PUTTING MAGNETISM IN ITS PLACE: A CRITICAL EXAMINATION OF THE WEAK-INTENSITY MAGNETIC FIELD ACCOUNT FOR ANOMALOUS HAUNT-TYPE EXPERIENCES

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ABSTRACT

A growing number of laboratory studies have shown that anomalous haunt-type experiences can be artificially induced by applying temporally complex, weak-intensity magnetic fields to the outer cortex of the brain. Although this neuromagnetic field theory has merit, it is important to place the account in an appropriate context based on the best available evidence. The present paper discusses the magnetic field account, its biophysical plausibility and its limitations. Important findings from high-intensity and mid-intensity magnetic field studies, as well as weak-intensity magnetic field studies, are reviewed. A discussion of a recent failure to replicate the effects of weak magnetic fields on consciousness is also provided. It is argued that future research should concentrate on independent double-blind laboratory-based replications of the effects and on producing more explicit biophysical mechanisms for an interaction between weak magnetic fields and the human brain. Some novel speculations on potential mechanisms of interactions between weak magnetic fields and the brain are also suggested. It is concluded that, although the magnetic field account has much to commend it, it is important to acknowledge that it is neither uncontroversial nor comprehensive in its current form.

INTRODUCTION

What makes a house *haunted?* What factors contribute to some locations, and spaces within them, becoming associated with anomalous haunt-reports? Contemporary research into apparitions has suggested that in order to answer questions like these a comprehensive examination of the location, the observer, and the interaction between location and observer is needed (Braithwaite, 2004; Braithwaite, Perez-Aquino & Townsend, 2005; Braithwaite & Townsend, 2005; Houran, 2000; Lange & Houran, 1997, 2001). Interestingly, field-based investigations of reputedly haunted locations have identified a number of potential factors that appear to enjoy some statistical relationship with clusters of anomalous reports. These factors include: (i) low lighting levels, (ii) ambiguous sources of stimulation, (iii) the presence of draughts, (iv) room size, (v) contextual and suggestive furnishings, and (vi) localised magnetic fields (Braithwaite, 2004; Braithwaite et al., 2005; Braithwaite & Townsend, 2005, in press; Houran, 2000; Lange & Houran, 1997, 2001; Persinger, 1988; Persinger & Koren, 2001; Persinger, Koren & O'Connor, 2001; Persinger, Tiller & Koren, 2000; Richards, Persinger & Koren, 1993; Roll & Persinger, 2001; Wiseman, Watt, Greening, Stevens & O'Keeffe, 2002; Wiseman, Watt, Stevens, Greening & O'Keeffe, 2003: see also Brugger, 2001; McCue, 2002 for a discussion).

With respect to magnetic fields, the basic suggestion is that specific spaces associated with haunt-reports may contain weak-intensity yet temporally complex magnetic fields that may have the capacity to alter ongoing neural activity (see Persinger, 2001; Persinger & Koren, 2001a for a review). A consequence of this biophysical interaction is that discrete changes in neurophysiology may vary in sympathy with the temporal complexity of the magnetic field—culminating in altered states, delusory attributions and, possibly, sensory hallucination. The clear and testable prediction is that these magnetic fields could be present at some reputedly haunted locations and may well underlie a number of haunt-reports (Persinger et al., 2001; Persinger & Koren, 2001a; Persinger & Richards, 1994; Persinger, Richards & Koren, 1997; Roll & Persinger, 2001).

According to Persinger's magnetic field hypothesis, these fields can be crucial for inducing anomalous experience in certain observers (who may also display an increased degree of neuronal vulnerability: see Persinger, 1983, 1984, 1987, 2001). However, while it may be argued that magnetic fields may have an important role to play in some cases, their impact may be bolstered by other psychological, situational and contextual factors. In the absence of these other factors, the potential for magnetic fields to influence experience may be greatly reduced or such fields may even be rendered redundant.

