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Electromagnetic-Field Theories of Mind

Abstract: *Neuroscience investigates how neuronal processing circuits work, but it has problems explaining experiences this way. For example, it hasn't explained how colour and shape circuits bind together in visual processing, nor why colours and other qualia are experienced so differently yet processed by circuits so similarly, nor how to get from processing circuits to pictorial images spread across inner space. Some theorists turn from these circuits to their electromagnetic fields to deal with such difficulties concerning the mind's qualia, unity, privacy, and causality. They include Kohler, Libet, Popper, Lindahl, Arhem, Charman, Pockett, John, McFadden, Fingelkurts, Maxwell, and Jones. They're classifiable as computationalist, reductionist, dualist, realist, interactionist, epiphenomenalist, globalist, and localist. However, they've never been analysed together as a whole, which hinders evaluations of them. This article tries to rectify this. It concludes that while field theories face challenges, they aren't easily dismissed, for they draw on considerable evidence and may avoid serious problems in neuroscience concerning the mind's qualia, unity, causality, and ontology.*

1. Introduction

Electromagnetic-field theories of mind treat minds as identical to, or derivative of, the electromagnetic fields generated by neural currents. These fields have detailed spatio-temporal structures and they weaken

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rapidly with distance via Coulomb's law.[1] They resemble and correlate with minds in various ways. For example, sensory images arguably arise from discrete neurons in field-like ways as fast-changing, continuous wholes spread across space, as we'll see. These theories have existed for over seventy years, but they've proliferated only recently owing to growing recognition of their potentials for avoiding basic problems in neuroscience.

One aim of this article is to *explain and classify* the various field theories. As we'll repeatedly see, their differences involve how minds exist relative to fields, how fields unify minds, and how extensively fields and neurons interact (as well as lesser issues such as how fields create different types of experience). I've classified them in these terms in Table 1.

The other aim of this article is to *evaluate* field theories in terms of their ability to deal with neuroscience's basic problems, as well as their own potential problems (again see Table 1). Hopefully this humble advice will help field theorists and neuroscientists to better explain minds.

Minds are characterized by their intelligence and consciousness. Their intelligence consists of their problem-solving abilities. The real challenges come from consciousness — the mind's privately experienced inner life of perceptions, emotions, and thoughts. These experiences have conscious qualities (qualia) like pain or fear. Consciousness is private in that minds can't access each other's experiences. Consciousness also has unity, for example, the myriad shapes and colours in a visual image (and associated emotions and thoughts) are experienced as a unified whole. Consciousness also has causal characteristics, for it comes from brains and may affect brains.

The authors below repeatedly address these characteristics of minds — *qualia, unity, privacy*, and *causality*. Standard neuroscience explains them all in terms of how neuronal circuits and their computations work. But this raises serious problems. Field theories offer alternatives.

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[1] These fields are generated by neuronal ions. The electric force between ions is proportional to the product of their charges and inversely proportional to the square of their distance (Coulomb's law). As ions move, their currents create additional magnetic forces that are proportional to their charges and velocities, and are directed at right angles to the velocities. They're weaker than electric fields at atomic distances, but both weaken rapidly with distance. As we'll see, the brain's electromagnetic field has a detailed spatiotemporal structure that is measured by EEGs (electroencephalograms) which detect electric potentials in neural currents, and MEGs (magnetoencephalograms) which detect magnetic fields from these currents.

Field theorists address three main questions: 1. How do minds exist relative to fields?		
Dualist field theory: Minds are non-physical products or correlates of global electro-magnetic fields in brains.	**Examples**: Libet, Popper, Lindahl, Arhem, and perhaps Kohler.	**Evaluation**: This theory avoids neuroscience's problems in explaining the mind's unity and privacy. This unity is explained in terms of fields, and privacy is explained by placing minds outside physical, public space. But this theory is unclear about how non-physical causality works, how different qualia arise, how colours and shapes assemble into pictorial images, why only some parts of fields produce experiences, and why brains aren't telepathic given that fields pervade the world.
Reductionist field theory: Minds are reduced to certain spatio-temporal patterns in global electromagnetic fields and neuroelectrical activity.	**Examples**: Pockett, Fingelkurts, and perhaps Charman.	**Evaluation**: This theory avoids neuroscience's problems in explaining how minds are unified and how different qualia are created. This unity is attributed to fields, and different qualia are attributed to different field patterns. This theory avoids dualist field theory's problems in explaining which fields create experiences, how different qualia arise, and how mental causality works. But its reduction of private experiences to field patterns is problematic, and it can be unclear about how colours assemble into their right locations in images, and why we aren't telepathic.
Computationalist field theory: Minds are non-physical products or correlates of *information* carried by global electromagnetic fields in brains.	**Examples**: Only McFadden and John adopt this explicitly.	**Evaluation**: This theory uses fields to explain the mind's unity, which avoids neuroscience's problems in this area. It also nicely avoids some problems in dualist field theory. But it's unclear about how information in field patterns produces pictorial images, how qualia assemble into their right locations in images, and why we aren't telepathic.
Realist field theory: Minds are the underlying physical nature of localized (vs. global) neuro-electrical activity. Minds are hidden in this activity behind what instruments and reflected light show.	**Examples**: Only Maxwell and Jones adopt this explicitly.	**Evaluation**: This theory avoids the non-physical causes of minds in the dualist and computationalist theories above, for minds are the underlying physical nature of neural activity. It avoids the reductive problems above in explaining how private experiences are fields, for experiences aren't identified with observable fields but are instead the hidden (privately experienced) nature of these fields. This theory's localized fields may avoid other problems above about why only some parts of fields are conscious, why we aren't telepathic, how different qualia arise, and how images are assembled. But this theory is speculative about how images are created, and it treats even atoms as conscious.

