology; in other cases, they remain imaginary. Will Elon Musk achieve consensual telepathy? Probably not. However, as he takes on such a goal, public discourse regarding neural lace increases, and the popular imagination swells. More broadly, growing interest in neurotechnology among Silicon Valley's elite suggests that a new wave of sophisticated brain toys may be around the corner. In the meantime, public accounts of these efforts yield a novel vocabulary through which to express ever-elusive dreams.

Getting Smart

> One day soon, we will wake up and wonder how we ever survived in a world of "dumb" disconnected things. Our homes – including our pantries, closets and shoe racks – our offices, factories and vehicles will be full of connected devices.
>
> —Paul Taylor, "How the Internet of Things Makes Dumb Devices Smart"[13]

First came the smart phones. Now, everything from watches to vacuums achieves smart status. Smartness, in this context, refers to some sort of internet connection: a smart device is one that is one that, via Wi-Fi, becomes embedded in the so-called "Internet of Things" (IoT), which one author defines as "the concept of basically connecting any device with an on and off switch to the Internet (and/or to each other)."[14] Dumb things, apparently, are those without an online trace—appliances relegated to instantiation in physical space alone. Smart things, on the other hand, maintain a dual presence, existing both in the profanity of "real" space, and in sacred, virtual space.

The body of a smart light bulb, for example, resides on a wall sconce. The spirit of such a bulb, however, lives in a Wi-Fi-connected app that governs its brightness and color. Smart thermostats function similarly, permitting a user to remotely warm or cool her abode. An increasing number of household appliances function in this manner, allowing users to control everything from televisions to trashcans at a distance. Smart devices are also inherently telepathic: gadgets in the IoT can "talk" to one another via invisible waves. For example, a smart bulb's color might change according to the mood of music coming out of smart speakers. Consumers keen on such spooky synchronization may venture to construct a thoroughly *smart home*—a house haunted by Wi-Fi.

Unlike the turning tables of the nineteenth century, today's possessed kitchenware answers to digital, rather than spiritual mediums. Still, the modern assumption of internet ubiquity recalls an etheric view of the universe. Wi-Fi, like ether, invisibly pervades space, entangling otherwise disconnected objects and people. Yet, whereas undulations of the ether were thought to follow organically from any material motion, interaction with Wi-Fi requires an internet connection; and our brains, despite all those synapses, are not imbued with this type of connectivity. Any electrical waves produced by neurons do not penetrate virtual space—at least not without some help.

In the previous chapter, I discussed new consumer EEG and "EEG" devices—relatively affordable products that monitor electrical activity in the brain (or the forehead). As this tech genre expands, so-called brain "wearables" become increasingly, well, wearable. For example, in 2017 the neurotech company Muse partnered with Smith Optics to develop the Lowdown Focus, a pair of athletic sunglasses equipped with electrodes in the arms and bridge. On its website, Smith asserts: "Lowdown Focus is the first brain sensing eyewear in the world that gives you accurate, real-time feedback on your brain's activity level during a cognitive training session with the Smith Focus App."[15] The company states that their glasses-app combination will "help you develop a heightened sense of self-awareness" and can be used for "relaxation, improved mood and reduced stress."[16]

Figure 18. Marketing materials for the Smith Lowdown Focus. Left: photographs of "Lowdown Focus Brain Sensing Eyewear™." Right: sample user data, as featured on Smith's Website. Original caption: "Data & Personalized tracking challenges, and rewards designed to help you." Reprinted from "Lowdown Focus," Smith, accessed October 7, 2017, http://www.smithoptics.com/us/lowdownfocus.

Whether the Lowdown makes good on the above claims remains to be seen. Yet, the mere availability of "brain sensing eyewear" represents an apparent step closer to the integration of neural data into the IoT. Our biological tissue remains hopelessly unable to connect to Wi-Fi on its own; given as much, seamless incorporation of electrodes into common accessories may be the next best thing. Currently, many phones and smart watches act as pedometers—the assumption being that they are perpetually on our person and thus faithfully capture our movement over the course of a day. The Lowdown appears to serve an analogous function; yet rather than track the movement of our feet, it purports to track movement of the mind.

Lowdown, like the original Muse system, creates a virtual home for the user's brain data in a personal Muse account. To access one's neural history, a user simply opens an app on her smartphone; therein, she can review her brain's electrical behavior. Viewing the Muse app alongside the app for Philips Hue (a smart bulb), the two interfaces bear a striking resemblance (Figure 19). Within the Hue app (Figure 19A), a user may select from exotic light scenes such as "Savanna sunset" and "Tropical Twilight." Alternatively, one may select a functionality-based ambience, such as "Relax," "Concentrate," or "Energize." Similarly, Muse provides an assortment of "soundscapes" for its brain training sessions (Figure 19B), such as "Beach," Desert," and "Rainforest;" for functionality, the app offers a selection of courses, such as "Heartfelt Mindfulness" and "Dealing with Distraction."