For example, independent research from Houran and colleagues (Houran, 2000; Lange & Houran, 1997, 2001), from Braithwaite and colleagues (Braithwaite et al., 2005; Braithwaite & Townsend, 2005, in press) and from Wiseman and colleagues (Wiseman et al., 2002, 2003) has suggested that the stimulatory potential of such magnetic fields might be increased if they exist within certain 'spooky' experiential contexts and in the co-presence of contextually loaded visual and semantic stimuli (e.g. gothic architecture and contexts provided by ancient castles, halls and old houses). This could happen in a number of ways. One possibility is that the magnetic fields and experiential context work in concert to manipulate non-specific arousal and expectation in certain susceptible observers. This may be sufficient to initiate a neurocognitive cascade process resulting in transient micro-seizures in specific brain regions which are implicated in high-level cognition, emotion, imagery and memory. Such a process could be analogous to certain forms of experiential reflexive seizure (sometimes called psychogenic seizure), where patients can induce seizure and aura experiences merely by concentrating on particular thoughts and memories (where neural events are initiated by cognitive states: Fenwick, 1991; Martinez, Reisin, Andermann, Zifkin & Sevlever, 2001). Alternatively, the magnetic components may have generic effects on arousal which then may bias subsequent interpretations, and impressions of ambiguous stimuli that occur within this context, towards a paranormal interpretation (Beyerstein, 1999; Houran, 2000; Lange & Houran, 1997, 2001). The source of the ambiguous stimuli could be in the immediate microenvironment (in the form of bangs, raps, draughts, fleeting visual effects, shadows, etc.) or indeed may be entirely internally driven (i.e. from within the brain itself). Irrespective of the source, once such ambiguous signals are provided in contextually loaded environments, a paranormal interpretation can now occur. This may also have reciprocal feedback implications where such biased interpretations and attributions lead to subsequent increases in arousal and a heightened suggestive state in the observer. The implication is that even the same ambiguous stimuli (e.g. a simple bang) may elicit responses of different magnitude depending on the dynamic and ever changing state of arousal in the observer. All these more comprehensive accounts suggest that the effects of magnetic fields may well be mediated by other contributory factors in the natural situation and in the observer. Thus anomalous magnetic fields, on their own, may not be sufficient to induce haunt-type perceptions in observers—but when and where they are present, experiences may be more striking and sustained (Braithwaite et al., 2005; Braithwaite & Townsend, 2005; Houran, 2000; Lange & Houran, 1997, 1999, 2001; Lange, Houran, Harte & Havens, 1996).

The argument that weak-intensity (<10,000nT) magnetic fields could be implicated in some instances of haunt-type reports has been based on three main strands of evidence. These are: (i) correlational studies examining the relationship between changes in the general geomagnetic field and the incidence of anomalous reports, (ii) field-based studies of reputedly haunted locations and specific regions within them, and (iii) laboratory studies where complex magnetic fields have been applied to the brains of observers (see Persinger, 2001; Persinger & Koren, 2001a, for a review). Correlational studies argue that anomalous reports are influenced by small rises or drops (usually around 40nT–60nT) in the Earth's geomagnetic field (Persinger, 1985, 1988, 2001; Persinger & Koren, 2001a). These studies are perhaps the most questionable and the least convincing. For example, the magnetic field measurements that make up the background geomagnetic indices are typically based on averages which span thousands of miles and may even represent averages based on generalised measurements from around the world. It is difficult to see how very small changes in such general averages could have such specific and localised effects, for a minority of people, in particular regions.[1] The magnetic field variability available from just walking through the average home will be far greater than that available from geomagnetic sources and so the problem becomes one of how such small and general background transients could exert an influence in the presence of more localised, specific and far stronger sources (see also Rutkowski, 1984, for other criticisms). In addition the degree of change that occurs in the geomagnetic field is not only small, but also very slow.[2] As discussed below, this stands in contrast to the laboratory evidence, which suggests fast-changing temporally complex fields are important for inducing neurophysiological changes. Furthermore, although such interactions between weak geomagnetic fields and neural processes are

[1] Note: in support of this, the mid-intensity magnetic field research (which is discussed later in the paper and is often ignored in parapsychological debates on this issue) employs magnetic fields many tens of thousands of times stronger than that seen in background geomagnetic variations in order to elicit any neruophysiological effects in highly vulnerable brains.

[2] One reviewer suggested that Schumman resonances could be important with respect to these effects. However, this is unlikely for the following reasons. Firstly, Schumman resonances are incredibly weak (typically lower than 0.5nT). Secondly, they are also far too diffuse—indeed they are everywhere. The explanatory gap for these common, though frustrating, ideas is how such an incredibly weak and generic source can have highly specific localised influences. Adding the notion of some people being epileptic also fails to make the account work, as seizure occurrence and epilepsy are more common than striking haunt-reports and according to some authors (Persinger & Koren, 2001a) epileptiform EEG traces are very common amongst believers in the paranormal. This would predict far more numerous reports than surveys have revealed. That being so, a convincing biophysical causal case for geomagnetic sources and Schumman resonances in anomalous reports has yet to be made.

theoretically possible it is important to acknowledge that a plausible and testable mechanism for such an interaction in humans has proved elusive.