2. Are minds unified by global or local fields?		
Globalist field theory: The mind's unity comes from global fields pervading large brain areas. The fields' structures aren't pictorial like images are.	**Examples**: Only Jones explicitly challenges this.	**Evaluation**: This theory explains the mind's unity without problematic synchrony. But it's unclear about how colours and shapes bind together in their right locations in images, and why the pervasive fields across the world don't make us all telepathic.
Localist field theory: Mental unity comes from highly localized fields reaching continuously along circuitry membranes. Images reside there in pictorial form behind appearances (this relies on realist field theory).	**Examples**: Only Jones explicitly makes both of these claims.	**Evaluation**: This theory explains the mind's unity without the problems involved with synchrony or global fields. But it's speculative about how images are created.
3. How extensively do fields and neurons interact?		
Interactionist field theory: Neurons generate conscious fields that act back on voltage-gated channels in neurons, thus creating free will.	**Examples**: Only Pockett seriously challenges this.	**Evaluation**: This theory shows how minds can affect behaviour. Critics argue that consciousness plays no role in controlling simple bodily movements. But it may still play a role in higher activities.
Epiphenomenalist field theory: Neurons generate conscious fields that don't significantly affect neurons and lack free will.	**Examples**: Only Pockett considers this.	**Evaluation**: This theory shows how minds can obey physical laws. But it implies that non-experiential brains create experiences. Such causality seems inexplicable.

Table 1. Taxonomy of electromagnetic-field theories of mind.

For example, standard explanations of perceptual *unity* are problematic. This needs to be established from the start. There's no single unifying brain area that all visual circuits funnel into, and no known cortical circuits that bind (unite) colour and shape processing to form unified images. Yet there is considerable evidence that perceptual binding involves the synchronized firing of circuits in unified lockstep (as a temporal binding code). But evidence actually shows that while neurons in shape circuits synchronize together, neurons in colour and shape circuits *don't* synchronize (Hardcastle, 1996; also see Larock, 2006).[2] This point is widely overlooked. So while binding involves synchrony, binding seems to be more than synchrony.

Field theories may avoid this problem. Here visual experience is unified by a single field, not by a single brain area or by synchrony. Images reach continuously as a unified field across the discrete neurons that produce them. Yet synchrony plays a vital supporting role by amplifying field activity.

Standard approaches to the mind's *qualia* are also problematic. They're unclear on how brains encode colours, pains, etc. in the detector circuits that process sensory stimuli. These qualia are processed quite similarly, by cross-checking outputs from several detectors to reduce ambiguity. So why are qualia experienced so differently? It's often said that qualia further come from more global circuits that fire in synchrony to bind together. But again synchrony is problematic. Nor is it clear how all this processing yields the pictorial images we actually experience.

Field theories may avoid these problems too, for they look beyond neurons in explaining qualia. For example, there's evidence that sensory qualia correlate with specific spatio-temporal patterns in neural fields, and with specific electrical activities in sensory detectors. Field theories may also help to intelligibly explain how all this yields pictorial images.

Standard accounts of mind–brain relations also have problems explaining the mind's *privacy* and *causality*. Reductive accounts have

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[2] Hardcastle (1996, p. 60) points to widely overlooked data from Gray and Singer which shows that 'if neurons in different hypercolumns were sensitive to different features, but still responded to the same particular input, then these cells were not phase-locked'. She reiterates (Journal of Consciousness Studies' online thread http://www.imprint.co.uk/online/hard.html) that these authors found 'no evidence that neurons oscillated in unison across different features of the same object… if the cat was shown a blue square, they did not find any color-responsive neurons oscillating with the shape-responsive neurons, which is what you would need to find if you think their 40 Hz oscillations solve the problem of perceptual binding'.

trouble with privacy, while dualist accounts have trouble with causality. Field theories offer new alternatives here, we'll see.

Although field theories face their own problems, some are easily dealt with. For example, it's often said that field theories were long ago falsified by showing that animals can do visual tasks after their cortical currents are blocked. But, as we'll see, these experiments were poorly designed. It's also argued that qualia correlate with field patterns only because neurons create both. But as just noted, neuroscience has serious problems explaining how neurons create qualia. Nonetheless field theories do face problems. Yet arguably they're developing various potential solutions (see Table 1).

While these theories have ancient precursors,[3] developed electromagnetic-field theories of mind arose only recently. We'll look at them now author by author in roughly chronological order.

2. Kohler

Field theories first appeared as Gestalt theorists like Kofka, Wertheimer, and Gurwitsch devised holistic approaches to perception based on overall form. Gestaltists argued that forms aren't perceived as amalgams of isolated sensations, as in empiricist analyses — but as wholes that persist despite changes in their parts. One idea was that the forms come from fields created holistically (as unified wholes) across various neurons.

Developing this idea, Wolfgang Kohler (Kohler and Wallach, 1944, pp. 323–4) said that visual images come from electric currents spread globally as a continuum across the visual cortex. Here he cited studies by Libet and Gerard (e.g. 1941) which showed that brain operations in frogs aren't affected by slicing brain tissue. In Kohler's view, electric currents flowed across the slices, using tissue fluids as a volume conductor (Kohler and Wallach, 1944, pp. 323–5).

EEG studies by Kohler and Held (1949) linked visual images to these currents. They showed that 'when bright objects appear in the

[3] Ancient atomists explained everything via the motion and structure of indivisible particles (atoms). Lacking our ideas of energy, they said that our sensory images start as films that enter the body via sense organs. They then imprint upon the fine, facile atoms of the mind which mingle between larger, bodily atoms and interact with them. This resembles some field theories where images arise in sensory pathways from intangible energy fields that pervade and interact with brain matter. Other precursors to field theory are the ancient Greek philosopher, Thales, and the early British scientist, Gilbert. Both likened magnetism to the souls that animate bodies (as Popper noted). Later Hobbes, Locke, and Hume stressed the force-like nature of volition. Minds have also been treated as a 'ghost in the machine', i.e. as an ethereal substance, an energy at work in bodies. Field theories often differ from all these views, but they agree that minds act like force fields.

visual field, visual cortex is pervaded by currents'. Kohler didn't reduce images to these currents. Instead images are 'associated with' and 'determined by' these currents and their electrical forces (Kohler, 1940, pp. 55, 80–1; Kohler and Wallach, 1944, p. 316; Kohler and Held, 1949, p. 414).

Kohler felt that these neural currents are similar in form (isomorphic) to the layouts in our visual images. For example, dense current flows constitute figures and sharp current gradients constitute contours (Kohler, 1940, p. 55; 1947, pp. 301–2; Kohler and Wallach, 1944, pp. 344–5; Kohler and Held, 1949, p. 414). Of course, the visual cortex is split into two hemispheres, so why aren't our pictorial images split in two? Kohler said here that strong callosal currents between the hemispheres in effect remove the cortical split, making the image whole. This strong conductance of currents between cortical locations lessens distances between locations in images (Kohler and Wallach, 1944, pp. 319ff., 329, 343ff.).

