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Affective Response to 5 μT ELF Magnetic Field-Induced Physiological Changes

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Research into effects of weak magnetic fields (MFs) at biologically relevant frequencies has produced ambiguous results. Although they do affect human physiology and behaviour, the direction of effects is inconsistent, with a range of complex and unrelated behaviours being susceptible. A possible explanation is that these effects, rather than being directly caused, are instead related to changes in affective state. A previous study showed that MFs altered the affective content of concurrent perceptions, but it was unclear whether the emotional response was direct or indirect. Here it is shown that exposure to a 0–5 μT MF (DC-offset sinudsoidal wave form) within EEG α-band frequencies (8–12 Hz), results in a reported change in emotional state. This relates to a decrease global field power but lacks the frontal α-asymmetry that would physiologically indicate a directly induced emotional state, suggesting that participant experiences are due to an interpretation of the effects of MF exposure. Bioelectromagnetics 28:109–114, 2007. © 2006 Wiley-Liss, Inc.

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INTRODUCTION

Research into the effects of weak magnetic fields (MFs) at biologically relevant frequencies has produced ambiguous results. Although such fields do affect human physiology and behaviour, the direction of effects is inconsistent [Cook et al., 2002; Leitgeb and Schröttner, 2003] with a range of complex and apparently unrelated behaviours being susceptible, including mental health declines [Beale et al., 1997], pain sensitivity [Papi et al., 1995], 'paranormal' experiences [Wiseman et al., 2002, 2003; Braithwaite, 2004], and sleep disturbances [Graham and Cook, 1999].

One possible explanation is that, rather than directly causing all the different behaviours, the fields act by altering the underlying affective state and the observed behavioural changes are a secondary effect. In general, emotion is seen as being the subjective experience of certain states of the nervous system: a sensory stimulus [or the memory of one] is detected and interpreted in terms of both emotional and physiological responses, triggering subcortical "emotive circuits"—anatomical networks of interconnected neurons tied into endocrine, paracrine and immune systems [Panksepp, 1998]. Such circuits have extensive links with higher cognitive functions and are thought to play an important role in sensory, perceptual and motor activities, as well as being involved in aspects of physiological regulation (including immune functions) and processes of learning and memory [Panksepp, 2000].

Any stimulus which produces an affective response could thus also influence a wide range of cognitive and behavioural states. This would occur whether that stimulus was perceived via the standard sensory pathways and resulted in an associated emotional response or if it were activated directly by artificial stimulation of specific brain regions, for example, the electrical stimulation studies performed by Heath [1964] wherein the stimulation resulted in self-reports consistent with the full experience of a particular emotion. This latter example raises the possibility that emotive circuits could also be activated

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by an external MF stimulus—an idea which is supported by the use of transcranial magnetic stimulation to alleviate drug-resistant depression [Panksepp, 1998], Persinger et al. [1994] research into affect changes by localised, weak MFs and by Stevens' [2001] work showing changes of affect perception related to fluctuations of the ambient MF.

Given that such MFs do appear to evoke an affective response, the question becomes whether the fields directly evoke a specific emotion, or whether the response is an interpretation of any MF-induced physiological effects by the affected person. Persinger et al. [1994] demonstrated that a localised MF stimulus changed activity selectively in right or left frontal regions, resulting in a state of positive or negative affect. They concluded that the field suppressed activity in the hemisphere it was applied to but noted that all applications appeared to result in variations of evoked positive affect rather than evoked positive or negative affects. This finding was conceptually replicated by Stevens [2001] in which a 50 μT, 20 Hz sinusoidal MF resulted in more positive affect rating of concurrently presented images, irrespective of image content, but no EEG measures were taken to show what occurred in the underlying physiology. In another study by Cook and Persinger [1997], negative affect, along with a "sense of presence," was induced by a different patterned field.

Such studies imply that the specific characteristics of the applied field are important in addition to the hemisphere to which it is applied, possibly suggesting that selective activation of different neural structures can occur. On the other hand, any affective responses may be an individual interpretation of MF-induced physiological changes: a deductive process based on expectations and perceived environmental cues as to possible stimulus sources. This is an important distinction that may offer a different perspective to those attempting to model the underlying processes by which MF-induced behavioural changes might occur.

This study thus attempted to evaluate which of these processes might be involved by monitoring both behavioural and physiological responses simultaneously. If behavioural responses (i.e., the participant's description of their experienced emotion) matched the physiological responses (i.e., frontal alpha-asymmetry), then we might reasonably conclude that the MFs were directly inducing the affective response through stimulation of structures in the emotive circuits. If no matching occurred, then it would seem that any affective response was interpretive. To maximise the possibility that direct induction could occur, the applied MF for each participant was set at a frequency which matched the peak frequencies observed during autobiographical recall of positive and negative emotion memories. The effect would thus be one of MF entrainment wherein the dominant frequency of EEG records reflects the driving frequency of the applied stimulus, as has been demonstrated by previous research [e.g., Bell et al., 1994].

