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Neuromagnetic Effects on Anomalous Cognitive Experiences

A Critical Appraisal of the Evidence for Induced Sensed-presence and Haunt-type Experiences

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Abstract

A growing number of laboratory studies have shown that anomalous sensed-presence experiences can be artificially induced by applying temporally complex, weak-intensity magnetic fields to the outer cortex of the brain. The present paper discusses this neuromagnetic account, its biophysical plausibility and its limitations when applied to spontaneous experiences. It is argued that future research should concentrate on both independent laboratory-based replications of the effects and on producing more explicit biophysical mechanisms for an interaction between weak complex magnetic fields and the human brain. It is concluded that although the neuromagnetic account has much to commend it, it is important to acknowledge that it is neither uncontroversial nor comprehensive in its current form.

Key Words: neuromagnetic effect, anomalous cognitive experiences, sensed-presence

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Introduction

What factors make a house 'feel' haunted? What factors contribute to some locations, and spaces within them, becoming associated with anomalous sensed-presence and haunt-type reports? To effectively answer questions like these, it has been suggested that a comprehensive examination of the statistical properties of the location, the observer, and the interaction between both location and observer is needed (Braithwaite, 2004; Braithwaite, Perez-Aquino & Townsend, 2005; Braithwaite & Townsend, 2005; Houran, 2000; Lange & Houran, 2001, 1997).

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 in the spontaneous setting. 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 complex magnetic fields (Braithwaite, 2004; 2008; Braithwaite *et al.,* 2005; Braithwaite & Townsend, 2005; Houran, 2000; Lange & Houran, 2001, 1997: 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).

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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 which 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 sensed-presence and haunt-type reports (Persinger *et al.,* 2001; Persinger & Koren, 2001a; Persinger & Richards, 1994; Persinger, Richards, & Koren, 1997; Roll & Persinger, 2001).

According to this 'neuromagnetic' account, these fields can be crucial for inducing anomalous experience in certain observers (who may also display an increased degree of neuronal vulnerability: see Persinger, 2001, 1987, 1984, 1983). 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 even redundant.

For example, independent researchers have 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 available in the spontaneous setting (i.e., gothic architecture and contexts provided by ancient castles, halls and old houses: Braithwaite, 2008; Braithwaite *et al.,* 2005; Braithwaite & Townsend, 2005; Houran, 2000; Lange & Houran, 2001, 1997). 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 paroxysmal events in specific brain regions. 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, 2001, 1997). The source of the ambiguous stimuli could be from the immediate microenvironment (in the form of bangs, raps, draughts, fleeting visual effects, etc.) or indeed may be entirely internally driven (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. 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. As such, complex magnetic fields, on their own, may not be sufficient to induce sensed-presence / haunt-type perceptions in observers in the natural setting – 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, 2001, 1999, 1997; Lange, Houran, Harte, & Havens, 1996).

The neural effects of complex weak-intensity magnetism: The evidence

The argument that weak-intensity (< 10,000nT) magnetic fields could be implicated in some instances of haunt-type reports has been made based on three main strands of evidence. These are; (i) correlational studies examining the relationship between changes in the general background 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). Each is examined here below.

Correlation studies

Correlation studies argue that anomalous reports can be influenced by small rises or drops (usually around 40nT – 60nT) in the

Earth's geomagnetic field (Persinger, 2001; 1988; 1985; 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 really small changes in such general averages could have such specific and localised effects, for a minority of people, in particular regions. The magnetic field variability available from just walking through the common 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. As discussed below, this is in some friction with the research from the laboratory evidence which suggests fast changing temporally complex fields are important for inducing neurophysicological changes. Furthermore, a plausible and generally accepted mechanism for such an interaction between weak magnetic field and the human brain has proved elusive.

