USING DIGITAL MAGNETOMETRY TO QUANTIFY ANOMALOUS MAGNETIC FIELDS ASSOCIATED WITH SPONTANEOUS STRANGE EXPERIENCES: THE MAGNETIC ANOMALY DETECTION SYSTEM (MADS)

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ABSTRACT: Recent laboratory studies have revealed that human exposure to low-frequency complex electromagnetic fields (EMFs) can induce anomalous hallucinatory and delusional experiences in normal observers. The implication from these laboratory studies is that such EMFs could underlie some spontaneous instances of anomalous cognition in the natural setting. Although the laboratory-based studies are interesting they remain to be systematically field tested with an appropriate methodology and suitable equipment. Based directly on the findings from neuroscience, this paper introduces the first truly appropriate environmental-based measuring system for the systematic recording of the complex magnetic signatures identified as being crucial by the laboratory studies. The magnetic anomaly detection system (MADS) is a fully computerized dual sensor high-speed digital magnetometer system that can be easily adapted to EMF field and laboratory research. The MADS is capable of illuminating scientific theories by detailing the complex characteristics of such anomalous transients and helping assess their implications for cognition.

Multiple magnetic and electromagnetic fields are constantly bathing our brains throughout the course of modern daily life. We have never lived in an environment as magnetically dense as we do today. Recent research suggests that both low-frequency natural geomagnetic fields (GMFs) and man-made power-frequency electromagnetic fields (EMFs) can induce a number of biological, neurophysiological and behavioral changes in humans (Bell, Marino, & Chesson 1992, 1994; Cook & Persinger, 2001; Fuller, Dobson, Wieser, & Moser, 1995; O'Connor, 1993; Papi, Ghione, Rosa, Del Seppia, & Luschi, 1995; Persinger, 1988, 1993; Persinger & Koren, 2001; Persinger, Ludwig, & Ossenkopp, 1973; Randall & Randall, 1991).

For example, variations in such fields have been associated with the onset of abnormal behavior in vulnerable psychiatric populations (Bell et al., 1992; Konig, Fraser, & Powell, 1981), increasing epileptic activity in the brain (Fuller et al., 1995; see Persinger & Koren, 2001), discrete changes in skin conductance (Stevens, 2001), performance at reaction time tasks (Friedman, Becker, & Bachman, 1967), and instances of hallucinations in normal waking adults (Bell et al., 1992, 1994; Cook & Persinger, 2001; Fuller et al., 1995; Gearhart & Persinger, 1986; Persinger, 1988, 1993; Persinger & Koren, 2001;

Persinger, Ludwig, & Ossenkopp, 1973; Persinger, Tiller, & Koren, 2000; Randall & Randall, 1991; Richards, Persinger, & Koren, 1993). Collectively these findings highlight the importance of the modern magnetic environment and its potential implications for cognition, behavior and health. The potential influence from such magnetic signatures also establishes the need for a detailed assessment of the magnetic environment with appropriate technology and methodologies. This paper outlines a fully computerized high-speed digital magnetometry system capable of quantifying crucial complex magnetic environments over space and time.

Hallucination, Magnetic Fields and the Brain

Recently scientists have taken the nature of hallucination very seriously indeed. Cognitive neuropsychologists study brain-damaged patients for two main reasons. Firstly, such studies provide an insight into the nature of any altered performance from those patients in relation to their particular form of damage. Secondly, these studies allow researchers to understand fundamental principals of neural organization and its implications for cognitive function generally in the non-brain-damaged population. In a similar manner, neuroscientists are now looking at both spontaneous and artificially induced instances of hallucination in an attempt to see what such experiences tell us about brain organization and the mechanisms involved.

For example, recent functional magnetic resonance imaging (fMRI) brain-imaging studies have revealed that specific regions of the visual cortex are involved in visual-based hallucinations reported by some clinical populations (ffytche, 2000; ffytche & Howard, 1999; ffytche, Howard, Brammer, David, Woodruff, & Williams, 1998). Similarly, other studies have shown that stimulation of the auditory cortex can induce hallucinations of speech and sounds in schizophrenics and controls (see Penfield, 1955; Penfield & Perot, 1963; Siegal, 1977). Collectively, these studies show a definite neural substrate to the hallucinatory experiences being reported. Similar brain areas involved in processing visual and auditory stimuli from the outside world are also recruited in producing instances of hallucination without any external stimuli. Hallucination is not just a fiction of the fanciful mind; it is an internal reality for the observer with a very real neural substrate.