But even if this explanation is accepted, it doesn't deal with other cortical distortions. For example, why do we experience a single image even though currents flow globally over various cortical areas, each with its own depiction of the visual scene? Neuroscientists today rarely accept Kohler's claim that images are pictorial due to pictorial-like cortical activity. But to be fair, these neuroscientists have also failed to explain how we experience pictorial images. As we'll see, local field theorists today try to salvage Kohler's view that images reside in our heads in pictorial ways, while computational field theorists say that images are encoded in fields non-pictorially.

Kohler's field theory was attacked by Sperry and Miner (1955) and others. They showed that animals can do visual tasks such as running mazes even with obstacles put in their cortex to disrupt the global currents that form images. However, Kohler attributes consciousness not just to currents but also to the fields they generate. These fields could have arched over the obstacles, so these experiments are flawed (Libet, 1996a, p. 224; Pockett, 2000, p. 119).

Sperry (1952) raised other questions about Kohler's theory, including how neuroelectricity can produce our various qualia and abstract concepts. Later field theories have dealt with these and other questions in various ways, we'll see. This illustrates how field theories are continually improving themselves.

So in Kohler's view, images are associated with, determined by, and isomorphic with global electrical currents pervading the visual cortex. This pioneering field theory isn't easily classified, other than to say that it's globalist but not computationalist, and that it's perhaps dualist (see Table 1).

3. Libet

Benjamin Libet explicitly set out to deal with two basic problems in standard theories based on neural connections, namely, how unified experiences arise from billions of discrete neurons and scores of brain areas, and how experiences apparently act back upon brains (Libet, 1993, pp. 393–4, 400). Libet's solution is that experience is a unified, holistic field that interacts with discrete neural activities, yet doesn't exist apart from these activities (Libet, 2006, §3). This holism resembles Kohler's theory.

This unified, conscious field may emerge from, or correlate with, electromagnetic fields in brains, but it isn't reducible to any physical events (Libet, 1993, pp. 394–5; 1996a, pp. 223–4; 1996b, p. 113). It's non-physical in that its consciousness isn't accessible by instruments or other physical means — it's private (Libet, 2006, §1). This cautious non-reductionism is closest to dualist field theory (though it may also resemble realist field theory somewhat).

Libet (1993, p. 394) also embraced Kohler's idea that the conscious field is global in nature. It arises from all across brain areas, yet it doesn't arise across 'substantial gaps of space' or 'nonneural barriers' (*ibid.*, pp. 393–4, 396) such as split hemispheres in brains. He devised a test of this idea that experience is created as a global field across discrete nerve activities (*ibid.*).

In this experiment, a slab of human sensory cortex that's being therapeutically removed would first be isolated from the surrounding cortex by, for example, slicing connections into it. Libet predicted that if this isolated slab is artificially stimulated, it will continue contributing to reportable experiences along with the surrounding cortex. For experience doesn't reside in neural connections, but in a 'conscious mental field' arising from the cortex as a unified whole (*ibid.*, pp. 396, 400). (Note that localist field theory predicts the opposite, for slicing connections will disrupt the localized field that creates unified experience all along neuronal circuits.)

This test can also show whether the conscious field acts back on the brain. If the subject reports that visual images are unaffected by the slicing procedure, then this report could only come from the conscious mental field activating verbal areas (*ibid.*, p. 399). In these ways, Libet's field theory is globalist, interactionist, and perhaps dualist (though he later modified this interactionism).[4]

Libet (1996b, p. 223) said in summary that the conscious mental field (CMF) 'would emerge as a function of appropriate neural activities in the brain; it would have the attribute of conscious subjective experience; it could act back on certain neural activities and therefore affect the behavioral outcome, as in a willed action; it would account for the unity of subjective experience even though the latter emerges from the myriad of activities of billions of nerve cells and their synaptic and nonsynaptic interplays'. Also the CMF 'would be accessible only to the individual having the experiences; it could not be directly observed by any external physical device except indirectly'.

One of Libet's shortcomings was that he wasn't clear on how conscious fields (minds) work together with brains. For example, why exactly do conscious fields reach across cortical slices but not across more 'substantial gaps' in space? Also how does brain structure translate into the structure of minds? For example, how are colour qualia created and then assembled into their proper locations in images?

Other issues arise if consciousness is actually tied to electromagnetic fields (which Libet permits). These fields pervade brains, so why do some parts of brains seem conscious and others non-conscious? Also these fields are parts of a larger electromagnetic field pervading the world, so why isn't consciousness in brains unified together, as in telepathy? Furthermore, if electromagnetic fields support consciousness, why don't other energy fields too?

Such issues arise partly because the conscious field is global. But another problem is that this field explicitly differs from the physical, so mind–brain interaction becomes obscure.

4. Popper, Lindahl, and Arhem

Like Libet, Karl Popper felt that minds and brains differ irreducibly, yet interact. These perennial ideas in Popper's thought were extended by his dualist field theory (Popper *et al.*, 1993) in which minds are non-physical correlates of electromagnetic fields in brains.

Popper replied here to anti-dualists who reject that incorporeal, unextended minds can make brain circuits fire. He argued (*ibid.*, pp. 168ff.) that physics attributes these very traits to electromagnetic

[4] Libet (1996b) argued that some voluntary movement is initiated by non-conscious readiness potentials that precede consciousness. He added that possibly we can consciously veto these movements, which preserves interactionism and free will (Libet, 1999). Pockett and Purdy (2010) reply that these readiness potentials aren't necessary or sufficient for voluntary movement. Yet Pockett *et al.* (2006) still cast some doubt on free will, we'll see.

forces. These Newtonian forces are vectors that have magnitudes in a direction, yet are incorporeal and unextended in space.

Also like minds, these forces act on bodies, depend on bodies, and are influenced by bodies. These vectors also resemble the intentional (representational) nature of minds, for both point to something and bring something about (*ibid.*, p. 172). But the mind differs from bodies and their forces: 'mind emerges from body, somehow, but is not reducible to it' (*ibid.*).

Popper ends his brief field theory by saying that non-physical minds are neither deterministic nor computer-like (*ibid.*, pp. 173ff.). This differs from computationalist field theory.

Popper's field theory is lucidly interpreted and developed by Ingemar Lindahl and Peter Arhem (1994). They note that it ties into his epistemological works, where three different worlds interact. World 1 consists of physical objects. World 2 consists of subjective experiences. World 3 consists of products of the human mind.