Field-based studies

Field studies have tried to quantify the magnetic fields in reputedly haunted locations and compare them to appropriate baselines (see Braithwaite, 2004; 2008; Braithwaite *et al.,* 2004; 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; submitted). The studies of Braithwaite and colleagues have employed high-speed dual sensor time-synchronised digital fluxgate magnetometery to examine both the spatial and temporal characteristics of magnetic anomalies implicated in sensed-presence hallucinations occurring in reputedly haunted locations. These investigations have provided perhaps the most comprehensive attempt to explore Persinger's account in the spontaneous natural setting. Here, both time-varying fields (<125Hz) and distortions in the localised geomagnetic (DC) field can be quantified separately and simultaneously, down to 0.5nT (nanoTesla) in three-dimensions (x,y,z magnetic components) 250 times a second. In addition, these studies developed a protocol of employed time-synchronised measurements from a baseline sensor as well as that quantifying the spaces associated with such hallucinations.

As noted by Braithwaite (2008), this procedure has identified only two of around 50 investigated locations as being associated with magnetic fields that could be described as 'temporally complex'. These instances could not only be termed rare, but also may in fact be coincidental. Although the advancements in precision and measurement are welcome, it remains to be seen whether the waveforms measured and detailed in these studies have any implications for human experience even in a contextually loaded experiential setting.

Although more direct and methodologically superior to correlational studies, field studies are, on the whole, only capable of supporting an association between the locations where sensed-presence and 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 it 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). A causal account would be supported by a direct manipulation where the specific magnetic fields measured at locations were then applied to the brains of observers resulting in reliable behavioural and neurophysiological responses (relative to appropriate sham-baseline conditions where no magnetic field would be applied).

It is also worth pointing out that some of these field studies are not beyond question themselves. For example, in the Wiseman et al (2003) study of Hampton Court Palace, the variability in magnetic fields between the reputedly haunted locations and the baseline locations was statistically significant. It was argued that this supports the studies of Persinger and colleagues and lends weight to the plausibility of the neuromagnetic account. However, in real terms the difference in this variability was only a standard deviation of around 11nT between areas. This is extremely weak and hardly likely to be important in terms of the magnetic field account, at least in terms of the amplitudes and variations employed in laboratory studies (around 10,000nT). In addition, no time-based information about the nature of the magnetic waveforms or their heterogeneity over time was provided and no frequency components were identified (time-based variability is crucial to the neuromagnetic account). Furthermore, the magnetometer employed only sampled the environment very slowly and was simply not capable of measuring the detailed time-based complexity that is argued to be crucial by proponents of the neuromagentic account (Persinger, 2001). Finally, although two sensors appear to have been employed, the measurements taken do not appear to have been time-synchronised (or at the very least, this is not clearly reported) – so any differences measured across difference spaces could not be separated from differences that may have occurred over time. As a consequence, this study does not provide convincing evidence for the neuromagnetic account and may represent little more than a false-positive.

Laboratory studies

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, 2001; 1997; Persinger, 2003; 2001; 1999, 1988; Persinger, Koren, & O'Conner, 2001; Persinger, & Richards, 1994, Persinger, Richards, & Koren, 1997; Persinger, Tiller & Koren, 2000; Richards, Persinger & Koren, 1993; see Perisnger & 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 (i.e., certain forms of epileptiform activity: Cook & Persinger, 2001; Makarec & Persinger, 1990, 1987; Persinger & Makarec, 1993; 1986; Persinger & Koren, 2001b).

According to Persinger, anomalous perceptions can arise because these temporally complex magnetic fields are capable of inducing partial micro-seizures (paroxysmal events) 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 (< 10,000nT) 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-blinded conditions, only one study appears to have been carried out under double-blind conditions (and this is questionable for other reasons – see below). To count as truly double blind in this context none of the experimenters (or participants) running, or analysing the experiment, 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. One recent study did attempt to replicate the effects reported from Persinger's laboratory and did indeed employ a double-blind procedure (Granqvist, Fredrikson, Unge, Hagenfeldt, Valind, Larhammer, & Larsson, 2004). This study failed to find an effect of the 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. It would have been more preferable, with these types of experiments, that people act as their own controls and so wherever possible, a within-subjects design should always be preferred. A between-subjects design would only have added more noise and more between-brain variability to the study. In this sense, it is important to note that the Granqvist et al (2004) study is not a pure replication of the Persinger protocol. It seems odd to go to all the trouble to run a double-blind study and not at least give the effects as much chance as possible of emerging. Therefore, the definitive 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 (possibly due to alterations in the temporal characteristics of the waveforms: see also 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 Windows which would have distorted the temporal profiles of the fields applied. It is very difficult to achieve highly accurate timings through modern PC operating systems. However, it is not clear at all 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 argued that as the amplitude levels employed in the laboratory studies are commonly available in the natural environment, the effects have a considerable amount of ecological validity (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 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 legion of haunt-type instances, as the amplitudes required are commonly available (increasing its ecological validity), and the notion that very specific types of time-based complexity are necessary (reducing its ecological validity).[2]