As well as evaluating spontaneous hallucination in patient populations, researchers can now artificially induce hallucination by applying relatively weak low-frequency magnetic fields to the outer cortex of the normal human brain (Persinger, 1995, 1999; Persinger et al., 1973; Persinger & Richards, 1994; Persinger, Richards, & Koren, 1997; Persinger et al., 2000; see Persinger & Koren, 2001 for a review). This experimental stimulation is revealing not only what brain areas may underlie certain hallucinations but also how such EMFs can interact with neurophysiology itself. Persinger and colleagues have suggested that these complex magnetic fields can cause epileptic-like partial microseizures in the temporal-lobe regions of neuronally hypersensitive participants. The result is hallucination. These experience-inducing fields (EIFs: see Braithwaite, 2004) are described as being a series of weak but very complex electromagnetic fields with the potential to influence human conscious experience. It has been argued that field complexity rather than excessive field magnitude itself is an important factor for inducing these types of experience (Persinger, 1995, 1999; Persinger & Koren, 2001; Persinger & Richards, 1994; Persinger, Richards, & Koren, 1997). The intensity of the fields typically used in the laboratory is generally in the range of 10 nT–1,000 nT, though as much as 5,000 nT have been used in some cases. These fields can be pulsed and emitted in short bursts of around 3–6 ms (milliseconds) duration every 3,000-5,000 ms for a period of 15-30 min. The amplitude of the pulses can also vary within the pulse train sequence. All of these manipulations produce extremely complex magnetic profiles that are somewhat akin to the emerging complex neural patterns recorded from the human brain. The effects of such stimulation are not instantaneous and seem to result from constant exposure to these fields over a prolonged time period. By varying the number of bursts; their amplitude, duration, and rotation; and the region being stimulated, many distinct forms of experience can be elicited (see Persinger, 1999; Persinger & Koren, 2001 for a further discussion of the technique).

Many of these experiences mimic those reported spontaneously in more natural everyday settings from individuals. Examples of this include hallucinatory experiences commonly associated with temporal-lobe epilepsy (Bear, 1979; Gloor, 1986; Gloor, Olivier, Quesney, Andermann, & Horowitz, 1982; ; Halgren, Walter, Cherlow, & Crandall, 1978; Penfield, 1955; Penfield & Perot, 1963), migraine attacks with aura (Comfort, 1982; Lippman, 1952; Sacks, 1995), out-of-body and near-death experiences (Blackmore, 1982; Irwin, 1985), and even the perception and experience of apparitions in normal waking adults (Persinger, 1995, 1999; Persinger & Richards, 1994; Persinger & Roll, 1985; Persinger, et al., 1997; see Persinger & Koren, 2001 for a review).

In the case of apparitions, researchers have argued that perhaps some aspect of these EIFs could be present at locations that have been associated with producing multiple instances of these experiences spontaneously (Persinger & Koren, 2001; Persinger, Koren, & O'Connor, 2001; Roll & Persigner, 2001). The implication from this is that many strange (i.e., haunt-type) experiences reported at such locations could actually represent a spontaneously occurring magnetically induced hallucination. According to this hypothesis, individuals who report haunt-type experiences (and who might also display a degree of neuronal hypersensitivity) may well have been exposed to crucial EIFs present at that location. The prediction here is that discrete changes in the magnetic field will correlate to sympathetic changes in neural activity that will have consequences for cognition under certain circumstances.

Based on this evidence many researchers are now searching for the spontaneously occurring natural environmental homologue of the artificially created complex EMFs. The EMF/brain account is attractive as it provides a useful and testable framework for one particular mechanism that could underlie occurrences of such spontaneous strange occurrences as haunt/apparitional type experiences in the natural setting (at least in some circumstances). For instance, one important question is whether these microenvironments are indeed magnetically remarkable in any way compared to baseline locations. If so, what is remarkable about them and what are the potential consequences for human experience, health, and cognition? Is there something permanently remarkable about the ambient field levels available at such locations that when mixed with neuronal hypersensitive individuals can induce hallucination (often interpreted as being "paranormal" on the part of the observer)? Or are such critical fields more transient and volatile, occurring sporadically from time to time? Perhaps both factors are crucial.

Although some field studies have indeed shown that both increased levels of the localized ambient GMFs (Nichols & Roll, 1999; Roll & Nichols, 1999; see Persinger & Koren, 2001; Roll & Persinger, 2001 for reviews) and increased levels in EMFs (Nichols & Roll, 1998; Persinger et al., 2001; Roll, Maher, & Brown, 1992) can be associated with anomalous effects on electrical equipment and human experience, others have failed to find any relationship (Maher, 2000; Maher & Hansen, 1997). Of the studies that found positive effects of increased GMFs/EMFs, the implication seems to be that locations associated with strange experiences do contain overall excessive levels of such fields relative to baseline locations. However, in line with the laboratory stimulation studies, other findings suggest that a crucial difference between locations may not be so much in the nature of the overall field levels themselvesas in the manner in which such fields actually vary over time (i.e., their complexity: Braithwaite, 2004; Braithwaite & Townsend, 2005; Braithwaite, Perez-Aquino, & Townsend, 2005; Wiseman, Watt, Stevens, Greening, & O'Keeffe, 2003; see Persinger & Koren, 2001). Indeed, researchers have yet to demonstrate consistently what components of these GMFs/EMFs (i.e., amplitude, frequency, direction) are actually available at and distinguish such locations, as well as to identify the crucial components causally related to reports of strange experiences in the natural setting. Research directed at quantifying behaviorally relevant characteristics of the environment will contribute greatly to our theoretical understanding of how such experiences occur spontaneously on a number of levels from geophysics and neuroscience to cognition and consciousness.

