12 The CEMI Field Theory: Seven Clues to the Nature of Consciousness

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Summary. In this chapter I examine seven clues to the nature of consciousness and explore what they reveal about the underlying physical substrate of consciousness. The consciousness clues are: it impacts upon the world; it is a property of living brains but no other structure; brain activity may be conscious or unconscious; the conscious mind appears to be serial; learning requires consciousness but recall doesn't; conscious information is bound; and consciousness correlates with synchronous firing of neurons. I discuss field theories of consciousness and introduce the conscious electromagnetic field (CEMI) theory that suggests that consciousness is a product of the brain's electromagnetic field. I show that the CEMI field theory successfully accounts for each of the seven clues to the nature of consciousness. Finally, I show that although current quantum mechanical theories of consciousness are also field theories, they are physical untenable and should be discarded.

12.1 Why Do we Need a Theory of Consciousness?

A theory of consciousness is only necessary if there is something that needs to be explained. With several journals, hundreds of books and ruminations of thousands of philosophers cogitating over various theories of consciousness, it may seem that this question must obviously be answered in the affirmative. I agree. But it is instructive to explore exactly why we need a theory, because the answer isn't as obvious as we may suppose.

Firstly, if what we are discussing is a scientific theory then such a theory is only of value if it explains facts in the world. This immediately drops out of consideration any steam whistle "theory" where it is supposed that the consciousness is merely an epiphenomenon. I don't for one moment believe that this is the case but there is a considerable body of opinion that asserts that consciousness has no impact on the way our brain works. If this is the case then consciousness makes no difference to the world; it generates no facts. Science can only deal with facts – data points, observations, phenomena. Scientific theories are a means to make sense of those facts in order to make predictions. Without the facts, there can't be any theories – at least none that are scientific. If consciousness is an epiphenomenon then, as scientists, we must turn aside and leave the topic to the philosophers and theologians to make sense of. It is not a subject for scientific theories.

But consciousness does of course generate phenomena. One of the most obvious is this chapter, and indeed this book, and all the other books and articles that have ever been written on the subject. If consciousness is an epiphenomenon locked inside our brain then why does our body write endless treatises on it? How does it even know it's there? The train isn't aware of the steam whistle; it has no impact on its function. But consciousness has had a major impact on the lives of philosophers, scientists and theologians who have studied the subject. It cannot be a steam whistle.

The approach in this chapter will be to examine seven clues to nature of consciousness and discuss how the conscious electromagnetic field theory (CEMI field theory) makes sense of those clues. Space constraints do not permit me to examine the other theories of consciousness against these clues, but it would be an interesting exercise for the reader to attempt this, at least for their favorite theory. The first clue, is what I have already discussed, the fact that consciousness has an effect on the world. Any theory must include a physical mechanism that allows our conscious mind to interact with the matter of our brain.

Clue 1: *Consciousness generates phenomena in the world. It is a cause of effects.*

The next clue to the nature of consciousness is the fact that it is associated with living flesh in particular configurations that we call brains. The type of brain that most clearly exhibits the phenomenon is a subtype of the basic design, called the human brain. We can (for the reasons discussed above) be pretty sure that our own brain and other people's brains are conscious (ignoring, because it is too unspeakably dull to even discuss, the solipsism argument) and most would make a case for the brains of higher animals, such as chimps, sharing that property, at least in some form. But not all living flesh is conscious. Our livers aren't conscious. Neither is our colon nor our kidneys. Only brains are conscious. So it must be something about the structure of brains that generates the phenomenon of consciousness. This fact requires an explanation.

Clue 2: *Consciousness is a property of living (human) brains. As far as we know, it is not a property of any other structure.*

Brains are of course involved in many activities but they share a common theme: information processing. But consciousness cannot simply be a property of information-processing systems. For a start, the brain isn't the only information processing system in the body. It's not even the most complex. With 10^{12} cells (compared to 10^{11} neurons in the brain), the immune system processes a vast amount of information concerning the interaction between the body and its environment. Like the brain, the components of the immune system (lymphocytes, macrophages, dendritic cells, etc.) communicate via a complex network of chemical signaling pathways. But the system completely lacks awareness.

And of course, artificial information processing systems, thus far at least, are not conscious. Despite the heady predictions of artificial intelligence (AI) pioneers in the 1960s and 1970s, no computer has ever shown even the faintest glimmerings of either general intelligence or consciousness. Even Marvin Minsky, champion of AI and cofounder of MIT's Artificial Intelligence Laboratories recently complained, "There is no computer that has common sense. We're only getting the kind of things that are capable of making an airline reservation. No computer can look around a room and tell you about it." (Interview with WIRED magazine, August 2003 [45].) And although the computing power of any single computer is puny compared to the human mind, the internet links together millions of computers (volume is set to exceed 15 terabytes per second by 2008) yet no spark of awareness has ever emerged from all those computations. Any theory of consciousness must explain why, thus far at least, only the wet systems that process information through neurons possess awareness.