Field studies have tried to quantify the magnetic fields in reputedly haunted locations and compare them against appropriate baselines (see Braithwaite, 2004; Braithwaite et al., 2005; Braithwaite & Townsend, 2005; Wiseman et al., 2002, 2003 for examples). The logic here is that if magnetic anomalies are implicated in a case of a haunting, then such anomalies should be measurable in the specific regions associated with haunt-reports and be absent in the baseline regions. There have been some notable instances of anomalous magnetic fields being identified in some cases (see Persinger & Koren, 2001a). More recently, the technology and methods for investigating the spatio-temporal structure of anomalous magnetic fields (and their stimulatory potential) has improved and is proving to be very revealing (Braithwaite, 2004; Braithwaite et al., 2005; Braithwaite & Townsend, 2005, in press). Although more direct and methodologically superior to correlational studies, field studies, on the whole, are only capable of supporting an association between the locations where haunt reports occur and anomalous magnetic fields are found. That is to say, they do not necessarily establish a causal link between the two factors. Nonetheless, a causal link would require a clear association in the first place and so this does provide an important line of investigation into the magnetic field hypothesis (even more so if the amplitudes and temporal complexities are similar to those employed in laboratory studies). Indeed, if no association is found then there is no stimulatory process to be had. The only way to provide evidence for a causal account would be to manipulate the magnetic fields directly, apply them to the brains of observers, and measure behavioural and neurophysiological responses to these fields (relative to appropriate baseline conditions).

Laboratory studies have shown that anomalous perceptions and impressions can be artificially induced in the observer by applying temporally complex, weak-intensity magnetic fields to the brain (Cook & Persinger, 1997, 2001; Persinger, 1988, 1999, 2001, 2003; Persinger, Koren & O'Conner, 2001; Persinger & Richards, 1994; Persinger, Richards & Koren, 1997; Persinger, Tiller & Koren, 2000; Richards, Persinger & Koren, 1993; see Persinger & Koren, 2001a, 2001b for a review). The likelihood of an interaction between the applied field and a neuronal response is increased if individuals have an increased degree of neuronal vulnerability (e.g. certain forms of epileptiform activity: Cook & Persinger, 2001; Makarec & Persinger, 1990, 1987; Persinger & Makarec, 1986, 1993; Persinger & Koren, 2001b).

According to Persinger, anomalous perceptions can arise because these temporally complex magnetic fields are capable of inducing partial micro-seizures in temporal-lobe regions and the deep sub-cortical structures they house (i.e. the hippocampus/amygdala: see Persinger & Koren, 2001a). The essence of the account is that the induced micro-seizure can cascade through the neural landscape with sufficient intensity, endowing internal thoughts, images, memories, feelings and emotions with enough activation that they become recruited into, and embellish, current ongoing perceptions (Persinger & Healey, 2002; Ruttan et al., 1990). The outcome is a very real, yet very hallucinatory, experience.

Problems with the Weak-Intensity Laboratory Studies

With respect to the weak-intensity laboratory studies (< 10,000 nT) there are some issues that are worth highlighting. Although some laboratory studies that have produced positive effects have been run under what appear to be single-blind conditions, only one study appears to have been carried out under double-blind conditions (Granqvist et al., 2004: although this design is questionable for other reasons, as discussed below). To count as truly double blind in this context none of the experimenters running or even analysing the experiment (or the participants taking part) should be aware of which sessions contained the baseline sham fields and which sessions contained the crucial magnetic fields. If such procedures have been carried out, then they have not been clearly reported. In addition, there is a real need for independent laboratories to attempt to replicate the effects reported by the prominent laboratory associated with them. Granqvist et al. did attempt to replicate the effects reported from Persinger's laboratory and did indeed employ a double-blind procedure. This study failed to find an effect of weak magnetic fields impacting on experience and only found a role for prior belief and suggestion.