One of the main reasons why these field studies have produced diverse (and somewhat controversial) findings could be due to the technology employed across the studies themselves. The issue of using the correct and appropriate technology is not a trivial one. Many of the debates seem to reflect theoretical positions that do not always consider the limitations of the technology used in the studies, causing some confusion in this area of research. For instance some field studies have employed only geomagnetometers (devices for measuring the earth's DC geomagnetic field) for carrying out surveys of locations, and others only electromagnetometers (devices for measuring AC fields), few studies have employed both devices (see Roll & Persinger, 2001 for a similar discussion of such limitations). Based on these protocols it is easy to see how a study using only a coil-based electromagnetometer could not pick up any geomagnetic anomaly and how, at least in part, some confusion could emerge. In addition, many researchers have not outlined in detail a protocol for how the measurements were taken (irrespective of the equipment used), analyzed, and interpreted. This affects the repeatability of the findings and can have a detrimental influence on research.

To summarize, the potential influence from magnetic fields available at certain locations and their implications for behavioral effects and cognition necessitate the development of a comprehensive magnetic anomaly detection system that can measure environments in a detailed, useful, and consistent manner. Furthermore, there is a need for field-based research to develop clear protocols and methodologies for carrying out such studies in a reliable and valid manner that can be followed by the community. The Magnetic Anomaly Detection System (MADS) outlined here has been specifically developed to provide a detailed and standardized method of quantifying the magnetic environment in such a manner. Although the MADS has evolved in relation to the needs of measuring magnetic fields for their implications to environmentally induced hallucination (and spontaneous haunt reports), it is important to point out that the system is equally suited to other areas of research such as laboratory experiments, detailed field-magnetometry, archeology, geophysics, and environmental science.

Some Current Systems and Some Problems

Characterizing complex magnetic fields is a difficult task requiring not just appropriate equipment but also a suitable protocol for carrying out valid magnetic surveys. Many existing devices currently being used by psychologists and parapsychologists are very limited when it comes to describing important magnetic field characteristics in a useful manner. For example the Tri-field meter (AlphaLab) in its numerous guises has been employed in a number of field studies attempting to survey environments of interest. It has been used either as a simple hand-held meter on its own or as part of a more fully integrated system (i.e., MESA: Houran, Lange & Black, 1998; Harte, Black, & Hollinshead, 1999). However, the Tri-field is not likely to be appropriate for quantifying the magnetic environment in a manner detailed enough to match the field studies to the controlled situation of the laboratory.

There are two popular versions of this meter, one directed at measuring weak natural DC magnetic transients and the other directed at measuring broadband 50/60Hz AC magnetic fields. Both devices are limited but for different reasons. For instance, the natural DC version of the Tri-field is designed to measure transients in ambient background geomagnetic fields. The output of the meter does not provide any indication of the actual level of the background ambient field at that time. The researcher knows only that some form of change has taken place. Indeed, this device gives no indication of the actual direction (i.e., increase or decrease) of the very transient it measures.

Furthermore, as the Tri-field is a "transient" device, it does not provide a constant or even regular stream of data. That is to say, because it only responds to transients when they occur, its output is not suitable for detailed time-series analysis (i.e., Fourier Transforms/Wavelet analysis).

The broadband AC version has typically been used for surveys as a simple hand-held meter on its own, though a configuration system employing these meters has been proposed (i.e., MESA: Houran, Lange, & Black, 1998; Harte, Black, & Hollinshead, 1999). However, even the interpretation of the magnitude of that change is problematic because the meter is frequency-weighted for 50-60 Hz power frequency fields. This means a field of say 3 mG (3000nT) at 60 Hz will measure as 3 mG in the meter window. However, a field of 6 mG (6000nT) encountered at 120 Hz will also register as 3mG in the meter window. As these meters provide no frequency information whatsoever, the researcher cannot be sure what frequency domain the amplitude transient belongs to or what the true amplitude is, and therefore cannot detail the field in a useful manner. The main advantages of the device seem to be that it is relatively accurate, easy to use, and inexpensive.

