

Initiation of Intentional Actions and the Electromagnetic Field Theory of Consciousness

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ABSTRACT

The electromagnetic (EM) field theory of consciousness proposes that consciousness is identical with certain brain-generated EM field patterns. It initially seemed to be a point in favour of this theory that EM fields are known to affect neurons, which in principle provides a mechanism whereby consciousness could affect its brain. However, it is shown here that the sorts of EM fields proposed by the theory as being conscious can act only on neurons that are either identical with, or spatially close to, the neurons that generated those fields in the first place. This makes it difficult to see how putatively conscious EM fields could initiate bodily movements. It does not harm the EM field theory of consciousness however, because an accumulation of independent psychological and physiological evidence shows that consciousness itself is not the proximal cause of voluntary movements. The fact that humans are not directly conscious of the initiation of their own bodily movements is now used to reveal a basic structural feature that may distinguish conscious EM fields from the superficially similar fields produced by those parts of the brain that do not generate conscious experiences.

The electromagnetic (EM) field theory of consciousness (Pockett 1999, 2000, 2002; McFadden 2002a, 2000b) is an identity theory which proposes that consciousness is identical not with particular spatial patterns of neuronal activity *per se*, but with the extracellular EM field patterns that are induced by those spatial patterns of neuronal activity. The major difference between the EM field theory of consciousness and what might now be called the classical

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neural identity theory of Place (1956), Feigl (1958) and Smart (1959) is that the EM field theory allows for the possibility of generating consciousness in the complete absence of neurons, using hardware instead of wetware to generate the relevant EM fields.

This proposed identity between consciousness and EM field patterns in principle provides a mechanism by which consciousness could initiate bodily movements. It well known that EM fields can influence and even cause neural activity.¹ Thus, at first sight it appears reasonable to suppose that conscious EM fields could act on the brain to cause bodily movements. This was initially seen (Pockett 2000; McFadden 2002a, 2000b) as a point in favour of the EM field theory of consciousness. However, doubts soon appeared (Pockett 2002) and have since hardened in the present author's mind to frank disbelief that conscious electromagnetic patterns do, in the normal course of events, cause bodily movements. The main reasons for this disbelief are as follows.

REASONS FOR NOT BELIEVING THAT CONSCIOUS ELECTROMAGNETIC PATTERNS CAUSE BODILY MOVEMENTS

1. SPATIAL EM PATTERNS CAN ONLY ACT ON THE NEURONS THAT GENERATED THEM

The first reason for doubting that conscious EM patterns cause bodily movements concerns the physical characteristics of putatively conscious EM patterns. In order to understand the argument here, it is first necessary to understand the mechanism by which neurons generate the EM patterns in question.

The EM field patterns proposed by this theory as being conscious are spatial patterns of those transient, extracellular, electrical events known (quite independently of the present theory) as 'field potentials'. Field potentials are produced by the synchronous activation of chemical synapses on large numbers of anatomically aligned pyramidal cells in the cerebral cortex of the brain. The larger the number synapses on one pyramidal cell and/or the larger the number of spatially aligned post-synaptic pyramidal cells activated synchronously, the larger the field potential. The cellular mechanism by which

¹ See Adey 1981, Richardson *et al.* 1984, Taylor *et al.* 1984, Turner *et al.* 1984, Dalkara *et al.* 1986, Dudek *et al.* 1986, Snow and Dudek 1986, Yim *et al.* 1986, Faber and Korn 1989, Jeffereys 1995, Francis *et al.* 2003, Deans *et al.* 2007, Frölich and McCormick 2010.

field potentials are generated is well understood and is shown diagrammatically in *Figure 1*.