However, there were some important shortcomings with the Granqvist et al. (2004) study which should be noted. For instance, the study used a between-subjects design where different participants were subjected to the sham baseline condition and the magnetic field condition.[3] It would have been preferable, with these types of experiments, to have people act as their own controls, and so a within-subjects design should have been preferred. A between-subjects design would only have added more noise and more between-brain variability to the study. In this sense, the Granqvist et al. (2004) study is not a straight replication of the Persinger protocol. Secondly, the field exposure times for the crucial magnetic waveforms (the Thomas pattern) were relatively short and conservative (15 mins). Although such short durations have been employed, 20–40 mins is more typical for the use of that particular waveform (see Persinger 2001; Persinger & Koren, 2005 for discussions). It seems odd to go to all the trouble to run a much needed double-blind study and not at least give the effects as much chance as possible of emerging. Had the Granqvist et al. (2004) study used a stimulation period of, say, 40 mins, and employed a double-blind within-subjects design, yet failed to observe an effect, this would have provided a far stronger case against the magnetic field account. Therefore, it would appear that the definitive independent double-blind replication study has yet to be carried out.

Persinger has criticised the Granqvist et al. (2004) study by claiming that the fields used may not have been appropriate for eliciting a neurological response (for example in not including appropriate temporal characteristics of the waveforms; see Larsson, Fredrikson, Larhammar & Granqvist, 2005 for a reply). Persinger & Koren (2005) have argued that Granqvist et al. (2004) ran the stimulatory procedures on a PC through the Windows operating system, which would have distorted the temporal profiles of the fields applied.

[3] Although never explained, this is probably because double-blind procedures are arguably more easily implemented with between-subject designs.

It is very difficult to achieve highly accurate timings through modern PC operating systems. However, it is not clear how far distorted the fields would have been from those required. If the argument is that this procedure slightly distorted the crucial time-based nature of the applied fields, to the point that they would not have biophysical effects, then the question becomes one of 'At what point does temporal complexity become sufficient to induce biophysical effects?' Or, to put it another way, 'At what point is temporal complexity temporally complex enough?'

This leads to a related issue with this line of argumentation. Persinger has suggested that as the amplitude levels employed in the laboratory studies are commonly available in the natural environment, the effects have a considerable amount of applicability to the natural setting (Persinger 2001; Persinger & Koren, 2001a). However, in his criticism he seems to be making the argument for a very special role for only certain forms of temporal patterns. Persinger's argument that a PC operating system can sufficiently distort the magnetic field so as to render it completely neurophysiologically benign suggests that a high degree of temporal specificity may be necessary to elicit effects. If complexity is a very specific factor then presumably this would limit its applicability to haunt-reports in general, as such specific complexity is unlikely to be commonly available (though the debate is not at all clear on this issue). There is certainly some friction between the notion that the magnetic fields hypothesis could be applicable to a host of haunt-type instances, as the amplitudes required are commonly available (increasing its ecological applicability), and the notion that very specific types of time-based complexity are necessary (reducing its ecological applicability).

Magnetic Stimulation and the Brain

There are two well-known methods of non-invasive magnetic brain stimulation and, for the purposes of this discussion, they should not be confused. One method of stimulation is known as Trans-Cranial Magnetic Stimulation (TMS; see Walsh & Pascual-Leone, 2003). TMS employs high-intensity magnetic pulses of simple temporal structure. The other method of stimulation is known as Trans-Cerebral Magnetic Stimulation (TCS: see Persinger, 1988, 1999; Persinger & Koren, 2001). TCS employs weak-intensity magnetic fields with a complex spatio-temporal structure. Due to important differences between the amplitudes and time-based profiles of the fields employed, it is unlikely that they share the same biophysical mechanism. Both procedures are discussed more fully below.

Trans-Cranial Magnetic Stimulation (TMS)

At the neuronal level the biophysics of Trans-Cranial Magnetic Stimulation (TMS) is relatively well known and widely accepted (see Lomber & Galuske, 2002; Walsh & Pascual-Leone, 2003 for detailed reviews). The biophysics of TMS revolves around the known physical laws of electromagnetic induction. This technique involves the use of an intense high-amplitude, focused magnetic pulse (or series of repetitive pulses—rTMS) that are easily capable of inducing large currents within neural systems in the outer cortical surface of the brain. The TMS pulse will directly and randomly excite only those neurons that fall within the spatial scope of that pulse (though the effects may then propagate over considerable neural distance through neural signalling). The electric field elicited in neural tissue by TMS is oriented perpendicular to the magnetic field and the subsequent induced currents in the brain flow in a direction parallel to the stimulatory coil (see Lomber & Galuske, 2002 for detailed discussions of the technique).