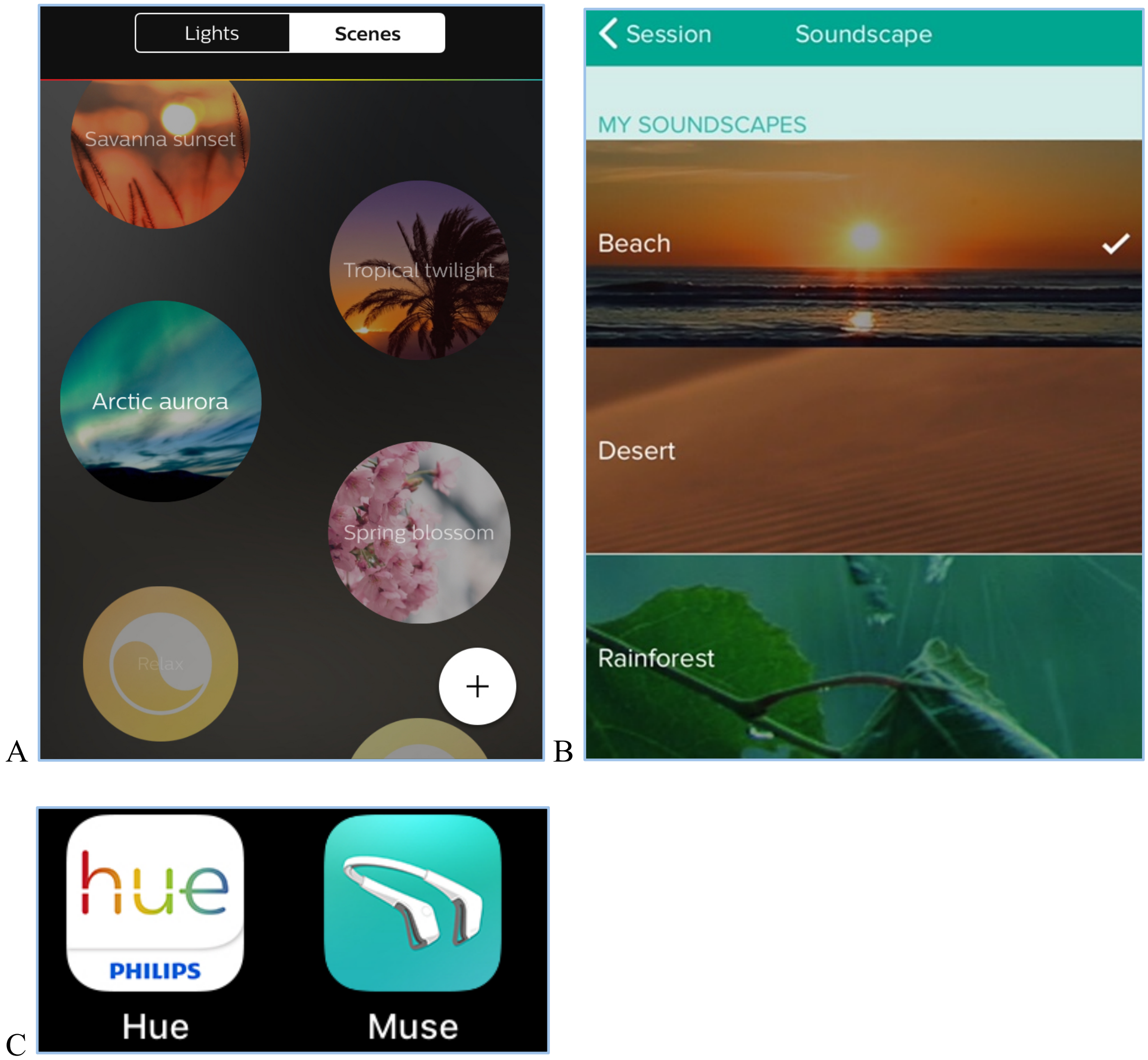

Figure 19. Hue & Muse. A. Philips Hue app interface, scene selection. B. Muse app interface, soundscape selection. C. Hue & Muse apps, side by side on an iPhone home screen. Screen shots from author's phone.

On an iPhone home screen (Figure 19C), the brain app and the bulb app achieve virtual parity—as if to suggest that controlling one's state of mind is as easy as controlling the brightness of one's living room. Moreover, embedded in the IoT, the brain, like smart devices, secures a virtual presence—a backup of neural data. Certainly, an app like Muse does not facilitate "mind uploading." However, it creates a precedent for thinking about brain data as part of the greater technoscape. Insofar as the internet is perceived to be *everywhere,* Wi-Fi-enabled brains represent a novel framework for imagining the transmission of brain waves across the universe.

Like ether, the internet seems to fill the air—real and proverbial—with possibility. With the growth of the IoT, the internet seeps out of computers and into our surroundings—into our kitchens, our living rooms, our bathrooms (yes there are "smart toilets"), and our bedrooms. And as Wi-Fi expands across new corners of physical space, it also expands the space of conceivable realities. The IoT makes thinkable a future in which the internet invades our bodies, and especially, our brains.

Though the Smith Lowdown made *Cosmopolitan* magazine's list of "7 Products That Will Get Rid of Stress ASAP," the glasses are not likely to impress electrophysiologists.[17] The device has only five electrodes, which don't correspond to standard EEG recording sites. Yet academics are not immune to the allure of online brains. In 2017, researchers at the university of University of Witwatersrand in Johannesburg announced a project called "Brainternet," a website that hosts wirelessly-transmitted EEG data.[18]

Brainternet graphs resemble figures one might find in a traditional scientific paper. However, unlike static charts, Brainternet data flows immediately to a dynamic viewing portal: as a subject thinks and electrodes collect data from her scalp, remote viewers can watch this neural action unfold in real time. The ability to live stream brain data jibes with other digital trends—streaming movies, streaming music, and so forth.[19] In this sense, Brainternet aligns with the current technological moment. Yet, neural streaming also recalls the aquatic ephemerality of older telepathic schemes: the imagery of *streaming* frames thoughts not as content that a brain stores, but as a dynamic current that ripples between hosts.