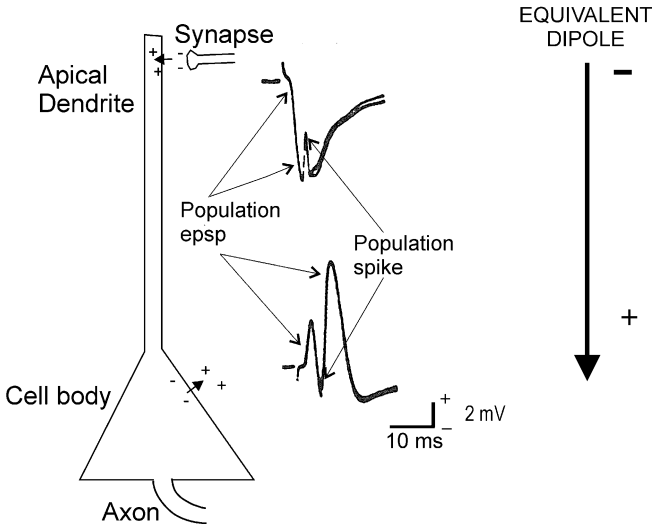


Figure 1: Diagram showing how the field potentials associated with a single pyramidal cell are generated. Activation of chemical synapses on the distal dendrites of pyramidal cells (top) causes a burst of positive ions to flow from the extracellular fluid into the apical dendrite. This leaves a short-lasting local negativity in the extracellular fluid around the synapse (top voltage trace). The product is a negative-going field potential known as a population epsp (excitatory post-synaptic potential). The intracellular positivity caused by this entry of ions to the dendrite essentially has to go somewhere, so to complete the circuit, positive ions flow out of the pyramidal cell at the cell body (bottom). This outflow produces a positive-going population epsp in the extracellular fluid near the cell body (bottom voltage trace). If the voltage transient in the cell body is large enough to cause an action potential to fire at the initial segment of the axon, a relatively small and brief “population spike” also appears in the middle of the population epsps.

Figure 1 illustrates two important points about the EM field theory of consciousness:

- (a) The field potentials that make up putatively conscious fields are dominated by *synaptic potentials*, due to the activation of *chemical synapses*. The external fields produced by action potentials *per se* have

relatively little influence on the shape of field potentials. The activation of electrical (as opposed to chemical) synapses has no influence on the shape of field potentials.

- (b) The field potentials that contribute to conscious field patterns always come in positive-negative pairs: one positive-going field potential at the level of the pyramidal cell body and one negative-going field potential around the distal part of the apical dendrite. These positive-negative pairs are conveniently modelled as dipoles (right hand side of *Figure 1*). The EM field theory of consciousness proposes that conscious fields are distinguished from non-conscious fields – and from different conscious fields – by the spatio-temporal pattern in which these dipoles are arranged.

With this background, we may now return to the question of why it is doubtful that conscious EM fields can cause bodily movements. The exact features of the spatio-temporal dipole patterns that covary with particular sorts of consciousness are not yet clear (although some progress on that question is made by the arguments later in the present paper). However, one thing which is very clear is that such spatio-temporal patterns propagate very badly through space. Pockett *et al.* (2007) show mathematically that, assuming the patterns covarying with sensation to be produced by cortical dipoles spaced 3 mm apart, with an inter-pole distance of 2 mm (the approximate thickness of the cerebral cortex), the point spread function of EM fields through a medium with the conductivity of brain tissue is such that the patterns in question can not be recognised more than 2.5 mm above their source. In fact (i) some of the relevant dipoles may not extend the full width of the cortex, and (ii) the inter-dipole spacing is probably closer to 1 mm (the width of a human ocular dominance column) than 3 mm, which makes the situation even worse with respect to the distance over which a putatively conscious pattern could propagate – in any direction – and still be recognisable. In short, the physics of electromagnetism dictates that by the time one of these field patterns has travelled a mere mm or so from its source, it is so smeared or blurred as to be indistinguishable from a completely unpatterned (and therefore non-conscious) field.

This means that on any physically realistic version of the EM field theory of consciousness, individual conscious experiences remain very localized around the neurons that generate them. The only neurons a conscious field can

activate or influence *in a way that depends on the spatial pattern* of (and therefore the experience encoded by) *the field* are the very neurons that generated the field in the first place. In this regard, it is notable that all the empirical demonstrations cited earlier about the effect of brain-generated EM fields on the brain do involve the back-action of fields *on the neurons that generated them*.