Lindahl and Arhem focus on interactions between worlds 1 and 2. As Popper puts it, electromagnetic fields, as part of the brain's physiology, 'represent the unconscious parts of our minds'. Also, conscious experiences 'are capable of interacting with these unconscious physical force fields' (Popper *et al.*, 1993, p. 179). In their view (Lindahl and Arhem, 1994, p. 115), Popper means that the mind's consciousness (world 2) interacts with neural impulses (world 1) by the mediation of electromagnetic fields (world 1) which are part of both the brain and the unconscious mind.

They reiterate Popper's claim that electromagnetic fields resemble minds (both being force-like, incorporeal, unextended, etc.), and that this makes their interaction more plausible (*ibid.*, pp. 115–6). They add that old criticisms of this interaction assume that causation requires 'contact of spatially extended bodies' (*ibid.*, p. 113), while Popper shows that Newtonian forces aren't extended. These mind–field resemblances are thus what allow fields to act as mind–brain intermediaries.

In this role, electromagnetic fields don't trigger inactive neurons, instead they 'sculpture' ongoing neuronal activity to affect 'membranes already fluctuating around a threshold potential' (*ibid.*, p. 117; *cf.* Eccles, 1960). They develop Popper here by arguing that random variation in even a single ion channel can trigger a neuron to fire. Weak forces in neural fields can thus act back on neurons to affect brain activity and volition (Lindahl and Arhem, 1994, pp. 117–8).

This interactionist, dualist field theory has real virtues. Arguably it explains the mind's privacy, unity, and causality. Minds are private because they're non-physical entities unobservable in public space. Minds have genuine causal roles in behaviour because they interact with brains. The mind can also be unified if (as with Libet) it emerges in field-like ways as a continuous whole from discrete brain activities.

But critics would still counter that this dualism involves an unwieldy duplication of electromagnetic activities and non-physical activities (minds) with obscure non-physical causality between them. They'd want to know how the mechanics of energy transfers work when non-physical minds move our bodies, and when non-conscious brains create conscious minds. Popper tried to make the former plausible above by treating forces in abstract terms as vectors, that is, magnitudes with direction but not material substance. Yet realists (§8 below) would ask what really exerts these forces. The quanta that carry these forces are material (not abstract), so arguably their interaction with immaterial minds remains problematic.[5]

Some dualists shift such causal issues to a third entity that underlies minds and bodies. But how it produces minds and bodies remains unclear. To avoid problems about how the physical and non-physical affect each other, dualists often treat causality as just correlations of perceivable events (like Hume did). But then there are no underlying forces that actually produce these events, so even coincidences are causal here. This renders events inexplicable.

Popper's causality is often seen as problematic for such reasons.[6] Yet to be fair, many theories of mind have similar problems. Nonetheless Popper (again like Libet) didn't shed much light on the other problems facing dualist field theory (see Table 1). The field theories below do address these issues.

5. Pockett and Charman

Susan Pockett (2000) is a landmark field theory that's rooted in extensive experimental evidence and strongly defended against criticisms. It may avoid problems in the field theories above about (for example) why experience just seems to arise from certain parts of electromagnetic fields and how our various qualia are created.

[5] Popper could reply that in his dualism minds don't differ from brains because they're immaterial versus material, but instead because they're subjective versus objective. Yet to be plausible, he still must explain how such different entities interact.

[6] Eccles and others try to avoid such problems with quantum mechanics. But such uses of quantum mechanics are controversial. Also, while consciousness is assumed to exist in selecting quantum states, this doesn't account for the key characteristics of consciousness (in §1).

Pockett's basic claim is that 'consciousness is identical with certain spatiotemporal patterns in the electromagnetic field' (*ibid.*, pp. vi, 109, 136–7). Her evidence comes mainly from extensive EEG and MEG studies of neural electromagnetic fields. They show correlations between sensory qualia and field patterns. For example, EEG studies by Freeman (e.g. 1991) show that various odours (e.g. from bananas or sawdust) correlate with specific spatial patterns distributed across mammalian olfactory areas. The patterns altered when animals were trained to associate the odours with rewards, showing that the correlations were with odour awareness, not just chemical stimuli.

Similar correlations appear in Freeman's studies of auditory and visual awareness. Also, EEG studies by Laurent *et al.* (1996) show that these sorts of spatial patterns evolve while odours are puffed onto locust antennae. So Pockett thinks that fields create a specific spatiotemporal pattern for each kind of sensory quality. She attributes these qualia even to possible electromagnetic fields created artificially outside brains (Pockett, 2011, pp. 175–6). These are potential ways of dealing with neuroscience's problems in explaining how our various qualia arise (recall §1).

Pockett also distinguishes non-conscious fields from conscious fields. Assuming that the latter reside in the cerebral cortex (which has a six-layered architecture), she suggests that 'conscious fields will have a surface layer of negative charge above two deeper layers of positive charge, separated by a distinct neutral layer' (Pockett, 2012, §3). The fields are boosted to these significant levels of electrical activity by synchronized feedback between cortical areas (*ibid.*, §4–5). Also, modes of consciousness and individual experiences will reside (respectively) in regional variations in cortical thicknesses and cortical modules (*ibid.*, §3). She gives various kinds of evidence for all these points, while acknowledging that they just provide necessary conditions for consciousness (*ibid.*, §5).

Pockett's analyses of these conscious patterns may also help explain why electromagnetic fields are the only conscious fields. In these various ways, she's making progress on issues left unclear above.

Pockett stresses that experiences are *distributed* across the brain's *global* electromagnetic field. For example, our perception of a red spot is widely distributed across this field, it's not in one area (e.g. Pockett, 2000, pp. 10–11, 65–7, 70, 108). The field binds the spot's colour, shape, and motion into an overall experience (*ibid.*, pp. 107–8). So this is a globalist field theory where images reside in global fields in non-pictorial forms. Pockett's later works also represent the only epiphenomenalist field theory (see §6 below).

Pockett replies convincingly to most potential criticisms. For example, one objection to experiences being neural field patterns could be that strong fields from the environment don't affect our experiences, even though they presumably do disrupt neural field patterns. She replies that there's no evidence to support that environmental fields actually do disrupt conscious neural field patterns (*ibid.*, p. 129).