Several researchers have shown that neuronal structures underlying a variety of cognitive circuits, including the emotive circuits, show distinct operating frequencies due to the underlying neuronal oscillations. For example, Pare et al. [2002] showed that fear responses have unique frequency patterns relating to neural circuit oscillations in the amygdala, these patterns being observed either as frequency components in the EEG or indirectly as modulations of EEG activity. Lehman and Koenig [1997] present a literature review and results from their own studies which demonstrate that different frequencies in the alpha band are "generated by neural populations at different locations and that the different populations subserve different functions," although they note that cases also exist wherein different populations are active simultaneously at the same operating frequency. Determining the frequency of the peak amplitude during specific emotional states might then offer the best opportunity of activating underlying neuronal structures and eliciting a physiology-driven affective state, should this be possible.

MATERIALS AND METHODS

Participants

The subjects were 20 (7 female and 13 male) self-selected, right-handed volunteers. Before participation, all had given informed verbal consent to undergoing the MF exposure, and the experimental protocol approved by the institution's ethics committee.

Magnetic Field Generation

Magnetic fields (MF) with maximum peak-peak amplitude of 5 μT at the subject's head and upper torso were generated by three wire-wrapped coils via a DC-offset sinusoidal current from a arbitrary function generator (FGA2030, Tecstar Electronics, Cambridge, UK). The coils, based on a Merritt et al. [1983] three-coil system (40/20/40 turns per coil), were embedded in the experimental room walls, with axes aligned North-South. Coils were 2.92 m in width by 2.51 m in height. Field flux densities were calculated throughout the room and confirmed by magnetometer measurements (Mag-03MS100/03DAM system, Bartington Instruments, Whitney, Oxford). The field in the region within which the subject's head and upper torso was situated was measured to be homogenous to within 1% of calculated values. Ambient fields were not measured.

Stimuli

Stimuli consisted of either a MF or no field (sham exposure). MFs for each subject were generated via sine wave superimposed onto a direct current such that the current amplitude oscillated between 0 and 0.14 A. The sine wave frequency was chosen to correspond to the mean peak frontal EEG frequency previously recorded for that subject during autobiographical recall of events associated with emotional states; positive and negative emotional states were collapsed together as the associated EEG frequencies did not significantly differ according to valence. Mean peak frequencies ranged from 8.3 to 12.2 Hz, depending on the individual, but were consistent for each subject.

Procedure

After an initial 5 min relaxation period, there were eight trials of 60 s duration, each trial being exposure to the weak MF or a sham exposure (MF_{SHAM}), four of each type being presented in the same session according to a pseudo-randomised, double-blind schedule. Before each period, they were alerted by an audio tone and instructed on-screen to close their eyes until they heard a second tone. After each period, they were again alerted by an audio tone and asked to select via touch-screen 4 words out of a possible 16 emotion-related words which best described their current emotional state. This was not timed, the session continuing only when all four words had been selected; and the presentation order of the words on-screen was pseudo-randomised for each trial. This was followed by a 30 s rest period before the next trial. The experiment was carried out in a sound-attenuated chamber with subjects seated in a comfortable chair facing North. Subject responses were recorded via emotion-word selection on a touch sensitive LCD screen. They were paid for the session which, including instructions, EEG setup and debriefing, took 70 min.

EEG Recording

EEG data were recorded from 12 Ag/AgCl sintered electrodes mounted on the subject's scalp according to the international 10–20 system (F3, F4, C3, C4, T3, T4, P3, P4, O1, O2, Fp1, Fp2) with linked ears reference. EEG data were collected for 8 periods, each of 60 s duration, using an on-line sampling rate of 500 Hz and band-pass filtering between 0.5 and 100 Hz. Initial checks were conducted to ensure there was no direct pick-up by the EEG of the MFs.