How does this relate to the possibility of conscious fields' initiating bodily actions? It is true that the EM field theory of consciousness proposes that an individual's consciousness as a whole is the sum total of all the conscious fields generated by the brain. So in one sense, consciousness *as a whole* has access to the whole brain. But any particular conscious field pattern – for example, the conscious thought “I should check my mail-box within the next few minutes” – is able to affect the neuronal activity only of neurons in the immediate vicinity of those that generated the thought. A conscious thought such as “I should check the mail-box” would probably be generated somewhere in the prefrontal and/or parietal cortices (Pockett 2006). The main point of this argument is that it is physically impossible for a patterned EM field generated in the prefrontal and/or parietal cortex to have any direct effect on motor neurons, as suggested by McFadden (2002a, 2000b). Quite apart from the pattern-blurring effect of the point spread function, as mentioned above, the propagation of dipole electric fields obeys an inverse cube law. Motor neurons live in the spinal cord, several hundreds of mm away from either the parietal or prefrontal cortex. By the time it gets to the spinal cord, the EM field due to a parietal or prefrontal dipole has been reduced by the inverse cube law to less than 1/100,000 of its source strength. So never mind the fact that its spatial pattern would be unrecognisable – the EM field due to even the strongest parietal or prefrontal dipole essentially does not exist at all in the spinal cord.

Of course, a patterned EM field generated in the parietal and/or prefrontal cortex *could* have a direct effect on the neurons that generated it, and these neurons could then activate all the standard action potential and synaptic mechanisms by which the motor system is usually understood to work to produce an *eventual* effect on motor neurons. But the parietal and/or prefrontal neurons in question could just as easily do that job all by themselves, without the need for any intervention from a conscious EM field – or indeed without the need for any conscious thought at all. And oddly enough, the next section of the present paper cites considerable evidence that usually, this is exactly what happens.

2. PSYCHOLOGICAL EVIDENCE THAT CONSCIOUSNESS DOES NOT CAUSE BEHAVIOUR

The second major reason for disbelieving that conscious EM patterns cause bodily movements concerns the psychologically measured properties of consciousness itself, independently of any theory as to its nature. The issue here is that there is now a large body of evidence that consciousness is *not* the direct cause of intentional aka voluntary movements.

Some of this evidence is summarised by Wegner (2002), Pockett (2004) and the various contributors to Pockett *et al.* (2006). The topic is too large allow its discussion in very great detail here, but in brief, consciousness is certainly not directly involved in the *control* of intentional movements. Jeannerod (2006) summarises a number of experiments showing that people are generally not even aware of having made the fine adjustments that serve to control their own intentional movements. The question of whether or not consciousness is involved in the *initiation* of voluntary movements is more complex, although ultimately the answer is just as clearcut.

The first and still most often quoted evidence against the idea that voluntary movements are initiated by consciousness is that generated by Libet *et al.* (1983). Libet and colleagues showed that the *Bereitschaftspotential* or readiness potential associated with a spontaneous voluntary movement begins some 350 ms before the subject reports having initiated the movement. This has been widely taken as demonstrating that voluntary movements are initiated un- or pre-consciously. Pockett and Purdy (2010) repudiate that conclusion by showing that:

- (a) Readiness potentials are neither necessary nor sufficient (in anything other than a definitional sense) for voluntary movements. Rather, they simply indicate readiness to make a spontaneous movement.
- (b) When subjects in Libet-style experiments are asked to make not spontaneous movements, but movements based on a definite decision about which of two acts to perform, the readiness potential is usually so much shorter than that associated with spontaneous movements that it starts at approximately the same time as the subject reports having initiated the movement.

These findings initially seem to reopen the possibility that voluntary movements might be initiated consciously. But the validity of *that* conclusion is immediately thrown into doubt by the subjective observation of one of Pockett

and Purdy's participants that for him, it was actually impossible to distinguish between deciding to move and moving. On closer inspection, this single observation turns out to be supported not only by the huge variability in the movement initiation times reported by the deliberately untrained participants in question (some of whom often reported that they had decided to initiate a particular movement after they had objectively moved), but also by a large body of experimental evidence from a whole series of other workers.² For example, Banks and Isham (2009) show that tricking a subject into thinking their own movements occurred progressively later than they actually did results in linear delays in the reported time of movement initiation.

The overwhelming conclusion from this body of experimental work is that humans do not consciously experience their decisions to initiate bodily movements in the same way as they experience sensory or even other cognitive events. Pockett and Miller (2007) show that subjects can report very accurately on the time at which they actually *make* a movement – perhaps because an actual movement is accompanied by a good deal of proprioceptive and other somatosensory feedback. But the psychological experiments of a number of labs now combine to suggest that when asked to report the time at which they initiated a movement, all a subject can do is infer that they must have initiated it sometime shortly before it took place.