But even living human brains aren't always aware. Our brain remains very active in the state we call unconsciousness, and even when we are conscious, we are only aware of a very small trickle out of the vast quantity of information flowing through our brain. Activities (like driving a car) may be performed on "automatic pilot" while our conscious mind is engaged elsewhere. Any theory of consciousness that fails to account for the difference between conscious and unconscious brain activity is clearly incomplete.

Clue 3: *Brain activity may be conscious or unconscious.*

It is useful to compare lists of those brain activities that are always unconscious (obligate unconscious), brain activities that may or may not be performed consciously (facultative conscious) and those activities that are always accompanied by awareness (obligate conscious, Table 12.1). Examination of the list highlights several interesting features. Firstly, there is clearly a tendency for the more primitive activities – those we share with lower animals and even plants – to be performed unconsciously and the more specialist activity – the strictly human actions, like use of language – to be accompanied by awareness. Why should this be? A straightforward explanation based on complexity – the more complex the information processing going on in the brain the more likely it is to be conscious – doesn't work. Imagine driving, alone in your car, along a familiar route. Your conscious brain may be reviewing the day's activities, planning an evening's entertainment or considering the latest football scores. You are unlikely to be aware of the numerous adjustments to the car's direction and velocity that your body will be making to maintain the vehicle on the road and prevent collision. These operations must require the information-processing capabilities of millions of neurons in the brain's visual system and motor centers, but you will be aware of none of

Table 12.1. Brain activity

Brain activity		
Obligate unconscious	*Facultative unconscious*	*Obligate conscious*
Endocrine control	Breathing	Reading
Temperature homeostasis	Maintaining balance during locomotion	Writing
		Creative activity
	Learned activities, such as driving or riding a bicycle	Learning
		Conversing
	Eating	Arithmetic
	Recalling information	Memorizing information

it. And then you feel a tap on your shoulder. You are not alone! The information processing associated with the sensory perception of that tap is likely to be vastly simpler than those involved with your driving manipulations but you will be acutely aware of one and oblivious of the other. Complexity per se cannot account for why we are aware of some, but not all brain activity.

So, if it isn't complexity, how else do our conscious and unconscious minds differ? Does the list provide us with further clues? I believe it does. Firstly, there is a very clear and stark difference between conscious and unconscious brain activity. Our brain is clearly able to perform several operations in parallel, if they are all unconscious. Nobody has trouble riding a bike whilst whistling a familiar tune. We can all drive a car whilst chewing gum. But try reading a book whilst writing a letter; or add up two six figure numbers whilst chatting to a friend. These operations must be performed sequentially. Any theory of consciousness must explain why our unconscious mind appears to be massively parallel but our conscious mind is infuriatingly serial. The question, as Bernard J. Baars puts it [4], is how does "a serial, integrated and very limited stream of consciousness emerge from a nervous system that is mostly unconscious, distributed, parallel and of enormous capacity".

Clue 4. *The unconscious mind can perform parallel computations but consciousness appears to be serial.*

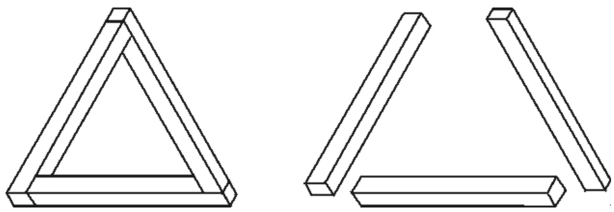
It is also interesting to consider why it is that the *higher* level activities that require consciousness, reading, writing (language use generally), arithmetic, etc., are all restricted to humans. The simplest explanation is that these capabilities evolved fairly recently and that they *require* the unique computation capabilities of the conscious mind: they simply can't be done with the unconscious mind, despite it having the same neuronal resources at its disposal. Any theory of consciousness must clearly delineate the operational difference between these systems.

It is also intriguing that the obligate conscious activities include memorizing information and learning, but recall of memorized information (such as the motor actions required to perform a learnt task) does not require consciousness. When learning a task such as playing the piano, one's first plodding fingering of the keys is painfully conscious but, once learnt, a practised pianist can effortlessly play a familiar tune whilst singing the accompanying song. Indeed, learning a skill seems largely to be about driving its accomplishment into our unconscious mind. Another aspect of this dualism is the fact that our visual system is constantly analyzing the changing scenery as we go through our day, but we only recall those items that we thought about. The memory of everything else is lost. Any theory should explain why our conscious mind appears to be the conduit for delivering information to our memory but is not required for its retrieval.