In order to have the capacity to impact on the brain almost instantaneously, the amplitudes used in TMS are very high and are usually around the 1-Tesla range (often 10%–30% less than the maximum of the coil). The pulses themselves have a fast rise time of around 200µs (microseconds), can provide a pulse for around 1millisecond (ms) temporal duration with an approximate 1cm spatial resolution at the neural level. The electromagnetic induction process states that the success of inducing such currents in the brain is linked to the rate of change in, and the overall intensity of, the stimulatory magnetic field. Interestingly, rTMS, which employs a train of pulses of a fixed and given amplitude (which employs a biphasic stimulation profile) can induce currents in the brain at lower field intensities than single pulse conditions (which employ monophasic profiles: McRobbie & Foster, 1984). In other words, neurons are more sensitive to lower intensity fields, if those fields are part of a repetitive sequence of stimulation as opposed to an isolated singular pulse.

It is important to note that even at these high amplitudes it is not possible to accurately target and directly stimulate deep brain structures buried beneath the outer cortex of the brain. However, it may well be the case that the successful disruption induced in localised cells can then propagate to other secondary structures which enjoy massive reciprocal connections with the region being directly stimulated. In addition, the relatively instantaneous biophysical mechanism outlined by artificial TMS procedures is unlikely to operate in the natural environment, as the high-intensity magnetic fields required are not freely available. To truly appreciate the intensity of the fields used in TMS studies it is worth bearing in mind that the Earth's background geomagnetic field is around 50,000nT in the UK. Changes in the geomagnetic field are very slow (they take many tens of seconds and minutes) and are weak (around 300nT during severe magnetic storms). In TMS the fields generated are around 1,000,000,000nT (1 billion nT or 1 Tesla) and, as noted above, this large change occurs in under 200µs.

Trans-Cerebral Magnetic Stimulation (TCS)

In contrast to TMS, Trans-Cerebral Stimulation (TCS) uses very weak intensity, temporally complex magnetic fields to induce neural and cognitive changes in the brain (Persinger, 2001). The fields employed in TCS are generally in the nanoTesla (nT) and microTesla (µT) range and of low frequency (typically <30Hz). Amplitudes in the 1000nT to 10,000nT range are typical (1µT–10µT). These fields are then often pulsed, to create a complex temporal sequence of magnetic variability. Indeed, the amplitude, rise time, fall time, and delay time between pulses (and pulse-train sequences) can all be varied to create highly complex sequences of constantly varying magnetic fields. It has been argued that such field complexity rather than actual excessive field magnitude is the crucial factor for eliciting responses in neuronal systems (Persinger & Koren, 2001a; Persinger & Richards, 1994; Persinger et al., 1997).

Importantly, unlike TMS, this method of stimulation does not induce immediate changes and effects, with participants generally undergoing 20–40 mins of exposure before the effects on experience are reported. In addition, the spatial resolution of TCS is not as specific, as these fields are applied in a much more general way to whole regions (e.g. lobes) of the brain at a time. Also it is typical with TCS to reduce sensory input (blindfolds, earmuffs, etc.) during experimental stimulation. Furthermore, the effects appear to be general, nebulous and non-specific. It may well be the case that the content of the reported experiences induced by TCS is being influenced by pre-existing belief systems and expectations of the observer, or the immediate experiential context at the time of the experience. These latter factors can be responsible for anomalous reports on their own and as such highlight the fact that, for many cases, magnetic fields are neither necessary nor likely to be sufficient for anomalous reports to occur.

It is clear from the descriptions above that the methods of TMS and TCS stimulation are quite distinct and produce diverse effects. TCS does not seem to induce a direct current in the brain in the manner that the high amplitude TMS is known to do. It is difficult to see how the same biophysical method of induction could occur at such low amplitudes. The traditional view is that neurons are somewhat leaky capacitors and require sudden and intense changes to overcome this; otherwise the energy trying to induce depolarisation (firing) in the neuron dissipates before depolarisation is complete (due to leakage). It may well be the case that some further processes need to be speculated for the more prolonged effects of TCS. Furthermore, the long (20–40 min) exposure time strongly implies a more subtle and indirect mechanism. The stimulatory effects of TCS, though well documented, certainly appear to be more subtle, nebulous and indirect.