One fully integrated survey system that has already been proposed is the multienergy sensor array or MESA system (Houran et al., 1998), which incorporates a host of sensors monitoring a variety of environmental factors. To conceptualize electromagnetic fields MESA employs two separate Tri-field meters configured to assess different vector components and the same location. Later modifications of this system included the addition of geomagnetic (DC) sensors as well (Harte et al., 1999). For the reasons given above, the explanatory capabilities of the EMF channels used in MESA are limited. Furthermore, as both meters in MESA are configured to measure different vector components at the same location, no simultaneous baseline measurements can be taken with MESA as the configuration currently stands. Tri-field meters are certainly quick and easy to use, relatively cheap, accurate, and sensitive, but for the parapsychologist the data they provide is limited with regard to giving a detailed representation of the magnetic microenvironment.

Although there may appear to be some similarities between MESA and the MADS system, MESA is geared toward measuring a broader range of environmental factors (including ultraviolet light and seismic activity). In contrast, the MADS is geared to provide a more detailed assessment of the geomagnetic and electromagnetic three-dimensional microenvironment over space and time. It provides considerably more detail but covers fewer variables. The main reason for this is that the laboratory studies clearly show that the magnetic component seems to be most relevant for brain stimulation (see Persinger & Koren, 2001).

There is also a problem with many commercially available industrial meters. Many meters use coil-based sensors that measure the amplitude of the induced current from the field moving across the coil, so only AC fields can be conceptualized. A DC field will not induce a current in a fixed coil-based magnetometer. Furthermore, performance curves indicate that few if any of the commercially available meters reliably go down to the important low frequencies implicated as crucial in the laboratory studies (< 30Hz and preferably down to DC). Any survey carried out with these devices could miss a good deal of the EMF spectra at locations of interest. Commercial devices also have sample rates typically in the region of tens of seconds, making them far too slow for picking up potential fast-acting transients (many of these will simply be averaged out across the other samples taken). In addition, although many commercial devices can respond to energy from a variety of frequencies, they often give no indication of the actual frequency associated with the amplitudes measured. These machines are simply not accurate or sensitive enough in the ways in which many researchers need them to be. One final yet perhaps crucial problem with commercial devices is that the output format of the data is usually in some final analyzed and summarized state. The operator has no access to the raw data with which to apply more complex analyses that may be more appropriate. The main reason is, of course, to make such devices easy to use. However, this often means that any magnetic project is limited to the parameters of the manufacturer. A far more useful and comprehensive system provides output data in terms of pure readings. In this case the subsequent procedures to be used to make sense of the data are much more at the discretion and needs of the researcher.

A System Guided by Neuroscience

It seems logical, if not necessary to base any environmental magnetic anomaly detection system on the general findings from the laboratory studies themselves. In the laboratory setting the nature of the magnetic field is known, controlled, and quantifiable. Indeed, these studies suggest that only a small window of frequencies (the frequency range of the brain) and amplitudes may be available and have brain stimulation implications (Bell et al, 1992, 1994; Persinger, 1999). The approach for the MADS has been to see what these studies have identified as being crucial in creating experience-inducing fields (EIFs) and then try to find a suitable sensor design that could cope with measuring these important aspects in an appropriate and interpretable manner as they may occur in the natural setting. It is also important to point out that the MADS is not based on just identifying these crucial fields, but it can also cover a wide range of amplitudes and frequencies throughout the critical region and far beyond.

Having used these studies as a guide, we believe an appropriate system should have several characteristics. Firstly, as field complexity and time-varying components seem crucial, any system needs to have a fast sample rate capable of measuring such variant fields. As noted above, laboratory studies use pulses varying in the 3–6 ms range and one field study has shown that a household appliance giving off a magnetic pulse every 16 ms was associated with specific hallucinatory events during sleep (Persinger et al., 2001). Secondly, the system should be able to measure and quantify both the AC and the DC fields, as both have been implicated as being important for different types of experiences. Furthermore, it is crucial that the system provides not only a measure of the magnetic field strength but also of field frequency at a given strength (for AC fields). The measuring of *strength and frequency* combined is particularly important for quantifying the fields in a detailed and meaningful way. It is also important that measurements can be taken in a multiaxis three-dimensional manner to describe the magnetic environment as comprehensively as possible in any given instance. It is crucial that the system can accurately cover a frequency spectrum from around DC-50 Hz; the brain generally operates at 1-50 Hz and these very low-frequency fields have been implicated in brain stimulation studies. Sensors should also be interfaced to computers so that all data can be logged for further analysis away from the field. The system also needs to have some form of frequency analysis software (Fast Fourier Transform/Wavelet transform) for a detailed assessment of important time-variant characteristics and field frequencies.

The Magnetic Anomaly Detection System: Technical Overview

In response to the need for a comprehensive magnetic measuring system the Magnetic Anomaly Detection System (MADS) has been developed. The MADS represents a new configuration of customized hardware and easily available commercial software. The MADS employs high-speed digital magnetometry that is capable of providing detailed time-series data of complex magnetic fields. Neurophysiologists have been successfully using methods of digital signal processing for measuring fast-changing and transient brain signals (via EEG/ERP) for over a decade (see Eimer, 1998 for a review). Most contemporary EEG devices now use a system that digitizes the signal for ease of measuring and analysis. Indeed many of the complex analyses devised for filtering and comparing the digitized time-series EEG signals could be applied to the magnetic data gathered by the MADS (depending on the research context). This system is described in detail below.