Clue 5: *Learning and memory require consciousness but recall may be unconscious.*

The next clue to the nature of consciousness is usually known as the binding problem and is perhaps the most problematic, because it relies on introspection. Look at a tree. How many leaves do you seen? Tens, hundreds, thousands? The problem for science is that the information encoding all those leaves – their colour, texture, position in space – is being processed in quite distinct regions of your brain. There is of course no problem in accounting for the functionality of such a system. So long as the multiple independent pathways in the brain come together at some point to provoke an appropriate response, "this is a tree", then the system is functioning appropriately. A computer that similar dissects the complex scene and processes that information – perhaps in a set of quite independent but parallel processors – would generate the same response. But a computer would not be provoked into writing, "I think that I shall never see; a poem as lovely as a tree." (Joyce Kilmer). To understand such a line, you need to see the whole tree. And that is of course what we all report. We do not see individual leaves or scattered contours; we see the tree in all its leafy glory, as a single percept. Where does all the information come together? As Valerie Hardcastle (1994) put it [23], "given what we know about the segregated nature of the brain and the relative absence of multimodal association areas in the cortex, how [do] conscious percepts become unified into single perceptual units?".

It has of course been argued that the binding problem is a *pseudoproblem* since conceptual binding is part of the grand-illusion [5, 10]. According to the grand-illusion hypothesis, visual scenes (or any other bound aspect of consciousness) are actually as fragmented as the neuronal information within our brains but our minds somehow fool us into thinking the information is all stuck together. I fully accept that our visual experience is not as rich as we naively assume and the stream of consciousness may actually be closer to a dribble. However, despite this, binding remains a problem even within the grand-illusion hypothesis. "Change blindness", "inattentional blindness" and other cognitive effects indicate that our conscious mind can attend to only five or six objects within a visual scene but each attended object is a complex item whose informational content must be bound within consciousness. This can be illustrated by considering optical illusions, such as the familiar "impossible triangle".



The geometric inconsistencies of the object are a property of the percept corresponding to the whole object, not a collection of its parts. During the information processing performed first by the retina and then by neurons in the visual cortex, information corresponding to various properties of the object (in this case just lines and angles but normally including color, texture, shading, etc.) is stripped, separated, handled and processed by thousands of distinct neurons. However, the illusion only makes sense if this disparate information is somehow bound together again within our conscious minds to generate a unified percept of the triangle.

Clue 6: *Information that is encoded by widely distributed neurons in our brain is somehow bound together to form unified conscious percepts.*

There is of course no center of the brain where all this information is put together, but it is well established that there are a number of *correlates of consciousness* – dynamic activity that is usually associated with attention and awareness. The best studied of these is synchronous firing of neurons [8, 27, 11–15, 19]. For instance, Wolf Singer and colleagues at the Max Planck Institute for Brain Research in Frankfurt [27] demonstrated that neurons in the monkey brain that responded to two independent images of a bar on a screen fired *asynchronously* when the bars were moving in different directions but fired synchronously when the same bars moved together. It appeared that the monkeys registered each bar as a single pattern of neuronal firing but their *awareness* that the bars represent two aspects of the same object, was encoded by synchrony of firing. In another experiment that examined interocular rivalry, it was discovered that neurons that responded to the attended image fired in synchrony, whereas the same neurons fired randomly when awareness was lost [18]. In each of these experiments, awareness correlated, not with a pattern of neuronal firing, but with synchrony of firing. Singer, Eckhorn and others have suggested that these 40–80 Hz synchronous oscillations link distant neurons involved in registering different aspects (color, shape, movement, etc.) of the same visual perceptions and thereby *bind* together features of a sensory stimulus [12, 41, 42]. However, if synchronicity is involved in perceptual binding, it is unclear how the brain uses or even detects synchrony.

Clue 7: *Consciousness and awareness are associated not with neural firing per se but with neurons that fire in synchrony.*

12.2 Field Theories of Consciousness

The idea that our conscious minds are some kind of field goes back at least as far as the gestalt psychologists of the early twentieth century. Gestalt psychology emerged in opposition to the contemporary atomist movement, which claimed that perceptual experience is merely the sum of simple sensory inputs. The gestalt psychologists instead emphasized the holistic nature of perception that they claimed was more akin to fields, rather than particles. In this they were influenced by the ideas coming out of the newly emerging science of quantum mechanics (indeed, Wolfgang Köhler, one of the gestalt pioneers, studied with Max Planck, the founder of quantum mechanics). Fields share the holistic qualities of perceptual fields described by the gestalt psychologists but the Gestalt psychologists went on to propose that physical fields exist in the brain that are *isomorphic* to the objects they represented, in the sense that they had the same shape as the represented object. Palmer [36] generalizes this notion by distinguishing between intrinsic and extrinsic representation and claims that representation is intrinsic "whenever a representing relation has the same inherent constraints as its represented relation... [whereas] representation ... is extrinsic whenever the inherent structure of a representing relation is totally arbitrary and that of its represented relation is not." A model motorcar is thereby an intrinsic representation of an actual motorcar, whereas the word "motorcar" is an extrinsic representation of the same object.