Effects from Mid-Intensity Magnetic Fields

Other independent studies have employed far stronger (yet still relatively weak: 60,000 nT–400,000 nT / 60 μT–400 μT) mid-intensity fields, with simpler temporal sequences, over shorter exposure periods, and have reported changes in electroencephalographic activity (EEG) in the absence of any notable experiential changes (Bell, Marino & Chesson, 1992, 1994; Bell, Marino, Chesson & Struve, 1991; Cook, Thomas & Prato, 2002, 2004; Dobson, St Pierre, Wieser, Fuller, 2000; Fuller, Dobson, Wieser & Moser, 1995). These mid-intensity studies have typically employed brief simple pulses which are usually far more intense than those employed in Persinger's research. In addition, the stimulation procedure also differs in that these mid-intensity studies use a train of simple (constant magnetic amplitudes applied in a simple field-on and field-off manner) magnetic pulses that are applied in very brief bursts with EEG responses being measured during the field-off period between pulses (see Table 1 for a summary of high, weak and mid-intensity techniques).

The aim of these studies has been to establish the basic tenet of a biophysical reaction to the application of such mid-intensity fields. They have not typically been concerned with experiential responses and have rarely tried to elicit them (see Bell et al., 1991, 1992, 1994; Dobson, et al., 2000; Fuller, et al., 1995 for examples). The effects from mid-intensity fields have been documented with

Table 1

The Physical Characteristics of the Different Levels of Intensity Typically Employed in Magnetic Field Stimulation Studies. Low-Intensity Studies have been Associated with Haunt-Reports

Intensity	Levels	Temporal structure	Spatial structure	Response
High-intensity	1 Tesla (1,000,000,000 nT)	Simple	Focused	Instant
Mid-intensity	60,000 nT – 400,000 nT	Simple	Less focused	Soon after application
Weak-intensity	1000 nT – 10,000 nT	Complex	Diffuse	Latent (usually after 20 mins exposure)

normal observers and epileptic patients who display problems with the inhibitory regulation of neural activity. Some research suggests that the application of these fields can induce epileptiform activity in the epileptic brain or can reduce inter-ictal spiking and even stop seizures from taking place (Dobson, et al., 2000; Fuller, et al., 1995) — though other studies have found that the epileptic brain is no more susceptible to the application of such fields (again as measured by EEG responses: Bell et al., 1992). Nevertheless, collectively these mid-intensity studies lend support to the notion of a non-induction-based coupling or interaction process between the applied magnetic field and ongoing dynamic neural processes.

Some Speculations and Problems on the Biophysics of Weak Magnetic Fields

It is important to point out that the specific biophysics of how complex, low-intensity magnetic fields impact on the brain and influence experience, is somewhat obscure. This has led to some controversy over the biophysical plausibility of weaker intensity magnetic fields impacting on neural processing (see Adair, 1991, 1992, 1994, 1998; Baureus-Koch, Sommarin, Persson, Salford & Eberhardt, 2003; Del Giudice, Fleischmann, Preparata & Talpo, 2002; Gailey, 1999; Moulder & Foster, 1995). A good deal of the controversy stems from thinking being influenced solely by the electromagnetic inductive model (as discussed earlier for TMS effects). Inductive models state that the stimulatory magnetic field must induce a current higher than the inherent noise available in the neuron or neural systems. However, at the neuronal level, the energy associated with weak-intensity magnetic fields is several orders of magnitude lower than that which is necessary to overcome the existing energy parameters associated with ongoing electrochemical processes. According to this account, any energy weaker than that already inherent to, and available in, the system is unlikely to be detected by that system.[4]

[4] One alternative suggestion is that an interaction could be mediated via stochastic resonance processes (Stevens, personal communication) between noisy systems, but this remains highly speculative at the present time.

These observations are fair and legitimate concerns. However, these arguments are tied to the notion that electromagnetic induction is the *only* manner via which a biophysical interaction could occur. If one makes this assumption, then any situation that is not sufficient to produce such induction cannot lead to a neuronal and experiential response. From this viewpoint it would seem that low-intensity magnetic fields have no consequence for neural processing at all (since electromagnetic induction is biophysically implausible at these low amplitudes).