Procedures for magnetically stimulating the human 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 and Trans-cranial Magnetic Stimulation (TMS: see Walsh & Pascual-Leone, 2003). TMS employs high-intensity magnetic pulses of simple temporal

[2] Of course one could argue that the reduction in time-based complexity is compounded by the other limitations as well and perhaps, in the real world, such variability in time-based complexity is not so crucial as long as it occurs within certain necessary parameters.

structure. The other method of stimulation is known as Trans-Cerebral Magnetic Stimulation (TCS: see Persinger, 1999; 1988; Persinger, & Koren, 2001). TCS employs weak-intensity magnetic fields with a complex spatio-temporal structure.

At the neuronal level the biophysics of Trans-cranial Magnetic Stimulation (TMS) are 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 200us (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. 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 200us.

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 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 – 40mins 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 is clear from the description 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. Other independent studies have employed far stronger (yet still relatively weak 60,000nT – 400,000nT / 60µT – 400µT) 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, & Struve, 1991; Bell, Marino & Chesson, 1992, 1994; Cook, Thomas, & Prato, 2004, 2002; Dobson, StPierre, 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).

Table1. The physical characteristics of the different levels of intensity typically employed in magnetic field stimulation studies. Low-intensity studies have been associated with sensed-presence hallucinations and haunt-type reports

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

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 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). These studies are similar to those employing much weaker complex magnetic fields in that they also argue for a non-induction based coupling or interaction process between the applied magnetic field and ongoing dynamic neural processes.

The biophysics of magnetically induced hallucinations and altered-states of consciousness

It is important to point out that the specific biophysics of how complex, low intensity magnetic fields impact on the brain and influence experience, are somewhat obscure. This has led to some controversy over the biophysical plausibility of weak intensity magnetic fields impacting on neural processing (see Adair, 1998; 1994; 1992; 1991; 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.

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 assumes that electromagnetic induction is the only mechanism for biophysical interactions to occur, then any situation that is not sufficient to produce such induction cannot induce a neuronal and experiential response. From this viewpoint it would seem that low-intensity magnetic fields have no consequence for neural processing at all (as 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 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 {Ca2}, and potassium {K2} being frequently suggested (Engstrom & Fitzsimmons, 1999; Konig, Fraser, & Powell, 1981; Lednev, 1991; McLeaod & Liboff, 1986; Mcleod, Smith, & Liboff, 1987; though see Adair, 1998, 1994). 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 and Blackman, 1994). However, this has been criticised as being implausible by some (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 as being implausible (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 {Fe3O4}, which are particularly prominent in the most seizure-prone regions of the brain (*i.e.,* the hippocampus: Dobson, St Pierre, Wieser, & Fuller, 2000; Dobson & Grassi, 1996; Dunn, Fuller, Zoeger, Dobson, Heller, Caine, & Moskowitz, 1995). The existence of such highly magnetic particles in the brain may certainly be one way via 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 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. The outcome from such coupling must be the same – neuronal excitation. 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 neuronal assemblies moving them more gradually towards firing thresholds (depolarisation) until eventually this shift is sufficient and whole populations of neurons become excited. Although ultimately the slow-acting DC shifts may occur directly within the neurons, such shifts may also be sub-served within inter-neurons 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 of epilepsy (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.