It was the proposal that the brain contains real physical fields that correspond to perceived objects (as Kohler described it, that the brain acts as a "physical Gestalt") that led to the virtual abandonment of Gestalt psychology in the late 1950s. Modern neurobiology defined the neuron as the fundamental computational unit in the brain and there didn't appear to be any way of forming isomorphic gestalt fields out of static neurons. But although much of what the brain does can be understood in terms of standard neuronal theory, the peculiar features of consciousness led many to retain the concept of a field in order to account for these properties. Karl Popper [39] proposed that consciousness was a manifestation of some kind of overarching *force field* in the brain that could integrate the diverse information held in distributed neurons. The idea was further developed and extended by Lindahl and Århem [30] and by Libet [28, 29]. However, these authors considered that the conscious mind could not be a manifestation of any known form of a physical field and its nature remained mysterious.

Yet it has been known for more than a century that the brain generates its own electromagnetic (em) field, a fact that is widely utilized in brain scanning techniques such as EEG. In two papers published in 2002 I described the conscious electromagnetic field theory [35, 34], which was an extension of the CEMI field theory outlined in my book "Quantum Evolution" [33]. The theory has much in common with the electromagnetic field theory of consciousness proposed by Dr. Susan Pockett in her book "The Nature of Consciousness: A Hypothesis" [38]. The neurophysiologist E. Roy John has also recently published a theory of consciousness involving electromagnetic fields [26]. The key insight of these theories is the realization that, as well as generating chemical signals that are communicated via conventional synapses, neural firing also generates perturbations to the brain's electromagnetic field.

12.3 The Brain's Electromagnetic Field

At rest, the neuronal membrane forms a dipole in which the inside of the membrane is negatively (about –65 mV) charged in relation to the outside of the membrane. This charge difference is maintained by the action of ion pumps that pump cations (principally sodium and calcium) out of the neuron. Brain neurons are densely packed, with about 10^4 neurons/mm^2 so the fields of adjacent neurons will not be discrete but form a complex overlapping field made up of the superposition of the fields of millions of neurons in the vicinity. The electrical field at any point in the brain will be a superposition of the induced fields from all of the neurons in the vicinity and will depend on the geometry and the dielectric properties of neurons and tissue. The combined activity of all the neurons in the brain generates a complex electromagnetic field whose strength can be estimated from theoretical principles and measured during EEG or MEG, and is about 20–250 V/m [34].

When any neuron receives a signal from upstream neurons, synaptic transmitters stimulate ion pumps that cause the membrane to become more or less negatively polarized, depending on the type of signal received. If the membrane charge falls below about –40 mV then the neuron "fires" and a chain of depolarizations is triggered that travels along the neuron and stimulates release of neurotransmitters. Conventional neurobiology has focused on the chemical signal that is transmitted from one neuron to another. There is absolutely no doubt at all that most of the information processing performed by the brain is due to this type of signaling. However, the massive membrane depolarization will also generate an electromagnetic field perturbation that, traveling at the speed of light, will influence the probability of firing of adjacent neurons. Vigmond [44] modeled the electrical activity of pyramidal cells and demonstrated that neuron firing induced a peak of intracellular potential in receiver cells that ranged from a few microvolts to 0.8 mV, decaying with approximately the inverse of distance between the cells. For neurons that are arranged randomly, their induced fields will tend to sum to zero; but the laminar organization of structures such as the neocortex and hippocampus, with parallel arrays of neurons, will tend to amplify local fields. Using the model, a peak *intracellular voltage* of 2600 V/m (and thereby above the thermal noise level in the membrane) will be induced in receiving cells if they are located within a radius of 73–77 μm from the source cell [34]. Considering only those cells in the plane of the source cell embedded in the human cerebral cortex (about 10^4 neurons/mm^2), then approximately 200 neighboring cells will be within that field volume. The firing of a single neuron will thereby be capable of modulating the firing pattern of many neighboring neurons through field effects.

12.4 The Influence of the Brain's Electromagnetic Field on Neural Firing

The field across a neuronal membrane will inevitably be the product of the field generated by membrane dynamics (the ion pumps) but also the fields generated by the resting states and firing of all the other neurons in the vicinity. Mostly, the influence of the endogenous fields will be quite weak – maybe up to a millivolt of induced voltage across the neuronal membrane [34] – and so will only be capable of influencing the probability of firing if the neural membrane is already close to the critical firing potential. However, in a busy brain it is very likely that many neurons will be in that state, so the electromagnetic field that the brain's activity generates will inevitably influence neural dynamics. This will create a self-referring feedback loop that, I propose, is the physical substrate of consciousness.