The Brainternet website, of course, does not enable thought transference. Still, creator Adam Pantanowitz has stated that in future iterations of the technology "there could be information transferred in both directions – inputs and outputs to the brain."[20] Reacting to Pantanowitz's comments, journalist David DiSalvo imagines Brainternet as a potential avenue to something like telepathy. He writes:

> Imagine having an app on your phone that dials up other peoples' brains, and maybe your brain will be in their contact lists…Add interactivity, with people able to send signals back and forth, and we've turned yet another page in the science fiction novel we're all living.[21]

The embrace of neuroscience by the tech sector may entail engagement with fictional worlds in more ways than one. The company Neurable is currently advertising virtual reality (VR) goggles that respond to EEG input. If this product lives up to Neurable's claims, it will allow users to navigate and interact with manufactured environments using thought alone. The company's website states: "Immersive computing requires a new approach to human-computer interaction. Neurable designs software and solutions that function as a natural extension of our brains, creating new possibilities for human empowerment."[22]

Figure 20. Neurable. Photo from Neurable's homepage, the top of which reads: "Explore a world without limitations." Reprinted from Neurable (website), accessed October 2, 2017, http://www.neurable.com/.

If Neurable designs "solutions," one wonders what sort of *problems* the company has in mind. VR goggles blind the user to the goings on of the world beyond these lenses. And the relocation of motion from the body to a thought-controlled avatar is tantamount to paralysis. Blind and lame, the user does not, from the outside, appear the picture of "human empowerment." Yet, from another perspective, the user transcends her body, her environment, and all the imperfections associated with both. Though relatively young, the virtual transcendence industry is growing: the startup, Looxid Labs, claims to be developing a VR system that combines EEG and eye-tracking hardware to "create a unique and incredible experience."[23] Whatever that means.

In addition to goggles and glasses, the tech world continues to strive for good old thought transmission—or rather, new, computationally sophisticated thought transmission. At about the same time that Musk announced Neuralink, Facebook's Building 8 disclosed the development of new a wearable that, representatives say, would allow users to send text messages directly from their brains, hands free. Slightly less ambitious than "consensual telepathy," the technology would be closer to a neural dictaphone: a BCI-wearer composes verbal speech in her head, which the technology then translates into words on a remote mobile device. According to Facebook, the brain-to-text typing would occur at a rate of 100 words per minute.[24] This hypothetical speed far outpaces currently available medical BCIs, the fastest of which renders about six words per minute on a good day; and whereas these medical technologies require open-skull surgery, Facebook's device would be noninvasive.[25] Understandably, some experts familiar with BCI technology are skeptical of Building 8's claims.[26]

Beyond questions of feasibility, Facebook's project also raises questions of privacy. A technology used as frequently and casually as Facebook could potentially allow public access to neural data intended for personal use only.[27] Indeed, whether through VR games or IoT applications, the prospect of online brain waves exposes physiological information to the same vulnerabilities that the rest of our digital data suffers, including hacking.

In a 2009 paper Tadayoshi Kohno and colleagues at the University of Washington explored the risks of internet-connected brains, as well as potential measures for protection thereof. The authors classify this project as "neurosecurity," which they define as "the protection of the confidentiality, integrity, and availability of neural devices from malicious parties with the goal of preserving the safety of a person's neural mechanisms, neural computation, and free will."[28] In the paper, the authors primarily address the security of brains with implanted medical devices. Some individuals with Parkinson's disease, for example, have brain "chips" that deliver electrical pulses to the relevant neural regions via a process called deep brain stimulation. Were such devices enabled with internet connectivity, a hacker could theoretically alter electrical stimulation patterns with disastrous outcomes.

Though pernicious brain stimulation represents a particularly worrisome threat, a device that passively *listens* to the brain holds risks of its own. According to Nitesh Saxena of the University of Alabama at Birmingham, an individual wearing a consumer EEG device might unwittingly surrender details necessary to access bank accounts and other protected information. In a 2017 paper, Saxena and colleagues describe the development of an algorithm "which successfully predicts the sensitive keystrokes made by the users just from the event-related potentials passively recorded during those keystrokes."[29] In an article titled, "Using Brainwaves to Guess Passwords," *MIT Technology Review* summarizes:

> After observing a person enter about 200 characters, algorithms could make educated guesses at new characters a person entered just by watching the EEG data. That could let a malicious game, say, snoop on someone taking a break to go on the Web. It is far from perfect, but it shortens the odds of guessing a four-digit numerical PIN from one in 10,000 to one in 20.[30]

Saxena's study generated considerable media coverage, including headlines like "Brainwave-Reading Headsets Could Help Hackers Guess Your Passwords" (*Popular Mechanics*) and "Cybercriminals could soon be able to hack your BRAINWAVES to steal passwords and empty bank accounts, scientists warn" (the *Sun*).[31] Such headlines somewhat overstate the urgency of the situation. After all, very few people regularly don brain-sensitive caps; and those who do can easily avoid this sort of hacking by simply removing the device.

Though the average citizen needn't worry about brain spying just yet, fears to this effect may grow from more general, and very current hazards of digital life. Personal data regularly succumbs to hackers, and to the sanctioned theft embedded in "terms and conditions." As companies like Google and Amazon accumulate troves of data regarding to our clicks and keystrokes, the ubiquity of photo-ready smartphones subjects our likeness to perpetual monitoring. Simultaneously, the social media ecosystem fosters a virtual dissolution of skulls: pressure to post one's every thought blurs the spheres of inner and outer life. As technology renders human action increasingly visible, the privacy of subjective space may provide rare solace from surveillance. And brain-reading technology, even in the hypothetical, threatens that solace.