But some of Pockett's replies to critics may raise questions. She realizes the problem in traditional identifications of qualia with firing neurons, given their observable differences. Yet intriguingly she feels that this problem is lessened by instead identifying qualia with the brain's 'everchanging, shimmering, invisible' electromagnetic field (*ibid.*, pp. 136–7). She seems closest here to the reductionism of psychoneural identity theory (Pockett, 2000, pp. 109, 135–6; but *cf.* pp. 105, 136).

But since qualia can't be observed by investigating this everchanging electromagnetic field, their identity remains problematic. Pockett faces the 'explanatory gap' between the mental and physical that bedevils all reductionist efforts to fully explain minds in terms of physics (e.g. Levine, 1993). While we can explain (for example) how temperature is just kinetic energy, no matter how closely privately experienced pains correlate with field patterns they're too radically different for us to explain how pains are just field patterns. We can't explain why pains accompany fields instead of fields being non-conscious. But psychoneural identity theory might be able to avoid this problem. For qualia might be private because they're hidden from public view ('invisible') in the sense that they're the underlying nature of fields which we detect only quite indirectly with EEGs (see §8 below).

Charman (1997) fits in here, for he too identifies qualia with the electromagnetic fields of physics. He says that 'Neuromagnetic field energy is experiential mind energy in three dimensional field space, possessing both qualia and quanta, and binding, through field integrity, the physically separate functions of the modular brain into an experiential whole'. His admirable theory is brief and elegant. But it's no clearer than Pockett's about how this identity works (though potential explanations may exist).

A second possible objection is that since electromagnetic fields reach between our separate brains, Pockett's view implies that we should be telepathic. Yet she has a ready reply: we're unaware of other people's experiences because our brains lack proper antennae for receiving their signals (Pockett, 2000, pp. 129ff.). But why would we need antennae to be aware of these exeriences? After all, I don't use antennae to become aware of experiences that arise from separate locations in my own brain.

Arguably what instead unifies my experiences together is simply that my brain's field unifies my experiences. Pockett actually uses this approach to explain binding, as noted above. So arguably telepathy might be avoided here by saying that fields are too weak between brains to unite their experience. However, some of these fields are actually fairly strong (as she notes). Alternatively the fields between brains could just lack patterns that are conscious — leaving them incapable of unifying experiences. Similarly Pockett says that conscious patterns are fleeting and localized right around the neurons creating them (Pockett, 2011, p. 178; 2012, §1). This precludes telepathy. But she doesn't explain how these fleeting, local fields unify experiences across each brain.

A third possible objection concerns Pockett's view that qualia are widely distributed across the brain. While Freeman found that each olfactory stimulus creates widely distributed responses in the olfactory system, other studies show strong, isolated responses (e.g. Stewart *et al.*, 1979; Jones, 2010, §8). Actually the *strongest* responses in Freeman's own studies are rather isolated too — arguably his weaker responses are largely from the proclivity of detectors to respond faintly to diverse stimuli.

There's evidence that only this strong kind of sensory activity is fully conscious, while the rest is weakly conscious or subliminal. For example, qualia intensity covaries with the number and rapidity of neurons firing in sensory pathways. Also MEG studies show that electrical activity is far higher in fully conscious processing than subliminal processing of binocular rivalry (Edelman and Tononi, 2000).

Such evidence might support localist field theory, where an image of (for example) a yellow spot isn't widely distributed. Instead it appears when one type of wavelength detector and associated shape detectors are most strongly active. This fixes the spot's colour, shape, and location in the image (see §8 below).

By contrast, Pockett's global field theory is unclear on how globally distributed yellow spots would get their locations in images. If the field's *spatial* patterns are used to specify which colours exist, then what is left to specify the colours' *spatial* locations in images? This is part of a larger problem of how non-pictorial field patterns can be identical to pictorial images.

So Pockett has very important ideas about how qualia are created, which fields are conscious, etc. Her defence of field theory is also sophisticated. Yet questions may arise about how experience is identical to fields, how fields unite experiences without incurring telepathy, and how fields unite colours and shapes into all their right locations in pictorial images. To be fair, these questions apply not just to Pockett, but to many other field theories too.

6. McFadden and John

Despite their differences, the well-argued computationalist field theories of E. Roy John and Johnjoe McFadden compliment each other well. They specifically treat information as conscious. While John is more empirical and McFadden more metaphysical, both focus more on binding and less on qualia than Pockett. Yet Pockett's ideas about qualia might be adapted to their theories (see John, 2001, p. 207; McFadden, 2002a, pp. 30–2, 42).

John and McFadden question popular views that equate binding of diverse sensory information with synchronized firing of neurons. John (2001, pp. 191–208) argues that various synchronous and asynchronous activities must be integrated into consistent informational wholes, which requires a global field. McFadden (2002b, p. 25) argues that synchrony is a global event that no neurons can oversee, so it isn't even detectable while encoding images. Instead binding comes from fields, though synchrony still plays a role. Synchronized firing by neurons doing similar tasks amplifies their contribution to the brain's electromagnetic field, but it's the field that does the binding.

The brain's electromagnetic field is naturally suited for binding because its information is pooled as a continuous, global whole — in contrast to the discrete information in neurons (McFadden, 2002a, p. 43; 2002b, p. 25). While information in neurons is digital, discrete, and slowly processed, information in fields is analogue, continuous, and processed at light speed. The latter are features of minds that traditional, neuron-based theories have trouble explaining (McFadden, 2002b, p. 31, 2006, §12.5; *cf.* John, 2001, p. 208).

'Light speed' above doesn't refer to the speed of thought, but to the speed that synchronized activity propagates across brains. John's experiments (2001, pp. 185ff.) show that different brain areas synchronize their firing with *zero time lag*. So synchrony is mediated by the brain's global field which propagates at light speed, not by slowly propagating neuronal firing patterns.

John suggests that consciousness emerges from these neuronal ensembles and their digital information, 'sustained by an electrical field resonating in a critical mass of brain regions' (*ibid.*, p. 208; 2002, p. 3). As in Edelman and Tononi's (2000) 'dynamic core' hypothesis, these regions include the frontal and prefrontal cortex, thalamus, limbic system, and basal ganglia (John, 2001, pp. 184, 193, 200–8; 2002, pp. 16ff.). They're involved in attention, conscious perception, etc. (*ibid.*, p. 195) which control which brain areas are activated and synchronized.