Unfortunately investigating the role of the brain's endogenous electromagnetic field on information processing in the brain presents huge experimental challenges, as it is not possible to turn the electromagnetic influence off and on (nerve firing always generates electromagnetic field perturbations). But indirect evidence for the proposal that the brain's endogenous field plays a role may be gained from studies of the effect of external fields on neural activity. In humans, the strongest evidence for the sensitivity of the brain to relatively weak electromagnetic fields comes from the therapeutic use of transcranial magnetic stimulation (TMS). In TMS, a current passing through a coil placed on the scalp of subjects is used to generate a time-varying magnetic field that penetrates the skull and induces an electrical field in neuronal

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tissue. The precise mechanism by which TMS modulates brain activity is currently unclear but is generally assumed to be through electrical induction of local currents in brain tissue that modulate nerve firing patterns. TMS has been shown to generate a range of cognitive disturbances in subjects including: modification of reaction time, induction of phosphenes, suppression of visual perception, speech arrest, disturbances of eye movements and mood changes [21]. The field induced in cortical tissue by TMS cannot be measured directly but may be estimated from modeling studies. The evoked field depends critically on the instrumentation, particularly the coil geometry and strength and frequency of the stimulating magnetic field. In one study where stimulation utilized a set of four coils, the induced electrical field was estimated to be in the range of 20–150 V/m [16]. TMS voltages are thereby in the range of tens of volts per meter, values that are typical for the strength of the brain's endogenous electromagnetic field. Therefore, CE[41] since TMS induces modulations of the brain's electromagnetic field that affect brain function and behavior, it follows that the brain's endogenous field must similarly influence neuronal computation.

There is also very solid in vitro evidence for very weak em fields modulating neuronal function. Fields as weak as 10–20 V/m have been shown to modulate neuron-firing patterns of Purkinje and stellate cells in the isolated turtle cerebellum in vitro [9] or the guinea-pig hippocampus [25]. A molluscan neuron has even been shown to be capable of responding to earth-strength (about 45 μT) magnetic fields [31], associated with induced electrical fields of just 2.6×10^{-4} V/m.

12.5 The CEMI Field Theory

It is clear that very weak electromagnetic field fluctuations are capable of modulating neuron-firing patterns. These exogenous fields are weaker than the perturbations in the brain's endogenous electromagnetic field that are induced during normal neuronal activity. The conclusion is inescapable: the brain's endogenous electromagnetic field must influence neuronal information processing in the brain.

Information in neurons is therefore pooled, integrated and reflected back into neurons through the brain's electromagnetic field and its influence on neuron-firing patterns. This self-referral loop has physical and dynamic properties that precisely map with consciousness and are most parsimoniously accounted for if the brain's electromagnetic field is the physical substrate of consciousness. Conscious volition results from the influence of the brain's electromagnetic field on neurons that initiate motor actions. The conscious electromagnetic information (CEMI) field theory thereby proposes:

Digital information within neurons is pooled and integrated to form an electromagnetic information field. Consciousness is that component of the *brain's electromagnetic information field that is downloaded to motor neurons and is thereby capable of communicating its state to the outside world.*

The CEMI field theory [34, 35] suggests that processing information through the wave-mechanical dynamics of the CEMI field provided a significant advantage to our ancestors that was captured by natural selection to endow our minds with the capability to process information through fields. MacLennan [32] has proposed that the brain is capable of field computing (which has many of the attributes of quantum computing) that may perform some operations with greater efficiency, or with fewer resources, than can be achieved in a digital system. In a similar way, optical holograms can perform convolution, deconvolution and Fourier transforms, at the speed of light, acting on massively parallel data sets. Sending information through the electromagnetic field may similarly confer novel information processing capabilities on the human brain that have been captured by our conscious mind.

12.6 Why don't External Fields Influence our Minds?

The high conductivity of the cerebral fluid creates an effective "Faraday cage" that insulates the brain from most natural exogenous electric fields. A constant external electric field will thereby induce almost no field at all in the brain [2]. Alternating currents from technological devices (power lines, mobile phones, etc.) will generate an alternating induced field, but its magnitude will be very weak. For example, a 60 Hz electrical field of 1000 V/m (typical of a powerline) will generate a tissue field of only 4×10^{-5} V/m inside the head [2], clearly much weaker than either the endogenous electromagnetic field or the field due to thermal noise in cell membranes. Magnetic fields do penetrate tissue much more readily than electric fields but most naturally encountered magnetic fields, and also those experienced during nuclear magnetic resonance (NMR) scanning, are static (changing only the direction of moving charges) and are thereby unlikely to have physiological effects. Changing magnetic fields will, however, penetrate the skull and induce electric currents in the brain. However, there is abundant evidence (from, e. g., TMS studies as outlined above) that these do modify brain activity. Indeed, repetitive TMS is subject to strict safety guidelines to prevent inducing seizures in normal subjects through field effects. High-frequency electric fields generated by cellular (mobile) phones would be expected to penetrate the head more effectively (limited by the electromagnetic skin depth – the distance in which the field is attenuated by a factor of e^{-1} – which for the head is about one centimeter) but their high frequencies (in the MHz or GHz range) make them unlikely to interact with low-frequency brain waves.

Note, however, that although external fields are seldom able to influence nerve dynamics, this will not be true for endogenous fields. Indeed, the fact that EEG signals can be detected on the scalp indicates that endogenous electromagnetic fields do penetrate brain tissue. The reason for this is that the major source of EEG signals (and more generally, the brain's electromagnetic field) is not the firing of single neurons but assemblies of neurons firing synchronously (as discussed in my earlier paper). By firing in synchrony, neurons distribute and amplify field effects.