Just as current devices inspire our techno-utopian fantasies, so too do they shape dystopian fears. Thus, while the Knowlesian proposition to relay phenomenal waves may still enchant us, realities of the present virtual landscape reveal drawbacks of extreme sharing. Independent of brain-sensing technology, traces of our selves already live on the internet; and we cannot remove the proverbial headbands that monitor our digital incarnations.

Matter Matters

In 2017 Intel announced Loihi, a new computer chip that, the company hopes, will accelerate research in artificial intelligence (AI). Intel attributes Loihi's brilliance to the fact that the chip is *neuromorphic,* meaning, it emulates the processing style of the brain. An article in *Wired* states:

> Loihi's "neurons" and the adjustable connections between them function as both processor and memory, saving time and energy required to shuffle data around. The connections—analogous to synapses—between neurons can adjust to patterns in their activity over time, mimicking a learning mechanism seen in real brains.[32]

Put another way, Intel plans to use brain-like chips to achieve something closer to brain-like intelligence.

In a company statement describing the development of Loihi, an Intel representative writes: "The ideas were simple but revolutionary: comparing machines with the human brain."[33] As the preceding chapters show, comparisons between biology and technology are hardly new. They do, however, appear newly competitive. No longer shoddy approximations of "real" intelligence, machine minds increasingly match or surpass human performance at select tasks. Robots now threaten jobs in, for example, accounting and manufacturing. And if projections regarding autonomous cars hold up, AI will soon steal not only our careers, but also our commutes.[34] Of course, the human nervous system remains superior to computers in a number of arenas. It excels, for instance, at understanding social cues and at organizing motor commands. Further, even a poor comedian will put a computer comic to shame: AI jokes have the sophistication of dad humor, delivered with predictably robotic intonation.[35]

Still, assessing the merits of biology and technology, the former can, in some respects, come out looking comparatively weak. For all their cleverness, brains are not "smart" in the IoT sense of the word. Moreover, biological cells are prone to death in a way that silicon chips are not. And though mortality represents the most egregious sin of our flesh, neurons have additional shortcomings: biological brains can be forgetful, moody, and irrational. Computer "brains" do not suffer these embarrassments.

To make matters worse, brains rarely receive "upgrades" in the manner of digital technology. Indeed, though human intelligence appears a testament to the wonder of evolution, a comparison to computers' evolutionary history underscores the slothful pace of our intellectual growth. The first computers arrived less than a century ago, and already they threaten to overshadow biological processing systems. As entrepreneur Bryan Johnson puts it, "We've always built these tools, starting with the rock, thermostat, calculator. Now we have AI. Our tools and [artificial] intelligence are increasing at great velocity. On the flip side, human intelligence is just about the same as it's always been."[36]

In short, the rate of human evolution cannot compete with that of technological evolution; and since we cannot *beat* the machines, people like Johnson and Musk believe that, pretty soon, we'll have to join them. That is, a number of futurists and technologists surmise that humanity's survival depends on the successful fusion of human brains and machine "brains." CEO of the neuro-startup Kernel, Johnson hopes to develop brain chips that will one day boost human thinking capacity.

For this venture, Johnson recruited neuroscientist Theodore Berger (no known relation to Hans). For decades, Berger has worked on the development of implantable chips that connect to neurons in the (rat) brain, and that act like real (rat) cells.[37] Prior to joining Kernel, Berger focused on chips that interact with memory, with an eye towards developing therapies for individuals with Alzheimer's disease or other forms of dementia; and, in the immediate, Kernel remains devoted to the treatment of neurological disease. However, Johnson ultimately hopes to enhance perfectly functional brains—to supplement evolutionary adaptations with silicon upgrades. On its surface, this proposal has its appeal. Imagine, for example, a memory that does not fail. Imagine a brain that answers questions with the accuracy of a search engine, or an internal calculator that never forgets to carry the 1.

As companies like Intel continue to look to the brain for inspiration, humans may stare at computers with reciprocal awe. The yearning to be more like machines encompasses not just jealously of their infallible memories and impressive math skills, but also of their seeming ambivalence towards their own bodies. Regularly, our phones "die"—either by drowning, blunt force, or plain old age. Yet, a phone's memories do not wither along with its hardware. One purchases a new phone and, by reaching into the cloud, a technician imbues the new rectangle with the soul of its predecessor.

The ease of data transferability implies that the essence of a computer mind lies not in its hardware but in its command of abstract *information*. Put another way: process takes precedence over substance. If one considers the cortex to be a kind of computer, one might come to the conclusion that, in brains too, *matter* isn't all that important. This line of argument often becomes explicit in futurist literature, particularly the writing of Ray Kurzweil, who holds that that biological matter, like a dying phone, serves merely as a disposable vessel for all-important patterns. He writes:

> Although I have been called a materialist, I regard myself a "patternist." It's through the emergent powers of the pattern that we transcend. Since the material stuff of which we are made turns over quickly, it is the transcendent power of our patterns that persists.[38]

Nick Bostrom frames a version of this view as "The Assumption of Substrate Independence." He writes:

> Provided a system implements the right sort of computational structures and processes, it can be associated with conscious experiences. It is not an essential property of consciousness that it is implemented on carbon-based biological

> neural networks inside a cranium: silicon-based processors inside a computer could in principle do the trick too.[39]

Bostrom and Kurzweil argue that is not our matter, but our "computational processes" that give rise to intelligence and phenomenal experience. They oppose the notion that animal *stoff* uniquely possesses consciousness-making powers, thus challenging any thinkers holding on to some sort of biological exceptionalism. Yet, this stance breeds its own sort of exceptionalism—a kind of vitalism, even—that replaces magical matter with magical patterns.