MADS Hardware

The MADS consists of two separate high-speed digital fluxgate magnetometers. The specific sensors are the 540 digital fluxgate magnetometers from Applied Physics Systems, USA (for further detail see http://www.appliedphysics.com). These sensors are fully orthogonal (three-dimensional) and capable of sampling and measuring all three (x, y, z) magnetic components for both AC and DC fields simultaneously. The sensors are capable of sampling the environment 250 times a second (slower rates can be selected if needed). This equates to a measurement being taken once every 4 ms. The sensors are ideal for situations in which high-speed magnetic measurements must be made, and they are also capable of measuring magnetic field changes down to 0.5 nT resolution. They can cover the +/- 1 Gauss range (1,000 mG/100,000 nT). In addition, the 540s have a gain-offset sensitivity control with three levels that can be used to detect extremely small changes even in the presence of a large static field (see Table 1 for an overview of specifications). This function essentially zeros the sensors in to any background field and measures subsequent deviations from this zero value at differing levels of resolution.

TABLE 1
APS 540 DIGITAL MAGNETOMETER SPECIFICATION

Accuracy	+ / - 1% FS
Noise level	+ / - 0.5nT
Linearity	+ / - 0.1% FS
Maximum data transfer speed	250 3-axis samples / sec
Analogue to digital conversion	16-bit Sigma-Delta (AD 7731)
Baud rates (user selectable)	300, 1200, 2400, 4800, 9600, 19200, 38400, 72800
Operating temperature range	-25 to 70 degrees C
Gain offset facility (user selectable)	3-stage
Scale stability	+/-.05% FS / temp
Data transfer formats	ASCII & Binary

The sample rate of 250 samples/s equates to a flat frequency response of DC–125 Hz (250 Hz/Nyquist: see below), which easily covers the very-low frequencies identified by brain stimulation studies as being crucial (i.e., 1-50 Hz). Using the MADS means that there is no need for a separate system for quantifying static DC (geomagnetic) and changing AC (electromagnetic) fields; these sensors measure both at the same time with the same degree of sensitivity and accuracy. This is a big advantage for quantifying the fields in a detailed manner. As well as providing a total magnetic field reading, the MADS measures each of the three planes independently so magnetic anomalies can be detected individually in any of the three directions (per sensor). Furthermore, any magnetic anomaly occurring naturally in the microenvironment can be described in terms of its actual (and relative) contribution to the overall field at any time. This also means that the direction and movement of any such anomaly could be theoretically tracked in three-dimensional space with appropriate software, depending on the time-linked changes across the axes. Accuracy in this respect could also be increased even more with careful configurations of the dual sensors. (See Table 2 for a summary of the MADS features.)

TABLE 2
MADS SENSOR FEATURES

Orthogonal (X, Y, Z) independent simultaneous 3-dimensional measurements
High-speed digital sampling (250 / sec) in each plane
Quantifies amplitudes and frequency
Measures AC and DC fields simultaneously
3-stage gain offset / filtering
Direct PC port interface
Digital output providing time-series data (every 4ms) supports FFT analysis
Measures crucial frequency range (DC-125Hz)
Extremely sensitive to small changes in the magnetic field (down to 0.5 nT)
Anti-alias filter (roll-off down to 3 db @ 125Hz)
Portable and easy to use – fully computerized

The sensors are powered by their own low-ripple mains power source (AC/DC converters) but can also be used with a remote power supply if needed via an optional "breakout box" supplied separately by the manufacturer. The sensors of the present prototype MADS system are each fitted with 30 feet of cable (for remote sensing) that interfaces simply and directly to their own dedicated laptop PCs (Dell computers). No specific technical computer or electronic expertise is needed on the part of the operator.

Digital Magnetometry and Signal Analysis

The use of digital magnetometry, as in MADS, has important advantages over many analogue-based systems. For instance, there is no need for expertise in the use of analogue oscilloscopes or expensive spectrum analyzers. Furthermore, the use of digital magnetometry eliminates the need for any separate complex analogue-to-digital conversion board in the PC itself. Each 540 sensor uses three separate 16-bit sigma delta analogue-to-digital converters in order to achieve its high sample rate (this takes place within the sensor), greatly reducing both the cost and complexity of the system. As there is no need for an analogue-to-digital conversion board, the need for any complex programming of the conversion board itself is eliminated. One problem with analogue-based sensor systems is that after the signal has been digitized, programming the computer to sample fast and accurately enough to fulfill the sensitivity attributes of the sensor can be difficult, and there can also be major problems concerning alias fields (see below). At the very least this can mean the actual frequency range will not be matched to the capabilities of the sensor itself, making frequency analysis redundant, and at worst, causing researchers unaware of this problem to misinterpret their results. This is not a problem for the MADS.