12.7 Does the CEMI Field Theory Account for the Seven Clues to the Nature of Consciousness?

Clue 1: *Consciousness generates phenomena in the world. It is a cause of effects.*

A distinctive feature of the CEMI field theory is the proposal that consciousness corresponds to only that component of the brain's electromagnetic field that impacts on motor activity. This does not imply that the brain's electromagnetic field acts directly on motor neurons (which may of course be located outside the brain) but only that electromagnetic field information is communicated to the outside world via motor neurons [35]. The site of action of the brain's electromagnetic field is most likely to be neurons in the cerebral cortex involved in initiating motor actions, such as the areas that control speech, or the areas involved in laying down memories that may later be reported via motor actions (such as speech). Indeed, there is a good deal of evidence [1, 37] that all verbal thought is accompanied by subvocalizations (i. e. motor cortex activity accompanied by appropriate but normally undetectable vocal tract activity). This informational download via the brain's electromagnetic field avoids the pitfalls of most other field theories of consciousness that either suffer the classic "mind–matter problem" (a nonphysical consciousness whose interaction with the matter of the brain is left unresolved) or leave consciousness as a *ghost in the machine* (somehow generated by the brain but with no impact on its workings).

We experience the influence of the CEMI field as *free-will*. This is why our willed actions feel so different from automatic actions: they are the effects of the CEMI field as cause. Therefore, although like modern cognitive theory the CEMI theory views conscious will as a deterministic influence on our actions, in contrast to most cognitive theories it does at least provide a physically active role for "will" in driving our conscious actions. In the CEMI field theory, we are not simply automatons that happen to be aware of our actions. Our awareness (the global CEMI field) plays a causal role in determining our conscious actions.

Clue 2: *Consciousness is a property of living (human) brains. As far as we know, it is not a property of any other structure.*

The only place in the known universe where electromagnetic fields occur that are capable of communicating self-generated irreducibly complex concepts like “self” (and thereby persuading an observer that they are indeed conscious) is in the human brain. Artificially generated electromagnetic fields, such as the electromagnetic fields that communicate radio and TV signals, are only capable of communicating the information encoded and transmitted within their fields. They have *nothing else to say.* To question whether they are either aware or conscious is meaningless.

Clue 3: *Brain activity may be conscious or unconscious.*

Neurons in a complex brain display a range of excitability and in the busy brain of our ancestral animals there would have been many neurons poised close to their threshold potential with voltage-gated ion channels sensitive to small changes in the surrounding electromagnetic field. No less than electrochemical interactions, those field interactions would have been subject to natural selection. Wherever field effects provided a selective advantage to the host, natural selection would have acted to enhance neuron sensitivity (e. g. by maintaining neurons close to firing potential, increasing myelination or orientating neurons in the field). Conversely, wherever field influences were detrimental to the host (e. g. providing an electromagnetic field “feedback” that interferred with informational processing), natural selection would have acted to decrease that sensitivity (e. g. by maintaining neurons at membrane voltages close to resting). Therefore, with just the information that the brain’s electromagnetic field influences informational processing (as I have shown it must) and thereby affects host survival, the theory of natural selection predicts that over millions of years a complex brain will evolve into an electromagnetic field-sensitive system and a parallel electromagnetic field-insensitive system. These systems correspond to our conscious and unconscious minds, respectively.

Clue 4: *The unconscious mind can perform parallel computations but consciousness can only do one thing at a time.*

Neuronal computation, like any neural network, is ideally suited to parallel computations. So our unconscious mind is capable of performing many tasks in parallel. However, if conscious actions involve the influence of an electromagnetic field – the CEMI field – on neural pathways, then this interference is entirely explicable. Unlike digital (neural) addition, summation of two fields is not a simple addition but generates a linear superposition that depends on the phase relationships between the individual waves involved. Interference is therefore inevitable for conscious multiple tasks that require the influence of the CEMI field. The field can only do one thing at a time.

Clue 5: *Learning and memory require consciousness but recall may be unconscious.*

The job of the brain is straightforward: to decide what the body should do next. Mostly in humans, and probably all the time for most animals, these decisions are made automatically by standard neural networks without influence of the CEMI field. However, occasionally the automatic pilot routines may come unstuck. You may be presented with a new or unfamiliar situation. It is at these times that your brain will be more likely to have lots of neurons whose membranes are poised close to the firing threshold: the undecided brain. These undecided neurons will be sensitive to the (relatively weak) influence of the brain's electromagnetic field. Your conscious mind will be required to make a decision and the undecided neurons can plug into the vast quantity of information stored in the CEMI field. This proposed role for the CEMI field in brain activity in modulating neural activity is similar to what William James envisaged more than a century ago (as quoted in [40]) "if consciousness can load the dice, can exert a constant pressure in the right direction, can feel what nerve processes are leading to the goal, can reinforce and strengthen these and at the same time inhibit those that threaten to lead astray, why, consciousness will be of invaluable service".