I admit that a discussion of computer intelligence somewhat bends the mandate of this investigation: the patterns that fascinate Kurzweil and his ilk tend to take discrete, rather than wavy form. And indeed, the present technological mood overwhelmingly favors digital dialogue.[40] Amidst this digital turn, however, waves do not fade entirely from relevance. Though informational languages adhere to a discrete aesthetic, the invisible transfer of data remains quite oscillatory. After all, Wi-Fi ultimately amounts to glorified radio waves.

Patternist models rightly belong to the trajectory of brain waves in spirit, if not in style. For the history of brain waves illuminates the type of thinking that becomes possible when one forgoes substance for process. Like brain wave theorists of the past, patternists use the language of technology to promote beliefs in mind beyond body, and perhaps life after death.

Though the general population may not explicitly subscribe to a patternist system of beliefs, mundane engagement with digital technology subtly indoctrinates users in "the transcendent power of our patterns." Hours spent on computers and online accustom users to a reality in which intelligence is duplicable and mobile. Our digital ideas manifest in countless devices simultaneously; they know no single material form and, in fact, don't *seem* to run on matter at all. Online, we become abstract data—patterns and processes that transcend any particular piece of hardware.

Yet, processes—whether patterns, waves, or information—must instantiate in *something.* In *How We Became Posthuman* Katherine Hayles offers an insightful analysis of the present prioritization of process over substance, which she frames as a (false) tension between information and embodiment, or "pattern and presence." She begins her analysis with the question, "When and where did information get constructed as a disembodied medium?" and locates an answer in the 1940s.[41]

Computing, cybernetics, and information theory, Hayles contends, "made information seem more important than materiality"—a trend that persists via computational practices and theories today.[42] Looking towards the future, Hayles makes a case for a more complementary view of pattern and presence. She writes:

> Information, like humanity, cannot exist apart from the embodiment that brings it into being as a material entity in the world... As we rush to explore the new vistas that cyberspace has made available for colonization, let us remember the fragility of a material world that cannot be replaced.[43]

On the above, I agree with Hayles. However, by framing the pattern-presence tension as a product of the computer age, Hayles misses a longer history of dematerializing dreams—a history that (I hope) the preceding pages have elucidated. The desire to abandon one's corporeal form, or to evade mortality, is not a uniquely posthuman longing, but rather one of the *most* human desires imaginable. It presents perennially in religious thought; and, as secular authority comes to complement and contradict religion, this desire manifests in materialist theories—even if those theories elide matter proper. Dreams of disembodiment, in fact, thrive where materiality is uncertain or elusive—in ether, in electricity, in information, data, and waves.

On Gimmicks and Gullibility

In 1869 brain waves did not require a theory. Berger wouldn't observe neural oscillations for another half a century; thus, at the time that Knowles put pen to paper, there existed no wavy explicandum in want of explanation. Indeed, "Brain-Waves—A Theory," does not amount to a theory of why the brain waves; rather, the piece *invents* brain waves to explain a different set of phenomena.[44] Namely, Knowles proposes his vibrations to make sense of the seemingly miraculous talents "of mesmerists, spiritualists, electro-biologists, and clairvoyants."[45] Based on a number of anecdotes, Knowles came to believe that at least some of these characters sold more than parlor tricks. Thus, he posits brain waves as "a common action of force" in order to refashion these odd events as natural occurrences.

Put another way: Knowles collected a set of data (stories about uncanny mental experiences) and theorized a physical mechanism that would account for this trend. In this respect, his process is almost scientific. Yet, subjective reports of telepathic sympathy are not exactly reliable data points. As such, Knowles's argument likely failed to convince thinkers skeptical of ghost stories and thought transference. Still, to the individuals providing exceptional anecdotes—to those already inclined towards believing in extrasensory events—brain waves offered a conceptually satisfying theory, or at least a new vocabulary.

Today, satisfying brain waves theories are in short supply: the physiological function of neural oscillations remains unclear. Researchers hoping to show that brain waves do *something* tend to point to the incredible synchrony revealed by EEG. Recall that noninvasive electrodes cannot detect a single neuron firing; they hear only the coordinated firings of large neuronal populations. Some scientists cite this apparent coordination as a mechanism for crucial cognitive functions. Perhaps neural synchronization plays a role in sensory processing; perhaps it facilitates memory consolidation; perhaps it underlies the whole of consciousness.[46]

Why does the brain wave? Really, it depends on whom you ask, which techniques they use, and a touch of personal opinion. A 2010 review in *Frontiers in Neuroscience* summarizes: "Whether neural rhythms contribute to normal function, are merely epiphenomena, or even interfere with physiological processing are topics of vigorous debate."[47] Still, a lack of clarity as to the physiological role of brain waves only strengthens their cultural role—namely, to enable belief in phenomena that live on the outskirts of recognized fact. Just scientific enough to sound legitimate, and just vague enough to evade excessive scrutiny, brain waves volunteer as a mechanism of action that validates fantasies, from the trivial to the transcendental.