The *coup de grace* in favour of this conclusion comes from the work of Desmurget *et al.* (2009), who describe a series of Penfield-esque experiments in which they directly stimulate various parts of the cerebral cortex in awake patients undergoing brain surgery and then ask the patients to report on their conscious experiences. When Desmurget and colleagues stimulate parietal regions, which are thought to generate conscious intentions to move at some time in the near future (Pockett 2006) the subject reports a subjective intention or desire to move the relevant part of the body, which escalates with stronger stimuli to a belief that they actually have moved, even though no EMG (electromyographic) activity can be detected. However, when the experimenters stimulate premotor cortex, which is thought to underpin the initiation of movements, the patient reports no subjective consciousness of movement and in fact firmly denies that any bodily movement has taken place,

² Aarts *et al.* 2005, Lau *et al.* 2007, Banks and Isham 2009, Kühn and Brass 2009, Rigoni *et al.* 2010.

even when the stimulation is turned up so much that the experimenters can *see* the relevant part of the body moving.

The addition of this neurophysiological evidence to the accumulated psychological results now makes it reasonable to conclude definitively that subjective reports about movement initiation are not reports of on-the-spot conscious perceptions at all. They are *post-hoc* cognitive constructions. We are not directly conscious of the initiation of our voluntary movements. Thus consciousness can not be considered to be the proximal cause of voluntary movements. The fact that experimental subjects usually fail to realise this is probably due to the general inability of humans to perceive cause and effect accurately (Choi and Scholl 2006).

WHY IS THE INITIATION OF MOVEMENTS NOT ACCESSIBLE TO CONSCIOUSNESS?

From the point of view of the EM field theory of consciousness, one beneficial effect of the fact that we do not consciously experience the initiation of bodily movements is that it renders harmless the parallel fact (see (1) above) that the sorts of EM fields the theory says are conscious can have direct physical effects only on the neurons that generated them. If consciousness itself does not initiate movements, there is no reason to suppose that putatively conscious EM fields should be able to initiate movements.

However, there is also another important consequence for the EM field theory of consciousness of the fact that we do not consciously experience the initiation of bodily movements. This is that it potentially provides a valuable clue as to the characteristics of dipole patterns that *do* underpin conscious experiences.

As explained earlier, the EM field theory of consciousness proposes that different putatively conscious EM fields are characterised by different spatial dispositions of the standard ‘field potentials’ generated by activation of chemical synapses on the distal apical dendrites of cortical pyramidal cells (*Figure 1*). The spatial disposition of field potentials clearly depends on the anatomical disposition of pyramidal cells. This means that for the EM field theory of consciousness to work:

- (a) parts of cortex that produce different *types* of conscious experience should probably have different types of intracortical disposition of pyramidal cells
- (b) parts of the cortex that do not produce conscious experiences at all should definitely have a fundamentally different intracortical disposition of pyramidal cells from parts of the cortex that do produce conscious experiences.

Fortunately for the theory, it turns out that requirement (a) was shown to be broadly fulfilled a little over a hundred years ago. *Figure 2* reproduces the map of spatial variations in the cytoarchitecture of the cerebral cortex published by Brodmann (1909).³ This map is based on microscopically observed differences in the layering of pyramidal and other neurons from the outside to the inside of the cortex. Despite a mid-century flurry of complaints from Lashley (who, unable to find his ‘engram’, became convinced that the cortex must be pluripotential in function and therefore uniform in structure), the cytoarchitectonic areas delineated by Brodmann have since been shown to correspond so well with the functional areas delineated by modern electrophysiological and imaging techniques that particular regions of cortex are still routinely identified using their Brodmann Area (BA) numbers. For our present purposes the most relevant of these numbers are those of the motor and pre-motor cortices (BA4 and BA6).

³ Although Brodmann’s map is almost identical to an earlier map by Campbell (1905), the Brodmann version has become much more well-known, to the extent that its numbering system is still widely used.