So the CEMI field – our conscious mind – will be pushing and pulling on neurons to shift the brain towards some desired activity; like learning to play the piano. The CEMI field will initially be required to provide that fine control of motor activity necessary to perform the novel actions. But, if the target neurons for electromagnetic augmentation are connected by Hebbian synapses then the influence of the brain's electromagnetic field will tend to become hard-wired into either increased (long-term potentiation, LTP) or decreased (long-term depression) neural connectivity. After repeated augmentation by the brain's electromagnetic field, conscious motor actions will become increasingly independent of electromagnetic field influences. The motor activity will be "learned" and may thereafter be performed unconsciously, without the electromagnetic influence on the neural networks involved. We will then be able to play without conscious input. Similarly, in the absence of any motor output, the CEMI field may be involved in strengthening synapses to "hard-wire" neurons and thereby lay down long-term memories.

Clue 6: *Information that is encoded by widely distributed neurons in our brain is somehow bound together to form unified conscious percepts.*

Information in the conscious brain is encoded in the firing rates of billions of neurons scattered across the entire surface of the cerebral cortex. However, that information will be reflected into the electromagnetic field that permeates the cortex. In contrast to the discrete and distributed information encoded in the neurons, the field-based information is always unified.

Fields unify information. That is what we mean by a field. The brain's electromagnetic field has the same level of unity as a single photon. From the reference frame of an outside observer, a field is a continuum of values (information) extended in space and time. However, from the reference frame of the field, there is no space nor time between any part of the field or any bit of its information. This can be appreciated by following Einstein in imagining hitching a ride on the back of a photon. Because photons travel at the speed of light and time slows down to stop at this speed, it takes no time at all for the photon to travel from its point of creation to its point of annihilation – it is everywhere at once. So all of the information contained in the field is everywhere at once, bound into a single dimensionless point. The CEMI field theory proposes that consciousness resides in that dimensionless point.

Clue 7: *Consciousness and awareness are associated not with neural firing per se but with neurons that fire in synchrony.*

The superposition principle states that the em field at any point is a superposition of the component fields in the vicinity of that point. Like all wave phenomena, field modulations due to nerve firing will demonstrate constructive or destructive interference depending on the relative phase of the component fields. Temporally random nerve firing will generally generate incoherent field modulations leading to destructive interference and zero net field. In contrast, synchronous nerve firing will phase-lock the field modulations to generate a coherent field of magnitude that is the vector sum (the geometric sum – taking into account the direction of the field) of its components. The CEMI field – our conscious mind – will thereby be dominated by neurons that fire in synchrony. Synchronous firing will be a correlate of consciousness.

So the CEMI field theory accounts perfectly for each of the features of consciousness highlighted in the above seven clues. A challenge to any other theorist would be to do the same for their favorite theory of consciousness.

12.8 A Last Word, Concerning Quantum Theories of Consciousness

The em fields are not of course the only kind of field. Any quantum system may be described by a field and there is a great deal of interest in the possibility of quantum matter fields in the brain. However, whereas there is no doubt that electromagnetic fields exist in the brain there is no evidence for large-scale quantum coherence of matter in the brain on the scale that is necessary for quantum consciousness. There are also very real theoretical problems with understanding how quantum coherence in microtubules could be maintained for biological time scales [43]. The difficulty in maintaining quantum coherence in order to perform quantum computing with just a few atoms maintained at a temperature close to absolute zero [17] is evidence for the implausibility of maintaining quantum coherence for physiologically relevant periods of time in a warm wet brain.

There are also many theoretical problems with quantum consciousness. Information in consciousness is undoubtedly complex and must be encoded by a physical informational substrate capable of encoding a complex message. Quantum consciousness theorists who propose that the physical substrate of consciousness is some kind of quantum state of matter, such as a Bose–Einstein condensate (BEC), often ignore this requirement. Even if it were physically feasible to maintain a BEC in a hot wet brain (which it isn't), such a state would be an unlikely substrate for consciousness because all the atoms in a BEC are in the same quantum state and thereby encode the same information. Quantum states are nearly always small and simple because as they get larger and more complex, it becomes harder to maintain all the information in a coherent state: the system decoheres. This is why quantum computation is so difficult (and why only very simple calculations have so far been performed with qubits).

A related problem is the fact that consciousness is continuous but temporally dynamic; so the contents of consciousness change on a time scale of milliseconds or less. The substrate of consciousness must therefore be similarly dynamic. However, dynamic quantum states of matter (such as the putative gigahertz oscillations of microtubule protein) decohere in nanoseconds or less. Quantum states of matter could therefore not remain coherent for long enough to encode the continuity of thought.

A further difficulty arises because consciousness exchanges information with the world. Whether this informational exchange is one way or in both directions depends on whether consciousness has a causal influence on the world. But this property is incompatible with large-scale coherence of matter as the substrate of consciousness, since information exchange of a quantum state with its environment is precisely what causes decoherence. It is simply not physically possible to maintain coherence within a large-scale quantum system if it is freely exchanging information with its environment.