Today's brain waves, like those of Knowles, lend credence to otherwise questionable claims. And, increasingly, they help to sell not just peculiar ideas, but also peculiar products. Consider, for example, an innovation called Braintronics®. The website advertising this item recites classic refrains about brain rhythms, explaining, "There are four brain wavelengths – Beta, Alpha, Theta and Delta – each corresponding to a state of consciousness. The best known are Alpha waves, which emerge during conscious relaxation, or when you are deeply calm without sleeping."[48] Comparable verbiage appears on a slew of brain wave-related websites, indicating the endurance of views about famous neural frequencies. Alpha's link to "conscious relaxation," for example, reiterates its 1970s association with "attentive relaxation."[49]

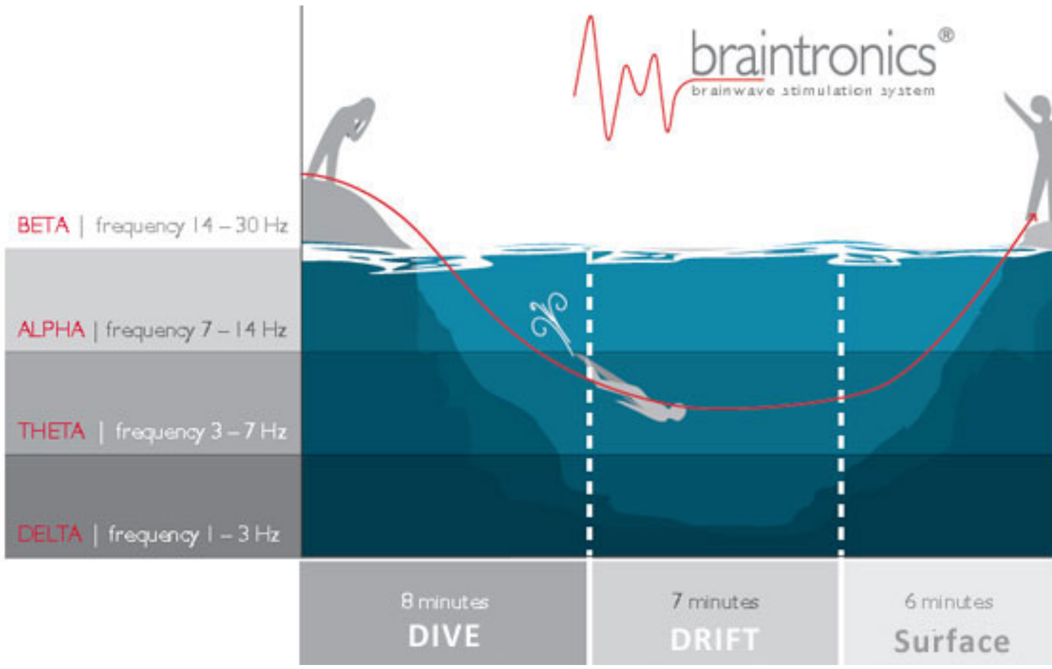

Figure 21. "21 Minutes Timeout for Body & Soul." Promotional diagram from Braintronics, which offers a particularly aquatic vision of "brainwave stimulation." Reprinted from "The Alphasonic Massage Chair," Elite Massage Chairs, accessed February 2, 2018, https://www.elitemassagechairs.com/massage-chairs/elite-alphasonic/.

Yet, Braintronics is not a biofeedback firm, *per se*; and is not a cutting edge VR experience in the vein of Neurable or LooxidLabs. Rather, Braintronics is essentially a line of La-Z-Boys—very expensive ($2,000-$5,000), technologically extravagant La-Z-Boys. Their manufacturer, Elite Massage Chairs, claims that the recliners synchronize audible tones and massage pulses to induce waves of relaxation in the brain. Elite's website states: "The brain responds to wavelength stimulus with the so called 'frequency following response,' in which the brain subconsciously aligns its own prevailing frequency to the frequency supplied by the outside source."[50]

The Elite website does not offer data to support its promise of "extremely deep relaxation." It does, however, allude to *entrainment*—a genuine biological phenomenon in which exposure to rhythmic sensory stimuli induces matching brain frequencies. Research on entrainment dates back to Grey Walter's flicker experiments, which indicated that a strobe light blinking at just the right pace can prompt the brain to wave in time. Walter observed that inducing alpha in this manner yields noticeable, and odd, psychological experiences.[51] Recent research confirms that carefully timed visual or auditory stimulation can, indeed, alter neural rhythms. Newer studies also suggest that entrainment may play a role in language processing and in the modulation of attention and perception.[52] Still, researchers have yet to determine whether exposure to rhythmic stimulation can significantly alter one's emotional or cognitive state.

Neural entrainment, like Knowlesian brain waves, surfaces as an explanation for a range of special subjective experiences. For example, according to some researchers, entrainment accounts for emotional responses to music.[53] No, one doesn't need scientific evidence to assert that a given melody provokes warm, fuzzy feelings. However, through such scientization, music appreciation graduates to a form of therapy.[54] A person inclined to believe that an hour of Hall & Oates lifts her spirits can thus reframe a pastime as a medical intervention, citing brain wave entrainment as the underlying mechanism of improved mental health.

Though some of the literature on music therapy is compelling, many proponents of entrainment use less than empirical methods. A collection of amateur musicians and sound technicians now market their work as self-improvement products that restore vitality by inducing a beat-based trance—a sort of millennial mesmerism.[55] And just like

Victorian mesmerists touted the science of their day (magnetism, ether) to validate their rituals, entrainment peddlers use the charisma of neuroscience to market their work.