Could stochastic processes underlie a coupling mechanism between weak magnetic fields, neural responses, and anomalous experience?

The presence of 'noise' within an information processing system is typically thought to be detrimental to the effective and efficient computation of information in that system. However, recent research has suggested that under certain circumstances the action of 'noise' in a system can actually benefit the processing of information within that system – via a phenomenon known as 'stochastic resonance' (Benzi *et al.,* 1981). Stochastic resonance (SR) can be defined as a nonlinear phenomenon by which, rather counter-intuitively, the action of additional input noise can improve the performance of signal-detection. That is to say, signals that would normally not reach a given and fixed threshold within a system (and hence not be detected by that system) can be increased so that they can be detected – by the addition of specific noise within that system. According to SR accounts, the initial signal is too small or ill-formed to elicit a response from a non-linear system like the brain and the neural systems it houses. By applying certain forms of additional noise, this amplifies the original small signal and elicits a more efficient response from the nonlinear system, thus overcoming the original given threshold.

Effects of SR have been demonstrated in the fields of biological systems, physics, and mathematical / computational psychology (Binhi, 2006; Stemmler, 1996) and have been postulated as a mechanism within neural and perceptual systems in the human brain (Longtin, Bulsara, & Moss, 1991; Moss, Ward, & Sannita, 2004; Rudolph &

Destexhe, 2001; Simonotto, Riani, Seife, Roberts, Twitty, & Moss, 1997). This latter observation is based on the fact that as spiking neurons can be described as threshold devices and complex neuronal assemblies are known to be non-linear. This has led to the suggestion that noise could be important for the nervous system for enhancing signal detection – where the response of a nonlinear system to a weak input signal is optimized by the co-presence of a nonzero level of noise. Importantly, for SR to occur the noise itself needs to obey certain characteristics – where when optimal, will produce maximal benefits to the detection of the signal, but thereafter additional noise will degrade the signal.

Although SR has been typically explored based on the noise within say, a specific sensory / perceptual system, applied to the present discussion we could wonder if the same would hold for noise applied externally to the system in a non specific way, namely – via the application of temporally complex magnetic fields. If we assume that that the procedure of TCS has the capacity to induce SR phenomena in the brain, then the magnetic fields themselves could be viewed as a source of additional input noise to that system. It follows that perhaps the induced noise resulting from the presence of temporally complex magnetic fields, has the capacity to elicit stronger signals from those brain structures important for mediating imagery, memory, and emotion. As a consequence, signals from these structures may well become more salient and enter or mediate conscious experience. Although this suggestion is highly speculative, the observation that only a small window of 'noise' can induce SR phenomena in the brain and in perceptual systems is in line with those observations that reasonably specific forms of complexity in the magnetic fields are required to induced hallucinatory experiences.

Future research

At present the current 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 non-induction based 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 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. If the effects can be shown across independent laboratories and under appropriate conditions then the need for viable mechanisms of interaction becomes greater. Conversely, if reliable effects are not observed then the need for an explanation becomes redundant.

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. Some suggestions have been outlined here and the notion of stochastic processes is attractive as they navigate around the problems associated with speculations at the quantum level – where there are large explanatory gaps between processes at the micro-minuscule level and observable effects at the macro level. 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, some principles of what is both necessary and sufficient across a variety of combinations would be a major advance in this field of research.

Summary

The idea that magnetic fields may be implicated in some instances of haunt-reports is a growing and influential one. One possibility is that the account could be a relatively common cause of sensed-presence hallucinations and haunt-type reports in the spontaneous natural setting. Although the suggestion of an effect between low-intensity magnetic fields and strange experience has merit – it is unlikely to be a common cause of haunt reports and is, almost certainly, not as common as other psychological factors such as expectation, prior-belief, suggestion and cognitive biases.

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 to exert an effect (TMS) is not controversial and the underlying biophysics are 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 – it makes the account 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-facia 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 them, 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 of an effect, but an effect which is rare and requires considerable further investigation.

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