McFadden develops a sophisticated metaphysics for computationalist field theory like Popper did for dualist field theory (§4 above), and Maxwell did for realist field theory (§7). But, unlike these others, he offers considerable empirical evidence (e.g. McFadden, 2002b, pp. 30–5).

McFadden says that information is conscious at all levels, which is panpsychism (*ibid.*, pp. 57–8). The 'discrete' consciousness of elementary particles is limited and isolated. But as particles join into a field they form a unified 'field' consciousness. As these fields affect motor neurons, the brain's consciousness is no longer an ineffectual epiphenomenon, for its volition can communicate with the world. This 'access' consciousness resembles Baars' global workspace (1988), where specialized processors compete for access to volition's global, conscious processing (McFadden, 2002a, pp. 39, 44; 2006, p. 397).

McFadden cites evidence that fields affect nerves as this last level stipulates (McFadden, 2006, §12.4; *cf.* 2002a, pp. 28ff.). For example, transcranial magnetic stimulation (TMS) produces fields as strong as the brain's own native fields, and these TMS fields make nerves fire. Field–nerve interactions occur mainly when fields are strong due to synchronized firing in regularly aligned nerves, and when nerves are myelinated and bent relative to field isopotentials (McFadden, 2002b, p. 29). This affects neurons poised near firing thresholds, which proliferate when we're undecided (McFadden, 2006, §12.7).

As noted above, McFadden rejects popular views that minds are just impotent epiphenomena of brain activity. Instead field–nerve interactions are the basis of free will. The conscious field is deterministic, yet it's free in that it affects behaviour instead of being epiphenomenal (McFadden, 2002a, p. 41; 2002b, pp. 57ff.). This seems to assume that determinism is compatible with free will construed as self-determination. Similar ideas appear in Libet, John, Fingelkurts, and Jones.

McFadden concludes (2002b, p. 46) that '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'. This focus on attention and volition compliments Pockett's focus on sensory qualia, which helps field theory to more fully explain minds.

McFadden's metaphysics avoids problematic reductions of private experiences to these fields of information. Instead phenomenology describes information from the inside where it's privately experienced, while physics describes information from the outside where it's physically observed (McFadden, 2002b, pp. 55ff.; 2002a, pp. 41–2). This echoes Chalmers' neutral monism, where the basic stuff of the world isn't mental or physical, but neutral. The mental is constructed from its inner, intrinsic nature. The physical is constructed from its outer, extrinsic relations (Chalmers, 1996, pp. 155, 305). John's claim above that minds emerge from fields is also non-reductive.

One objection is that McFadden is unclear about how abstract information can be experienced privately as qualia and observed publicly as fields. All three entities are quite different, and their relations are cast in merely metaphorical terms like 'inner–outer', 'neutral', and 'constructed'. This sheds little light on what seems inexplicable: how *non-conscious* information produces *consciousness*. Arguably this is like magic where anything goes — where the concrete can even arise from the abstract (Strawson, 2006, §3). But in fairness, standard neuroscience is equally unclear on similar issues (the difference is that neuroscience is stymied by what field theory best explains — the mind's unity).

A second potential objection concerns McFadden's interactionism, where neurons generate conscious fields that affect motor neurons and create free will. Pockett instead moves toward epiphenomenalism, where consciousness doesn't affect neurons. In her view, information in conscious field patterns smear and weaken too fast to affect distant motor neurons (Pockett, 2011, pp. 176–9). Yet she allows that cortical fields might act back on those neurons that actually generate them, so as to eventually affect motor activity, as McFadden's view requires (*ibid.*, p. 179).

While Pockett thinks that evidence supports epiphenomenalism, she judiciously notes (Pockett *et al.*, 2006, pp. 21–2) that this applies just to simple control of movements — not higher, deliberative volition. But she doesn't address epiphenomenalism's metaphysical problems. It assumes that non-conscious physical events produce consciousness. As already noted, this seems unintelligible (this problem is compounded if consciousness is non-physical, for then the physical realm presumably loses energy steadily as it produces experiences).

McFadden's adherence to free will faces another challenge. Influential 'manipulation' arguments contend that we lack free will (construed as self-determination) because we're wholly determined by laws of physics beyond our control (see §8 below).

Other objections are that McFadden and John are no clearer than Pockett about how colours and shapes bind together in their right locations in images, and about why we aren't telepathic given that unifying fields pervade the earth.[7]

7. Fingelkurts *et al.*

Andrew and Alexander Fingelkurts *et al.* have developed an impressive field theory based largely on their own extensive EEG studies. Unlike in other field theories where synchronous firing by neurons merely amplifies the electromagnetic field that has our experiences, they instead attribute experience to both the synchronous firing and the field (Fingelkurts *et al.*, 2010a, pp. 36, 45, 54).[8]

They stress how integrated, intricate, and fast-changing the structure of these activities is, and how this resembles the dynamic structure of our experiences. Synchronous firings by temporary neuronal assemblies act as communication bands to in effect rewire the brain in milliseconds without changing its synaptic hardware (*ibid.*, p. 22). This gives brains a highly integrated *operational architectonics* for cognitive operations that's more fleeting and flexible than synaptic architectures. It thus mirrors our experiences (*ibid.*, pp. 31, 63). It may explain how kaleidoscopic experiences arise from relatively fixed neuronal structures much like intricate music from a fixed orchestra.

Moreover, there's a functional isomorphism between the spatiotemporal structures of these neural and mental activities. For example, at lower levels, simple perceptual features (shapes, colours, etc.) correlate with the simple cognitive operations of synchronized neuronal assemblies. At higher levels, overall perceptual objects and scenes

[7] Like Pockett, McFadden could be clearer about how to avoid telepathy. In his view, it's 'seldom' that external fields from the environment penetrate our brains in the right strength, frequency, etc. so as to 'influence our minds' (McFadden, 2006, §12.6; 2007, §5). Yet he also repeatedly says that fields 'pool' information together. So do fields occasionally pool conscious information together from different brains, as in telepathy?

[8] Page numbers for the Fingelkurts's papers are from their online versions.

correlate with larger-scaled synchronized neuronal assemblies (*ibid.*, p. 39). Extensive EEG studies have helped to characterize these synchronized assemblies and their correlations with experiences (e.g. *ibid.*, pp. 2, 41–2). This evidence aligns with MRI studies of cortical activities involved in cognition.