Alias fields are crucial problems often discussed in relation to digitized signals. In their analogue form the 540 sensors come with a frequency response covering a DC–400 Hz bandwidth. However, the digital sample rate is 250 times a second. For analyzing time-series data, the Nyquist theorem specifies that the highest measurable frequency is half the sample rate itself (see Smith, 1998). Therefore, 250 samples divided by 2 equates to a bandwidth of DC–125 Hz. This is the frequency range of MADS. The problem is that the analogue sensitivity is not matched to the digitized sample rate, meaning that the sensors could still respond to fields of frequencies much higher than 125 Hz. What this implies is that the signals above the Nyquist limit can generate alias fields, which actually appear as increased energy at lower frequencies (though they are in fact associated with higher frequency fields, hence the term "alias"). This can be avoided by using an analogue filter known as an anti-alias filter, which must be applied to the analogue signal before the signal is actually digitized. Nothing can be done to correct for alias fields after measurements have been taken if no filter is used. This is a hardware issue and must be set within the sensors themselves. It is essential to install a suitable alias filter if researchers want to carry out detailed frequency analysis using Fast Fourier Transformations (FFT) or Wavelet transformations. To avoid this potential problem both the 540 sensors used in the MADS prototype have been fitted with a custom specified anti-alias filter so that the analogue sensitivity is matched to that of the digitized sample rate and frequency response of the sensors. This anti-alias filter has been set so the corner of the roll-off curve is now down to 3 db at 125 Hz and drops off rapidly. This greatly reduces the chance that aliasing will affect the results of MADS, especially at lower frequencies.

System Configuration

The use of two sensors means that one can act as a time-linked baseline sensor. Both sensors have been configured and labeled clearly: Sensor A (Active sensor) and Sensor B (Baseline sensor). The Active sensor is placed at locations of high interest and the Baseline sensor is placed for a reference at some proximal distance from Sensor A. The sensors are always firmly placed (on nonmagnetic tripods) and are not moved or carried around during the measuring period. Both sensors interface directly to their own dedicated laptop PC. Both PCs are Dell Inspiron 500m models equipped with 1.5 GHz processors, 512 mb memory, 40 GB disc space and a CDRW/DVD drive. The MADS is also provided with two optional high-speed user programmable USB/serial port converters (Amplicon). USB ports are much faster than serial ports, and tests have shown these particular converters to be highly stable and accurate. USB and serial ports can be used equally effectively with the current setup. Readers should be aware that many modern laptops no longer provide serial ports, in which case a USB/serial port converter is the viable option (see Table 3 for a summary of the MADS inventory).

TABLE 3
THE MADS INVENTORY

2 high speed digital magnetometers
2 connection cables (user specified length)
2 low-ripple AC-DC mains adapters
2 high speed Dell laptop PCs + analysis software
2 nonmagnetic sensor stands
2 hand held compasses
1 long tape measure

MADS Software

The sensors themselves are provided with their own data acquisition and display program (Windows compatible) that also acts as a kind of terminal emulator program. The software displays field amplitudes for (1) x, y, z components separately for the AC field, (2) x, y, z components separately for the DC field, and (3) minimum and maximum AC amplitudes for each axis for the duration of the recording period (and the Azimuth). A real-time scrolling graph of the varying amplitudes is also displayed.

For analysis, both laptops have been fitted with two signal analysis packages. These are Sigview v1.9 (www.sigview.com) and Autosignal v1.7 (www.systat.com). Both packages can handle data files consisting of millions of samples, and their ability to load up the data files is limited only by the available RAM specifications of the PC. Both are capable of numerous signal processing and Fast Fourier Transforms/Short-Term Fourier Transforms (FFT/STFT) procedures, are very easy to use, and can be accessible to the novice and expert. Sigview is perhaps more suited to the novice. Autosignal is a more complex and elaborate package requiring some expertise in signal analysis. Autosignal can be used to carry out far more complex mathematical procedures on the raw signal data and contains a vast library of parametric/nonparametric signal peaks analysis procedures and a number of Wavelet frequency analysis tools for exploring nonstationary data. Both packages can be employed depending on the nature of the study and the questions being asked by the researcher. Both packages can also be used to identify regions of interest for further more detailed FFT analysis. The result is a system that is easy to operate and capable of measuring complex magnetic fields in a manner not available to other devices.

Data File Handling

The output file can be configured to provide results in a number of formats. The most useful to psychologists is likely to be the decoded gauss format as this is the most transparent to use. This file provides three columns of magnetic data that relate to the values for all three axes (plus values for Azimuth, Mag roll, etc). Each reading can also be given its own time-stamp in the data file. The AC and DC fields are summed together in the output file. The AC field can be separated quite easily from the DC field either by using FFT or by taking an overall average reading (the nonvarying DC component) for a recorded period from the time-varying components (the AC components).