Of course, these modern-day mesmerists do not lay hands on their subjects, but instead, exert their healing powers over the internet. Streaming services and websites host audio recordings that, supposedly, synchronize brain waves to the rhythms of trippy tracks. Inclusive of binaural beats and isochronic tones, this sound genre has a strong presence on YouTube.[56] The channel "Brainwave Power Music," for example, currently has over 370,000 subscribers, and links to audio files that supposedly prime the brain for a number of activities, ranging from "Mandala Yoga" to "Erotic Lucid Dreaming."[57] Here, brain wave discourse meets other motifs of pop-neuroscience: the entrainment track, "Boost Your Serotonin, Dopamine & Endorphin Release," has over four million views.[58]

Online, one can also read claims that brain wave entrainment will "Boost Your Extra-Sensory Abilities" and "Develop your Psychic Abilities."[59] Like psychical researchers in the nineteenth century, these niche forums use waves to situate ESP within the realm of the science. The site IsochronicTones.com, for example, states: "Just as our eyes can perceive light waves of certain frequencies, and our ears sound waves, extra sensory perceptual abilities involve tuning into other forms of information that are also surrounding us in vibrational form."[60]

Though an unsupported reference to waves does not instantly transform a claim from bogus to brilliant, this breed of "science" serves as a makeshift junction that fastens the far-fetched to the factual. By positing brain wave entrainment, one may indulge in an extrasensory fantasy while maintaining an identity as a logical, empirically-minded thinker. Like other forms of brain-wavy hand-waving, online entrainment testimonials will not convert the seasoned skeptic; however, such forums offer assurance to extant believers. The sensitive spirit convinced that his mind perceives the whims of others may use invisible undulations to make sense of his "powers." And the customer who needs a way to justify a $5,000 chair may look to brain waves to validate her purchase as one that reduces anxiety via neural synchrony. In such instances, brain waves proper do not represent the primary phenomenon fighting for corroboration. Rather, the "science" of brain waves enables belief in something more.

Brain wave discourse allows subscribers to feel as though they understand something important—and enchanting—about the nature of the world. An atmosphere filled with common air holds no secrets, and performs no miracles. Filled with ether, however, the atmosphere seems to sustain amazing, but natural, forces. Likewise, a brain that waves has powers beyond a cortex that merely trades chemicals; it becomes susceptible to entrainment, capable of ESP, and embedded in the IoT. A brain that waves is more than a brain; it is a participant in an exciting, oscillating universe.

Conclusions & Confusions

> Do not go gentle into that good night,
> Old age should burn and rave at close of day;
> Rage, rage against the dying of the light.
>
> Though wise men at their end know dark is right,
> Because their words had forked no lightning they
> Do not go gentle into that good night.
>
> —Dylan Thomas, "Do Not Go Gentle into That Good Night"[61]

For all its kookiness, Philip Rhoades's letter to Elon Musk poignantly encapsulates both the curses and cures summoned by technological revolution. As the earth faces "large-scale ecological collapses," Rhoades does not blame technology, but instead looks to it for individual salvation: "I need to become a virtual person," he pleads.

Belief in mind uploading is, of course, far from universal. Yet, virtual people come in different shades and degrees. As work and play migrate to online spaces, embodied action holds less prominence in daily life. *Lazy* does not adequately describe the present distaste for physical labor. Consider the individual who emails a colleague seated ten feet away; hours later that same individual may run five miles on a treadmill. For, a scheduled gym jaunt restricts embodied exertion to a particular time-place—an exercise in muscular upkeep that isolates physical action from mental action, thereby reinforcing an imagined distinction between these realms. Yes, laziness partially accounts for our reluctance to move, but it does not capture the phenomenon in full. This reluctance, I propose, derives not simply from an aversion to using our bodies, but from a deeper uneasiness with the notion that we *have* bodies—that we *are* bodies.

As engagement with organized religion declines (at least in some countries), individuals anxious about corporeal transience may develop new ways to ameliorate this distress.[62] A narcissistic drive towards self-preservation may prompt the pursuit of diets, workouts, self-quantification, and other rituals that sacralize the body. Alternatively and paradoxically, corporeal anxiety may prompt total *neglect* of bodies—departure from physical space to cyberspace. Online worlds increasingly take precedence over the "real" world. Even as we walk down the street, we direct our gaze to screens—physically on our feet, mentally online.

The urge to disappear into digital environments at first appears to be a longing unique to the age of smart phones. Yet, the dissociation of electrical messaging and embodied labor, like the dissociation of the brain and its waves, echoes age-old dualisms: mind and body, body and soul. Just as current devices build on the accomplishments of inventors long dead, so too do modern dreams reiterate and elaborate upon those concocted by past generations.

Nineteenth century science yielded both tangible technologies and intangible reveries: telegraphs and telepathy, physical and psychical research. During this era, a combination of spiritual longing, technological progress, and etheric science collided to form Knowles's theory of brain waves. Accordingly, spirituality and technoscience mutually contoured use of this term throughout its history. Sixty years after Knowles introduced brain waves, Hans Berger pointed to an undulating artifact that inherited this name. The contributions of these two men may seem to belong to distinct domains—fantasy and reality. However, as we have seen, the line between these domains often fades to the point of undetectability.

Many of today's emerging neurotechnologies build on Berger's work. Though they use ever-smaller hardware and ever-more-complex software, these gadgets ultimately consist of electrodes that detect neural dynamics. And through these shiny new tools, the history of brain waves manifests. The genius of Grey Walter now vibrates out of an entrainment chair. William Dement's research on REM features in Neuroon Open—"The Smartest Sleep Tracker."[63] Muse and other "EEG" manufacturers suggest that neurofeedback holds the key to mindfulness, thus carrying Kamiya's torch. Yet, the most prized, most *futuristic*, brain wave toys harken back to the term's oldest usage. BCIs venture to detect the intent of the mind, without the invocation of words or bodies; and if we believe Musk, this line of technology will eventually enable "consensual telepathy." In this sense, Knowles's invention is as much alive as that of Berger.