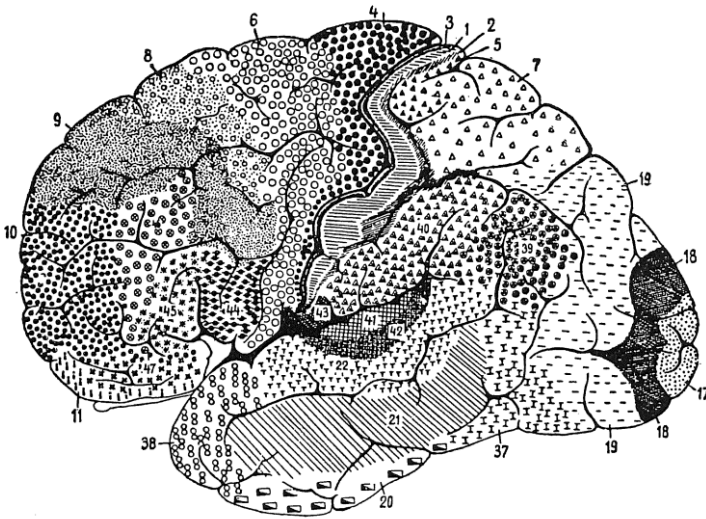


Figure 2: Brodmann's cytoarchitectural map of the human cerebral cortex. Brodmann Areas 4 & 6 are motor & premotor cortex. Brodmann Areas 1, 2 & 3 (somatosensory), 17 & 18 (visual) and 41 & 42 (auditory) are primary and secondary sensory cortex. Cerebellum not shown.

So requirement (a) above has been known for a century to be largely fulfilled. One very useful effect of the new information that movement initiation is inaccessible to consciousness is that it allows us now to test requirement (b).

While the longer term *planning* of movements (which is accessible to consciousness) probably occurs in the prefrontal and/or parietal cortices (BA 10, 11, 39 & 40), the *initiation* of movements is generally thought to occur somewhere in BA6, the area now known as pre-motor cortex (see Pockett 2006 for review). It is therefore deeply fortunate for the EM field theory of consciousness that the anatomical work of Brodmann's successor von Economo (1925 and 1927) does indeed show a fundamental difference between the cytoarchitectonics of premotor and motor cortices (BA6 & BA4) and that of all other regions of the neocortex.

Figure 3 shows in diagrammatic form the cortical locations and cell body architectures of the five general types of cortex identified by von Economo. *Figure 3(A)* shows that the area encompassed by BA6 and BA4 is classified as 'agranular' cortex. *Figure 3(B)* shows that the major difference between agranular cortex and the other four cortical types in Economo's classification

system is that agranular cortex lacks the ‘granular’ layer which in most cytoarchitectonic classification systems is called lamina IV.

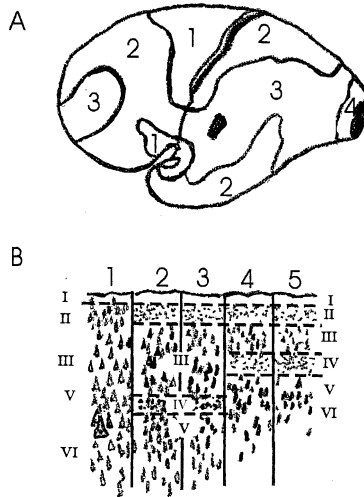


Figure 3: Cortical locations (A) and cellular structure (B) of the cytoarchitectonic types classified by von Economo (1925 and 1927). Roman numerals in B indicate cytoarchitectonic layers: surface of brain at top. Lamina I consists entirely of apical dendrites from the pyramidal cells of lower layers (see *Fig 4*) and incoming axons from other parts of the cortex, which synapse on the dendrites. Apart from lamina I, cytoarchitectonic type 1 (found mainly in areas BA 4 & 6) lacks well-demarcated layers. The five architectonic types named by von Economo are 1- agranular cortex; 2 - frontal cortex; 3 – parietal cortex; 4-polar cortex; 5 (solid black areas in A) – granular or koniocortex.

In all regions of the neocortex except the motor and premotor cortices, lamina IV is a largely pyramid-free layer of stellate neurons, which in Nissl stained sections⁴ somewhat resemble dust (leading to von Economo’s identification of the three major primary sensory areas, where lamina IV is particularly obvious, as ‘koniocortex’). The stellate neurons in Lamina IV

⁴ Nissl staining shows all cell bodies, but none of their axons or dendrites. Golgi staining selects a few neurons (in a completely uncontrollable way) and stains the whole cell, including the axon and all dendrites.

receive major synaptic input from the subcortical thalamus. However the contribution of these thalamo-cortical synapses to the field potential landscape would be negligible, because the dendrites of stellate cells extend at all angles from the cell body and thus the positive and negative voltage transients illustrated in *Figure 1* tend to cancel each other out. In contrast, the apical dendrites of most of the pyramidal cells in laminae III and IV – including those in motor and pre-motor cortices (Porter and Lemon 1993) – extend all the way up to lamina I, at the surface of the cortex (see *Figure 4*).