A maximum sample rate of 250 samples a second means that there will be 15,000 samples over 60 seconds (1 min). This equates to 900,000 samples/hour. These files are too large to be opened by programs like Excel. Therefore, the MADS laptops have been equipped with copies of SPSS, which is capable of opening files in excess of 2.5 billion data points (other suitable packages include Eviews for financial professionals). For ease of analysis, long measurement sessions could be divided into discrete 1-hr segments. From there data can be transferred to Sigview or Autosignal for further analysis. (Note that both software packages are also capable of handling large files; however, some operators may want to edit the data files before loading them into the signal analysis package.)

Data Analysis

The best method of analysis will depend on the nature of the study being carried out. Indeed a full description of analysis procedures is beyond the scope of this article; suffice it to say that the MADS provides highly detailed time-series data. These data can be used simply to describe overall field amplitudes, as might be required for spatial magnetic surveys of the microenvironment. They can also be used for identifying important EMF sources in the living or work environment that might be important for health workers. Here the data to be averaged is simply highlighted and the operator requests the statistics required. This procedure may be used to identify regions of interest for more complex frequency-based analysis (i.e., by looking for significant peaks or high variance).

For time-based measurements, frequency and amplitude analysis may be needed in some circumstances, which is usually done using an FFT applied to the output data file. The fact that the MADS also provides detailed raw measurements means that the operator is free to carry out a number of time-series frequency based analyses on the data at his or her discretion. Although for most purposes the FFT will be the preferred frequency analysis, there are others (i.e., short-time Fourier, Hilbert, Radon, and Wavelet transforms), and there may be reasons why the FFT is also not always the most suitable (Addison, 2002; Polikar, 2001). For instance, if the researcher is interested only in what frequency components were present over a particular measuring period then a FFT may well be useful. However, the FFT procedure assumes that the signal being analyzed is always stationary (a constant variation around the mean value of the series), but in practical circumstances this is unlikely to be the case all of the time. Magnetic fields may well vary rapidly and often in a number of frequencies and amplitudes. Therefore, from the point of view of exposure, it becomes important not only to ascertain what frequency components were present but also when and for how long. The problem is that the FFT procedure converts time-series data into the frequency domain. One cannot access time information from the frequency domain and vice versa. In other words the FFT shows how much of each particular frequency existed in the measured signal, but it does not show when each separate frequency component existed.

There are many ways to deal with nonstationary properties in data. One suggestion could be to improve the stationary qualities of the data themselves by applying normalization functions (Patterson, 2000; Stearns & David, 1988). However, as noted above, in some circumstances the fact that such fields are varying in frequency may be the crucial factor (consistent with the notion of field complexity). In these cases, it might be more appropriate to use a transform that provides a representation of time and frequency, and both Short-Term Fourier transforms (STFT, for stationary data) and Wavelet transforms (for nonstationary data) are useful candidates (see Addison, 2002; Polikar, 2000). These procedures can provide the time and frequency information simultaneously, hence giving a time-frequency representation of the signal. This will show what frequency bands existed across which time intervals. Both of these functions are particularly useful for displaying complex fields varying in both frequency and amplitude over time, allowing researchers to ascertain whether a frequency is changing though amplitude remains constant, whether the frequency remains constant but amplitudes are varying, or both (see Figure 1). As noted above, such possibilities are similar to the notion of "complex" fields described by brain stimulation studies as being crucial for eliciting hallucination. Therefore, the MADS can be used effectively by operators wanting to describe the magnetic fields at varying levels of complexity, from simple amplitudes alone to complex multichannel signal analysis, and frequency-over-time evaluation. The important point to note from this is that, unlike many commercially available industrial devices, the data output from the MADS supports all these procedures, and the operator is somewhat liberated from the assumptions of the manufacturer.

Quantifying the Magnetic Microenvironment

Although a full description of methods for employing the MADS is far beyond the scope of this paper, one or two aspects are worth mentioning as they highlight the merits of specific technical functions of the sensors themselves. For instance, an operator may want to know