Lastly, there is solid experimental evidence that appears to rule out large-scale quantum coherence mediated through microtubules, at least in the brain of mice. For quantum mechanics to account for binding, the microtubules must be entangled not only within single neurons but across the many millions of scattered neurons that encode conscious information. This is proposed to take place through "microtubule quantum states [that] link to those in other neurons and glia by tunneling through gap junctions (or quantum coherent photons traversing membranes)" [22]. However, a knock-out (KO) mouse has recently been generated that lacks the connexin-36 (Cx36) subunit of the principle gap junctions thought to be mediating neuronal electrotonic CE[42] coupling mammalian brains [7, 20]. As expected, the connexin-36 KO mouse

CE[42] Should 'electrotonic' read 'electronic'

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lacks gap junctions and therefore lacks many (if not all) of the proposed sites for the putative inter-neuron quantum tunneling. Yet, the KO mice "showed no obvious behavioral abnormalities" [20]. The findings indicate that, if gap junctions are the site for tunneling of microtubule quantum states, then the process appears to play no obvious neurophysiological role, at least in mice. And although the question of whether mice are conscious is obviously a matter of conjecture, it would seem unlikely that a neurophysiological role for microtubules in man (information processing) could be completely absent in mouse. The lack of an obvious behavioral phenotype of the Cx36 mice undermines a central claim of the microtubule quantum consciousness theory.

Interestingly, the Cx36 KO mice provide evidence that supports the CEMI field theory proposal that electromagnetic fields are the substrate for conscious binding. As already discussed, synchronous neuronal firing is a correlate of attention and awareness and fast transmission of signals through gap junctions has previously been proposed to mediate synchrony. However, high-frequency synchronous neuronal oscillations are still observed in the Cx36 KO mice [24], indicating that other mechanisms (such as electromagnetic fields) may be involved in maintaining synchrony and thereby potentially providing a substrate for conscious binding.

Although quantum theories of consciousness based on microtubule coherence are highly tenuous, the CEMI field theory does not exclude the possibility of direct quantum effects in the brain. In my book "Quantum Evolution" [33], I proposed that the most likely source of quantum effects in the brain would not be microtubules (which have no established role in information processing) but interactions between the brain's electromagnetic field and voltage-gated ion channels (with a clearly established role in information processing in the brain) in the neuronal membrane. Near to the neuronal cell body (where the decision to fire is made) the membrane potential is very close to threshold such that the opening or closing of just a few ion channels may be sufficient to trigger or inhibit firing. Opening of just a single ion channel in vitro has been shown to be capable of initiating an action potential [3]. The precise number of quanta of electromagnetic energy that must be absorbed from the surrounding field to open a single voltage-gated ion channel is currently unknown. The field has to push 7–12 charges of the channel molecule's sensor towards the open position, but it is likely that when the membrane potential is already close to the firing threshold, very little additional energy need be absorbed from the field. Absorption of a single photon is sufficient to initiate proton pumping by the bacteriorhodopsin proton pump. It is therefore likely that nerve firing may in some circumstances be triggered (or inhibited) by just a few quanta of energy and thereby be subject to quantum dynamics. It is interesting to speculate on whether such uncaused events play a role in human spontaneity or creativity. Neils Bohr, the founding father of quantum mechanics, considered (according to Bohm) that it is likely that "thought involves such small amounts of energy that quantum-theoretical limitations play an essential role in determining its character" [6]. It may be that to fully explain consciousness, we will have to bring quantum mechanics into our thinking. But what is needed is a quantum field theory for the brain's electromagnetic fields, rather than yet more fruitless speculations on quantum coherence within microtubules.

12.9 Conclusions and the Way Forward

The CEMI field theory provides an elegant solution to many of the most intractable problems of consciousness and places consciousness within a secure physical framework that is amenable to experimental testing. The proposed interaction between the CEMI field and neuronal pathways restores to the mind a measure of dualism, but it is a dualism rooted in the real physical distinction between matter and energy, rather than the metaphysical (Cartesian) distinction between matter and soul. Although in the CEMI field theory, free-will is deterministic, it does at least retain a crucial role for our conscious minds in directing purposeful actions. Consciousness is not a steam whistle. As a wave-mechanical driver of free-will, it may be the key evolutionary capability that was acquired by the human mind.

There is no such thing as a theory that cannot be tested. In my first CEMI field paper, I highlighted eight predictions that were consequent on the theory [34]. In my follow-up paper [35], I discussed the implications of the theory for artificial intelligence (AI) and the possibility of engineering consciousness into an artificial system. Crucial areas that need to be tackled are the development of a mathematical model to examine the interaction between neurons and the brain's electromagnetic field; analysis of the interaction between ion channels and the brain's em field at a quantum-field level; exploration of the role of fields in information processing performed by biological neurons; and exploration of the potential role of electromagnetic fields in AI. With appropriate support, these issues could all be tackled within the coming years. Hopefully we will soon discover whether our minds are really electric.

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