Knowles's contribution persists not just in telepathic fantasies, but in any of the various scientific and spiritual practices that borrow the term "brain waves." Lord Tennyson was prescient when he remarked that Knowles had "made a good word in 'brain waves,' and a word which would live."[64] Often, but certainly not always, journalists discussing new neurotechnology deploy the language of waves. For example, describing the Building 8 project, *Bloomberg* announced: "Facebook Envisions Using Brain Waves to Type Words."[65] And covering the latest in braintertainment, *TechCrunch* asserted: "Looxid Labs is combining brain waves and VR to build an analytics super engine."[66] Elsewhere, however, the promise of neural transcendence is conveyed in terms more specific to the digital age—in the language of programs, data, or mental Wi-Fi.

Hardly a departure from the topic at hand, these digital discourses in fact demonstrate the longevity of yearnings satisfied by brain waves. For what I have been driving at in this analysis is more than the persistence of a single, perhaps silly, phrase. The history of brain waves, I hope, both elucidates use of the term proper and, more broadly, demonstrates the ways in which spiritual dreams sometimes arrive disguised as scientific fact. Beyond neural oscillations, modern technoscience presents an abundance of frameworks through which to express such dreams. VR, WBE, and patternism all speak to a desire that some immaterial aspect of the self transcends the body. Indeed, if one pushes the forefront of digital technology just slightly, a reality in which minds migrate via data becomes thinkable.

Since Knowles's day, electrical technologies have shaped fantastic visions of how the mind might escape the skull. Simultaneously, these tools have yielded an actual reduction in the embodied action required for communication. The telegraph allowed humans to retreat from the land into their homes, moving messages via wires, rather bodies. The following century, bodies retreated yet further, becoming sedentary as pupils followed movement on television screens and then on computer monitors. Now, pulling the sheets over our eyes, we lie in bed with smart phones and barely move a muscle, our exertion restricted to a swipe and a tap. And in case swiping and tapping proves too burdensome, bold technologists maintain that the next step in efficient communication is to transmit messages directly from the brain. The ability to engage with digital environments using thought alone would finally offer an experience of virtual transcendence—an abandonment of both mushy bodies and polluted environs.

As the earth evidences signs of illness, it is only natural to seek a way out. So we look to a space ostensibly undamaged by hurricanes, drought, and demagogues—a virtual space in which bodies have extra lives and worlds are mere levels through which to pass. Yet, indulging in fictional worlds and imagined futures can promote neglect of the present circumstances. And the pursuit of technological fantasies holds real, material repercussions. After all, the nineteenth century annihilated space in more ways than one. In addition to producing rapid message transmission, the era introduced an unprecedented assault on the earth's resources. Footprints on soil yielded to a growing "footprint" of carbon: the former a palpable yet ephemeral imprint on reality, the latter conceptually abstract yet real and lasting in consequence.

Belief in electrical technology as the planet's savior is akin to the thirst of an alcoholic who drinks to blunt the aches of her inflamed pancreas. The problem and the problem and the solution cannot be one and the same. Digital environments, like neural oscillations, require a material substrate. The electricity that fuels our devices is entangled with the rest of the earth; and the action potentials that appear as immaterial waves on a graph represent real, physiological processes in the brain—processes that are made of *stoff.* The fantasy of brain waves fulfills a longing for message without medium, mind without matter, and transmission without time. In reality, however, neural oscillations cannot exist independent of neural tissue: brain waves emerge from fallible, mortal mush.

The brain's electrical dynamics *do* betray information useful to understanding the organ; and, connected to the appropriate machinery, these dynamics *do* yield wave-shaped scribbles. Brain waves are not entirely fiction. Still, we should consider when and why such artifacts of technoscience attract our attention—and from what they divert our attention.

That the mind should perish with the brain is a frightening proposition. Belief in salvation via science thus becomes a useful tool of self-preservation—a way to guard the mind from the psychological damage that sometimes accompanies contemplation of mortality. In this respect, humans have developed thick and resilient proverbial skulls—self-protective convictions that prevent existential crises from burrowing too deeply into our brains. And these skulls, like human crania, are indeed remarkably durable.

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> Binaural beats:
>
> In 1839, Heinrich Wilhelm Dove, found that when tones are played in each ear but separated very slightly in frequency, a single tone is made apparent to the listener depending on the difference between the two. For example, if a 300Hz tone is played in one ear and a 310Hz tone is played in the other through headphones, a "beat" frequency of 10Hz is heard to be present. This tone became known as a binaural beat and is perceived by the listener as occurring totally naturally, as if without hearing the tones playing separately in each ear. For this effect to be present, the individual tones should be below 1000Hz and the separation between the two individual tones played to each ear should be no greater than 30 Hz.
>
> If a wider band is applied than the tones become distinct and separate. Binaural beats are formed internally by the neural output from the ears. Created inside the olivary body within the brain, it is an attempt to locate a sound source based on phase.
>
> Isochronic tone:
>
> An isochronic tone can be defined as evenly spaced beats of a single tone which are repeated in rapid succession. They are sharp tones that quickly rise to full amplitude and fall away to nothing. This effect is again perceived most strongly in headphones. All these tones can be embedded in music or left as they are for the listener, though this may be unpleasant, particularly in the case of isochronic tones.

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