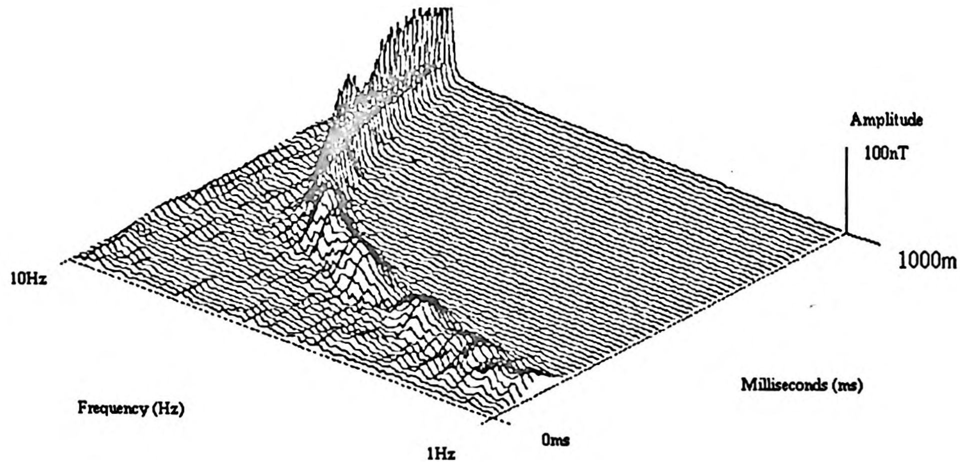

Figure 1. Example data adapted from Sigview, illustrating the usefulness of the "Time FFT" function analysis option. This three-dimensional figure shows the time period (in milliseconds), the frequency (in Hz) and the amplitudes (in nanoTesla: nT) for the recorded fields present. As can be seen, early during the measuring period the EMFs are both low-frequency and of low amplitudes (lower left corner). However, as the frequency increases, the amplitudes generally increase as well. Note, toward the end of the sample period (top right corner) fields of similar frequencies vary considerably in amplitude. These types of fields may well be what the natural occurring homologue of Persinger-type EIFs could look like (i.e., amplitude pulses) in such an analysis.

potential contributing sources to any magnetic fields measured and may also want to ascertain the degree to which any type of AC field may be present in the background geomagnetic (DC) environment (irrespective of whether the AC component is viewed as as interference or the object of study). The MADS is particularly well suited to these potential scenarios. For instance, as the sensors are fluxgate based, they measure AC and DC contributions together. From the provided output, MADS can measure AC fields impinged on a background DC (geomagnetic) field, and both can easily be separated by applying an FFT (or equivalent) on the output and establishing the time-varying component within the data. Any contributions from AC household wiring will show up as a 60 Hz/50 Hz source (US & UK wiring frequency, respectively) of a given magnitude. These can then be subtracted from the remaining DC or geomagnetic measurements. Therefore, AC fields can be separated from DC fields and measured; similarly, DC fields can be separated from AC fields, or, perhaps more interestingly, both can be studied together (i.e., AC ripples in a DC field) for potentially important interactions. Furthermore, time-linked measurements mean that both cross-sensor subtractions and coherence analyses can also be carried out on the fields encountered. Such possibilities mean that the researcher can more accurately evaluate the spatio-temporal aspects of the anomalies themselves to provide a detailed quantification of what may turn out to be significant magnetic events.

Finally, it is important to note that the MADS configuration outlined here is more than just a simple new piece of technology. The MADS has facilitated a number of improvements in field-based investigation methodology and has supported levels of quantification never seen before in field-based apparitional research. For example, the MADS was employed in the first study ever to employ time-linked measurements between reputedly haunted and baseline areas (Braithwaite, 2004), for a detailed assessment of magnetic variability levels over a prolonged measuring period (Braithwaite, Perez-Aquino, & Townsend, 2005), and for the first field-based investigation to formally compare spectral-frequency components between measurements (Braithwaite & Townsend, 2005). The MADS is an improved framework for testing and investigating the suggestion that magnetic anomalies could underlie some spontaneous haunt reports. The capability of using time-linked baseline measurements, measuring AC and DC contributions together, measuring magnetic variability continuously, and being able to compare frequency components from the immediate environment provides researchers with new opportunities in both the laboratory and the field. Future studies will illuminate how and where the magnetically remarkable signatures account is relevant, where it is not relevant, and more importantly, why. From this we can start to learn what might be both necessary and sufficient for a particular magnetic context to contain experience-inducing parameters for particular observers.

Summary

This paper has outlined a fully computerized, comprehensive, easy to use, and portable magnetic anomaly detection system. The MADS utilizes state of the art digital magnetometry capable of measuring both slow- and fast-changing transients in the geomagnetic and electromagnetic fields, respectively. This system can be employed for detailing both spatial and temporal characteristics of the three-dimensional magnetic environment. The use of dual sensors also means that, unlike many single-meter approaches, such readings can be time-linked to a concurrent simultaneous baseline recording. This system can also provide a more comprehensive picture of the magnetic environment than other integrated systems that have been proposed (Harte et al., 1999; Houran et al., 1998). The author is currently using the MADS to carry out detailed magnetic surveys of environments associated with inducing hallucinations and strange experiences compared to baseline locations. It is hoped that such an approach may reveal what is magnetically remarkable about these environments and what the implications are for cognition. Finally, it is important to point out that because MADS is based on contemporary neuroscientific approaches it is the most suited system to be directly correlated to any concurrent neurophysiological measures taken from individuals (such as EEGs). This will be an exciting area of future research.

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