Fingelkurts *et al.* feel that this functional, 'operational' architectonics for cognition helps bridge the mind–brain explanatory gap. For its integrated levels of operations mediate between the simple firing of each neuron (which lacks cognitive significance) and the integrated, conscious cognition of minds (*ibid.*, pp. 40–1, 53–4). Mental organization is thus explained via the brain's functional organization, in their view.

This supports Revonsuo's well-known claims that there must be something in brains that resembles experience (*ibid.*, pp. 35–6). The Finkelkurts's new paradigm is their hypothesis that the mind's subjective space-time structure connects to the otherwise distant space-time of external reality via the brain's operational (functional) space-time structure (Fingelkurts *et al.*, 2010b, p. 2).

Their attribution of experience to both the synchronous firing of neuronal assemblies and their resultant electromagnetic field may avoid a possible problem faced by McFadden and others, who attribute experience to the field alone. That is, the field alone might smear fine details in sensory images. This would preclude explanations of images in terms of fields alone. Yet McFadden might reply that fields contain (in one form or another) all the information in neurons.

The Fingelkurts's view that the brain's operational organization resembles the mind's organization is an astute and important hypothesis based on extensive empirical studies. But one objection concerns their claim that synchrony creates integrated experience (e.g. Fingelkurts *et al.*, 2010a, pp. 45–50, 63). This faces the problems noted in §1 and §6 above.

Pockett might offer a second objection, namely, while Fingelkurts *et al.* give neural accounts of the mind's spatial and temporal structures, they don't address the mind's qualia (e.g. how pain feels). Pockett's systematic accounts of qualia might help here.

A third objection concerns the Fingelkurts's views about how the mental and neural are related ontologically. They explicitly reject dualism (Fingelkurts *et al.*, 2010b, p. 2). While they also reject reductionism (Fingelkurts *et al.*, 2010a, pp. 26, 56), they may just be rejecting here that the mental is reducible to the simple firing of neurons, which lacks cognitive significance (as Fingelkurts *et al.*, 2010b, p. 3, states). Ultimately they actually seem to accept reductionism, for they explicitly adopt two views: (1) the operational level of brain organization is related to the mental level by supervenience, and (2) the mental level is reducible to the operational level, which is equivalent to a hierarchically organized local electromagnetic brain field (*ibid.*). Simply put, the mental and neural are related by both reduction, where the mental is nothing but the neural, and supervenience, where the mental can't change unless the neural changes.

Fingelkurts *et al.* can indeed consistently adopt both supervenience and reductionism, given their definitions above. Nonetheless they still face the stubborn mental–neural explanatory gap faced by Pockett. Neural structures and cognitive operations differ radically from the coloured scenes in visual images, so the former can't fully explain the latter.

This field theory can thus be classified as reductionist. It might also be interactionist in that it endorses downward causation by minds upon brains (Fingelkurts *et al.*, 2010b, p. 5), though this must be reconciled with the supervenience above. But it's not a localist field theory, for while its fields are described as 'local', they don't unify the mind by themselves, which is the defining trait of localist field theory in Table 1.

8. Maxwell and Jones

The realist field theories of Grover Maxwell and Mostyn Jones address the problems in other field theories. To start with, in Maxwell's theory the underlying nature of fields is conscious. Drawing on Russell (1927) and Feigl (1958), he argued that scientists describe fundamental entities by their observable, extrinsic interactions, not by their intrinsic (essential, underlying) nature apart from these interactions.

This resembles Locke's realist contrast between reality and appearances: we see matter indirectly by reflected light, instruments, etc. so we 'know not what' its hidden, underlying 'substance' is like behind these appearances (Locke, 1971, *Essay* 2: 8, 23). Some of this underlying stuff may thus be conscious for all we know, Maxwell (1978, pp. 391–401) says. We access it indirectly so there's no ground for replying that physical stuff can't intelligibly be conscious.

Arguably this bridges the explanatory gap facing Pockett and Fingelkurts *et al.* This gap arose because observable brains and private experiences are so different that those who treat them as identical can't intelligibly explain why experience accompanies brain activity. But arguably Maxwell intelligibly shows how private experience and brain events *aren't* different. He shows how experience can be the hidden, underlying nature of observable brain activity — which explains why they accompany each other.

In Maxwell's view, fields are the best candidate for what's intrinsically conscious, for only they are continuous and smooth like visual images (Maxwell, 1978, p. 398). This is his solution to Sellars' (1965) 'grain problem' of how discrete, grainy molecules and cells in brains create continuous, smooth images.

Maxwell treated all fields as conscious, even Pribram's holonomic fields. But electromagnetic fields are the only energy fields with any strength along neural circuits. And Pribram's fields are discrete postsynaptic microstructures (Pribram, 1990), so they can't avoid the grain problem. Unfortunately Maxwell's very brief field theory didn't address such issues. Nor was it based in experimental evidence.

Jones (2010) addresses these and other issues in realist field theory. He thinks that if the underlying stuff that comprises fields is conscious, then so is the matter emitting the fields — and whatever exchanges energy with this matter. So Jones (like McFadden) adopts panpsychism, where everything is conscious. Fields unify the isolated, minimal consciousness in the brain's discrete molecules and cells to form fully conscious minds.

Jones's realist field theory adopts Eddington's (1928, chapter 12) 'pure' panpsychism, where fundamental particles are pure consciousness. Jones adopts this rather strange view because the alternative is that particles have both consciousness and non-conscious mass, force, etc. — which leads to problematic dualist interaction between radically different entities. So instead the underlying nature of all particles (including their masses, forces, etc.) consists purely of consciousness that occupies the particles' spaces and exert their force fields (Jones, 2010, pp. 140–1). In brain circuits, fields unify these 'microexperiences' of conscious energy to form minds. While all force fields are conscious, only electromagnetic fields are strong enough along these circuits to fully unify experience.

This is indeed strange, but Jones feels that it's justified because it avoids the serious metaphysical problems in theories of mind (*ibid.*, p. 143), including field theories. For example, it avoids dualist field theory's problematic non-physical experience, for experience is instead the underlying, physical nature of matter-energy in space-time. It avoids reductionist field theory's problematic reduction of private experience to neuroscientific terms, for experience is instead the underlying nature of events studied by neuroscience. This experience is private in that it's thus hidden from public view.[9]

This is the only localist field theory. Since the brain's electromagnetic field consists of consciousness, it's most conscious where field energy is highly concentrated in space-time, that is, locally near the membranes of highly active circuits.[10] The field rapidly weakens, so consciousness is negligible further away (Jones, 2010, pp. 149–50). Jones thinks this realist, localist field theory avoids the problems in globalist field theory. For example, the latter is unclear about why the long-range field between our brains doesn't unite our experiences and make us telepathic. But in Jones's theory, this field between brains is always negligible relative to the intense local field created right inside the brains' ion currents (*ibid.*, p. 150). So experience is effectively unified in brain circuits, yet not between brains.