However, recent evidence suggests that patterns of activity across neuronal systems might not just be influenced by the impact of instantaneous large currents alone—but also by more graded and indirect processes that may lead, somewhat further down the cascade process, to depolarisation and neural firing. Most current theories posit a variety of mechanisms operating at the ionic level—with calcium {Ca^2}, and potassium {K^2} being frequently suggested (Engstrom & Fitzsimmons, 1999; Konig, Fraser & Powell, 1981; Lednev, 1991; McLeod & Liboff, 1986; Mcleod, Smith & Liboff, 1987; though see Adair, 1994, 1998).[5] Some of these and other studies have suggested various forms of ionic resonance phenomena (i.e. ion cyclotron resonance: cf. Leboff, 1992; McLeod & Liboff, 1986) which also appear to demonstrate particular responsive windows to certain amplitude and frequency combinations (Liboff et al., 1987; Blanchard & Blackman, 1994). However, this has been criticised by some as being implausible (see Halle, 1988). Both classical physical accounts (Zhadin, 1998) and quantum mechanical accounts for an interaction have also been suggested (Hart, 1990; see Baureus-Koch et al., 2003 for a discussion)—but these have also been strongly criticized (Adair, 1998). More recently, some studies have shown that the principle of large ionic current responses can be induced by the simultaneous application of a weak static and much weaker time-varying magnetic field—but again this occurs only over a certain range (window) of amplitude and frequency combinations (Del Giudice, et al., 2002).

Other ideas have drawn upon the recent discovery of ferromagnetic biogenic magnetite particles {Fe_3O_4}, which are particularly prominent in the most seizure-prone regions of the brain, the hippocampus (Dobson & Grassi, 1996; Dobson, St Pierre, Wieser & Fuller, 2000; Dunn et al. 1995). The existence of such highly magnetic particles in the brain may certainly be one means by which interactions between external magnetic fields and neural activity might occur. However, more recently it has been suggested that magnetite-based responses are fast-acting and fleeting and possibly too transient on their own to mediate large-scale neural changes over prolonged periods of time (though they may form part of a more comprehensive mechanism involving other later-acting factors: Fuller & Dobson, 2005).

Irrespective of the mechanisms potentially underlying such biophysical interactions, a host of studies have provided evidence that it is the *change* in magnetic field rather than its mere presence which may be the particularly

[5] Note: most of the studies discussed here employ mid-intensity magnetic fields to establish the premise of a non-induction-based coupling mechanism between magnetic field and brain. The logic is that if such a mechanism exists at these amplitudes it should also hold for relatively weaker fields (to a degree).

active component for eliciting neuronal responses in susceptible brains (Cook, Thomas, Keenliside & Prato, 2005; Cook, Thomas & Prato, 2004; Dobson et al., 2000; Dobson, St. Pierre, Paola, Schultheiss-Grassi, Wieser & Kuster, 2000; Fuller, Dobson, Wieser & Mozer, 1995). The somewhat metaphorical suggestion is that constant complexity in the stimulatory field may prevent the brain from habituating to it, and thus effectively filtering it out.[6]

Irrespective of the specific underlying mechanism, the outcome from such coupling must be the same—neuronal excitation (i.e. partial micro-seizure). Such excitation may come about by the unusual and increased involvement of the specific ionic and synaptic processes that lead to depolarisation and firing, or failures in the processes which mediate inhibition (leading to disinhibition or inhibitory failure—which also leads to excitation). It may even occur if an inhibitory neuronal network is itself inhibited (hyper-polarised) — releasing other neurons downstream from their usual modulatory action. All these circumstances can lead to increased neural excitation and its increased propagation through the neural landscape.

One consequence of a biophysical interaction could be the emerging presence of slow DC shifts in the baseline membrane potentials of neuronal assemblies, moving them more gradually towards firing thresholds (depolarisation) until eventually this shift is sufficient for whole populations of neurons to become excited. Although ultimately the slow-acting DC shifts may occur directly within the neurons, such shifts may also be sub-served within interneurons or glial cells in the neocortex (which do not fire—but have a direct effect on firing neurons). Baseline shifts in membrane potentials can be slower and more graded before reaching some critical value with the capacity to then impact on the generation of action-potentials and paroxysmal burst-firing. These firing action-potentials may then ride on the back of such slow-acting DC shifts. Such mechanisms of complex firing have now been identified and do form part of contemporary seizure-based models (see Somjen, 2004 for an extensive review). At the neuronal level the result would be disinhibition of local neuronal cell assemblies; at the cognitive level this could result with internal representations becoming excessively activated, and thus they may compete with external information to represent the contents of consciousness or subsequent attributions about them. While these mechanisms remain a tantalising possibility, it is important to be clear that they are also, at the time of writing, largely speculative.