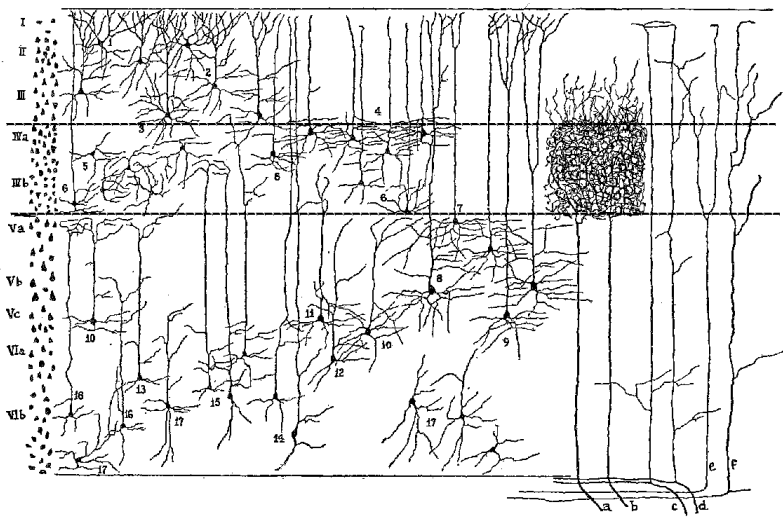


Figure 4: Semi-diagrammatic view of Golgi stained neurons in adult mouse parietal cortex (after Lorente de No, 1951). Axons are not drawn in the original “to avoid complication”. Nissl-stained cells at left illustrate cortical layers. Dotted lines added by present author. Differences in detail doubtless exist between mouse & human and between different cortical areas within a given species: this figure is intended simply to illustrate general structural features of non-motor cortex.

In terms of the overall disposition of dipoles, this tendency for the apical dendrites of most pyramidal cells to extend right up to the surface of the cortex means that those parts of the neocortex which do generate conscious experiences are likely to produce a field potential landscape characterised by one layer of negative poles at the surface of the brain and two deeper layers of positive poles, separated by an electrically neutral field in the position of

lamina IV (*Figure 5*). In contrast, any area of brain that does not produce conscious experiences is likely to produce something more like a simple surface-negative, depth-positive dipole, without the complex double-layering of the deeper positive field. This latter class of brain areas would definitely include the cerebellum, which (a) does not generate conscious experiences (Jeannerod 2006) and (b) does not exhibit anything like the 6-layered anatomical structure characteristic of neocortex (Eccles *et al.* 1967).

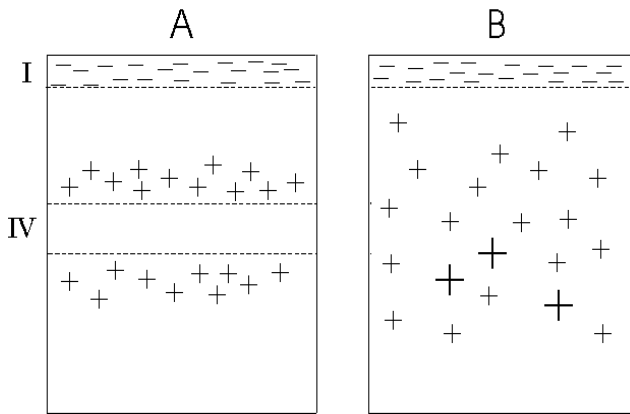


Figure 5: Schematic diagram of the proposed EM field shapes characterising conscious (A) and unconscious (B) fields. Roman numerals on left of diagram indicate cortical layers: Lamina I is at the surface of the cortex. The sprinkling of larger positive charges in B is intended to represent the giant Betz cells found in motor cortex.

For logistical reasons it would not be particularly easy (although not impossible) to perform experimental tests in human subjects of these predictions about the dipole landscapes produced by parts of the cortex that do and do not generate conscious experiences. But the predictions made here could relatively easily be tested in animals. Pending such testing, these speculations may point the way with regard to further elaboration of the EM field theory of consciousness. However, considerably more work on the relationship between cytoarchitecture and neurophysiological activity is necessary before any more detailed predictions can be made about the EM field shapes underpinning the various different modalities of conscious experience.

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