In this theory fully conscious activity generally arises where neural activity is unified by a strong, continuous field along interconnected circuits — and is also concentrated in space and time within these circuitries. All this is promoted by densely packed neurons in cortical modules that are firing rapidly in the feedback loops between cortical areas. This concentrates intense levels of conscious activity on tasks regulated by executive attention. This fits considerable evidence that we're most conscious when neural circuits are highly active, highly connected, and engaged in feedbacks between cortical areas (e.g. Edelman and Tononi, 2000; Goldberg, 2001; Jones, 2010).

In this theory, it's the brain's electrochemistry that's conscious, not its information processing (as in computationalist field theory).

[9] Chalmers (1996, p. 136) would reject that realists avoid dualism, for they rely on dual perspectives (private–public). But Jones's realism actually treats both perspectives as physical: qualia exist physically as the hidden (private) nature of brain matter behind what's observed of it; and qualia are viewed (publicly) as grey matter by physical processes involving reflected light. Jones tries to avoid other problematic views too, including emergentist claims that experience arises from non-experiential matter once it's properly organized. Instead matter consists of microexperiences whose existences don't depend on how matter is organized. He may also avoid idealist claims that matter just exists as perceptions in our minds. Instead matter consists of microexperiences that exist outside our minds' perceptions. They're physical (not ideal) since they occupy physical space, exert physical force, and don't require any mind or spirit for their existence. This seems to avoid idealism's obscurity about why minds correlate so tightly with brain matter.

[10] In these highly active circuits, ion currents circulate continually through membrane channels along myriad neurons. Their local field is intense and continuous from neuron to neuron and instant to instant (Jones, 2010, p. 149). This supplies the continuous substance along circuits that's needed for microexperiences to effectively unify into overall minds. Note that in these strong localized fields, quanta form a probability cloud of continually high energy. Yet as fields weaken with distance, quanta grow more sparse, and field continuity deteriorates. Fully unified experience thus requires strong fields localized right near rapidly firing circuitry.

Computations are just treated as convenient ways of describing electrochemical interactions — only the latter really exist. So images are hidden in electrochemical activity in pictorial (not encoded) form. Here Jones cites recent, accumulating evidence that our different sensory and emotional qualia are closely linked to the different electrical channels of sensory detectors and hormonal receptors (*ibid.*, pp. 152–3). In his view, colour qualia are the underlying substance of molecules in these electrical channels of colour detectors. The strong, local field in visual circuits unites these microexperiences to form coloured shapes in images. When these circuits give different colours such as red and blue to the same spot of an image, they fuse to create purple. In this way, very few detectors create the entire range of colours we experience.

The pictorial form of images derives from how brain areas connect into retinas. The retina is the only visual area with this pictorial form, yet it isn't fully conscious since it lacks re-entrant (feedback) connections from the cortex. But the retina systematically connects into higher areas like V1, and it has its own conscious unity since it's densely packed with millions of interconnected cells. It can thus unite the visual activities above it into a single pictorial image. For example, V1 detectors connect densely into the retina's centre, yet not into its periphery. This makes images pictorially detailed at their centre, yet coarse at their periphery. V4 connects into V1 giving full colour to each pictorial detail. All circuits for colour, shape, motion, constancy, object recognition, etc. ultimately bind together via their connections into retinas, thus forming unified pictorial images.

Jones feels that this avoids globalist field theory's problems with how colours and shapes bind into their correct locations in images. In his theory, colours and shapes simply bind together via known connections into retinas. Nor is there a problem with how to get from global field patterns to these conscious images. For images are just hidden in neural areas behind appearances (Jones, 2010, p. 157).

The electrochemical nature of perception and emotion above also helps explain thought, for emotion drives thought, and thought's images arise in the same areas that create perceptual images (Jones 2010, p. 153). Thought's private, qualitative deliberations about feelings and preferences (e.g. which foods taste best) arguably bring emergent dynamics to brains (*ibid.*, p. 155). This conscious field affects brains by activating voltage-gated channels in neurons. These emergent dynamics counter influential 'manipulation' arguments that we lack free will (construed as self-determination) since we're fully determined by laws of physics outside our control (*ibid.*, pp. 155–6).

In general this approach counters prevalent mental irrealist theories of mind (reductionist and epiphenomenalist) that free will and responsibility are illusory.

Jones's field theory is new and not yet fully evaluated in the literature. But a basic criticism may be that his account of how images arise in circuits is often speculative. He might reply that all theories of image creation are speculative. But his speculations must ultimately be scrutinized to evaluate his claims that he avoids globalist field theory's problems.

Scrutiny is also needed for his new metaphysical claims that identifying qualia with the underlying nature of neural activities can avoid the fundamental mind–body problems in theories of mind, including field theories.

Finally Jones's panpsychist claim that all particles consist purely of experience is decidely strange. He thinks it nonetheless helps him to avoid fundamental mind–body problems. But whether this justifies the theory's strangeness is perhaps a matter of subjective opinion.

9. Conclusions

Standard neuroscience investigates how neuronal processing works. But it has problems explaining the mind's qualia, unity, privacy, and causality this way. For example, it isn't clear about why colours and other qualia are processed so similarly yet experienced so differently, how colour and shape information unite in visual processing, and how abstract information, concrete brain activities, and private experiences are causally and ontologically related given their radical differences.

Field theories of mind try to avoid such problems by turning from neurons to their fields. Here minds typically get their unity from the continuous nature of the fields generated by discrete neurons, while different qualia arise from different structures in the fields. These qualia are private (not publicly accessible) either because they're non-physical or because they're the underlying nature of fields (hidden behind what instruments and reflected light show). Mind–brain causality is (in the simplest field theories) just field–brain causality. Field theories offer new ontological approaches to dualism's problematic causality and reductionism's explanatory gap.

Field theories face their own problems, but they're progressively improving upon each other (see Table 1). These theories can't be easily dismissed, for they're based on considerable evidence and they offer powerful ways of dealing with standard neuroscience's deepest problems.

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