Weak-Intensity Fields: Future Research

At present the evidence for the effects of weak-intensity magnetic fields on the brain and human experience (including anomalous human experience) appears sufficient to warrant considerable further investigation. The effects on EEG and behaviour implicate some form of coupling mechanism between magnetic field and brain. However, future research needs to make scientific improvements in two main ways. These improvements can be thought of as improvements in *'proof-oriented'* research and improvements in *'process*

[6] Which is problematic for the claimed geomagnetic effects (discussed earlier), where such changes are incredibly small and very slow.

oriented' research. To improve proof-oriented research there is a real need for independent laboratory replications, under appropriate double-blind conditions, to be carried out (following the lead of Granqvist et al., 2004). A major principle of science is that such effects should be independently replicable. This principle stands even for subtle effects.

Improvements in process-oriented research need to come in the form of more explicit, testable biophysical mechanisms for the effects of weak-intensity fields to occur. Indeed, there may well be more than one mechanism capable of generating coupling effects between the magnetic environment and the brain. The different mechanisms may work in concert or may work under specific and discrete contexts. In addition, the delineation of the spatio-temporal characteristics required to endow a magnetic field with experience-inducing properties needs to be examined. Obviously, at such weak intensities, experiencing inducing effects may also be co-dependent on other factors such as context, levels of arousal, cognitive biases and neurophysiological susceptibility. Nonetheless, the establishment of some principles of what is both necessary and sufficient across a variety of combinations would be a major advance in this field of research.

Putting Magnetism in its Place

The idea that magnetic fields may be implicated in some instances of haunt-reports is a growing and influential one. One possibility is that such fields could be a relatively common cause of haunt reports in the spontaneous natural setting. Although the suggestion of an effect between low-intensity magnetic fields and strange experience has merit, this effect is unlikely to be a common cause of haunt reports and, almost certainly, is not as common as other psychological factors such as expectation, prior-belief, suggestion and cognitive biases. Based on personal evidence from my own cases, I have encountered two instances (from around 45 cases in total) where quite striking localised magnetic fields have been measured in specific regions also associated with anomalous haunt-type reports (one of which has been detailed in the literature: Braithwaite, 2004; Braithwaite, Perez-Aquino & Townsend, 2004; Braithwaite & Townsend, 2005). Even if we accept that these fields may be causally involved in the experience of a haunting (which has still to be demonstrated), this still suggests only around 5% of cases where such fields are implicated. This means we require quite different explanations for the remaining 95% of cases (this is also around the level of a statistical borderline—though much more research is required before any firm conclusions can be made for those field studies as a whole).

The evidence for weak low-intensity temporally complex magnetic fields impacting on conscious experience is not incontrovertible. Correlational studies are perhaps the most controversial and least helpful to the debate (see Rutkowski, 1984). Field-based investigations are providing a more detailed account of the spatio-temporal magnetic anomalies that might by associated with haunt reports, though they are insufficient on their own to support a causal account. Laboratory studies have the potential to provide the most useful, direct and reliable evidence. However, the need for independent laboratories to carry out appropriate replications under double-blind conditions has never been greater.

The evidence for high-intensity magnetic fields exerting an effect (TMS) is not controversial, and the underlying biophysics is reasonably well understood. Investigations using mid-intensity fields have reported neurophysiological responses in the brains of observers for both normal and epileptic patients—though the mechanisms for these effects, and those of low-intensity fields, remain elusive. The lack of explicit accepted mechanisms for the effects of low-intensity fields does not make the account biologically implausible, although it does make it biologically obscure (at least based on the recent evidence). Candidate mechanisms have been proposed and are currently being explored. The evidence is certainly mixed but sufficient *prima facie* evidence of good quality exists to warrant a dedicated approach to investigating the subtle and somewhat non-specific neuromagnetic account. However, the lack of a clear mechanism, or collection of mechanisms, should be openly acknowledged and provide the context for present and future theorising (at least until this situation is resolved). Perhaps a useful and parsimonious view for the evidence currently available is one that acknowledges the possibility and plausibility of an effect, but admits that it is an effect which is rare, non-specific, and requires considerable further investigation.

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