Data Analysis

For off-line data analysis, EEG data were used to calculate z-normalised Global Field Power (GFP: defined as the standard deviation across multiple channels as a function of time within a sample interval). GFP is a highly robust, reference independent measure that represents the maximal activity in a given brain area in response to a stimulus [Lehman and Skrandies, 1980]. Averaged power spectra for each subject were individually constructed for frontal electrodes F3 and F4 (FFT: 75% overlapping 8.192 s epochs, 10% cosine bell taper) and filtered in the alpha band (8–12 Hz) to give the average power for right-frontal and left-frontal alpha for each stimulus condition. These values were then used to calculate frontal asymmetry (FA) in alpha for each stimulus condition such that:

$$\mathrm{FA} = \ln\left(\frac{\mathrm{Right} - \mathrm{Frontal\ Power}_{\alpha}}{\mathrm{Left\ Frontal\ Power}_{\alpha}}\right)$$

Subject's choice of emotion-related words were used to construct a reported emotional state (RES) for each stimulus type:

RES = (Total number of positive words selected for a stimulus/Total number of words selected for that stimulus)−0.5.

Thus, RES ranged from +0.5 to −0.5 for completely positive to completely negative emotional state, respectively.

Hypothesis 1 was that a MF of any frequency will show decreased arousal in subjects' cortical activity, based on GFP measures. Mean GFP for MF stimulus trials were compared to those for MF_{SHAM} trials using a two-sample Wilcoxon test. Hypothesis 2 was that the EEG frontal assymmetry would differ for MF versus MF_{SHAM} trials, that is, MF effect is to directly evoke an affective state. FA for MF stimulus trials were compared to those for MF_{SHAM} trials, again using a two-sample Wilcoxon test. Hypothesis 3 was that the RESs would differ for MF versus MF_{SHAM} trials, that is, MF effect is interpreted as an affective state. RES for MF stimulus trials were compared to those for MF_{SHAM} trials, again using a two-sample Wilcoxon test. In all cases, the conservative, non-parametric Wilcoxon test was used due to the non-normal distribution of the data.

RESULTS

Table 1 shows the means for the z-normalised GFP, EEG-alpha FA and RES for each subject, split by stimulus condition. Figure 1 shows the GFP averaged over all subjects during exposure to either the sham field (top sequence) or the MF (bottom sequence). By

TABLE 1. Means for Z-Normalised Global Field Power (GFP), EEG Alpha Power Frontal Asymmetry (FA) and Reported Emotional State (RES) for Each Subject, Split by Stimulus Condition

GFP		FA		RES	
MF	MF_{SHAM}	MF	MF_{SHAM}	MF	MF_{SHAM}
22.83	24.04	−0.08	−0.11	−0.25	−0.50
10.81	10.58	0.03	0.02	−0.06	−0.22
16.52	16.95	0.18	0.25	−0.06	−0.36
*	*	*	*	−0.06	−0.20
12.68	13.28	−0.01	0.00	0.13	−0.06
13.84	14.43	0.11	0.02	0.25	−0.25
17.44	17.41	0.00	0.01	0.50	−0.17
11.37	13.47	−0.09	−0.07	0.00	−0.50
17.99	20.21	0.11	0.06	0.06	−0.19
33.88	39.07	0.00	0.00	0.00	−0.50
15.29	16.11	−0.06	−0.07	0.00	−0.50
18.11	17.04	0.03	0.05	−0.25	0.08
12.51	24.05	−0.04	−0.03	0.38	−0.08
10.17	9.96	0.17	0.68	0.13	−0.13
16.36	17.32	0.01	−0.03	0.13	−0.30
17.39	23.51	−0.10	−0.13	0.13	−0.50
12.33	10.82	0.22	0.17	−0.38	−0.05
12.84	15.40	0.12	0.15	0.31	−0.50
14.87	14.65	0.14	0.08	0.00	−0.19
20.08	16.43	0.02	−0.09	−0.19	−0.26

*Unable to calculate GFP or FA for subject 4 due to bad EEG data.

the end of the exposure period, a decreased GFP for the MF is seen with respect to the sham condition (two-tailed Wilcoxon $V = 48$, $P = .03$), this resulting from individual GFP decreases in 65% of subjects. The development of the GFP topography differs for the two stimuli during the exposure period, with the MF stimulus initially showing increased activity compared to the MF_{SHAM} stimulus and also appearing to show hemispheric GFP asymmetries, but such effects were transient and not statistically significant.

Mean FA for MF was 0.04 and MF_{SHAM} was 0.05, indicating a non-significant decrease in positive FA in response to the MF.

However, subjects' RES was +0.03 for MF and −0.27 for MF_{SHAM}, suggesting a significant increase in reported positive affect (or a decrease in reported negative affect, given that the sham condition had an overall negative affect rating, though the former interpretation would be consistent with earlier research, Stevens, 2001) associated with MF exposure (two-tailed Wilcoxon $V = 189$, $P = .002$). There was no significant correlation between the RES and FA (Pearson $r = 0.09$, non-significant), or between RES and change in GFP (Pearson $r = -0.26$, non-significant), demonstrating that the apparent emotional

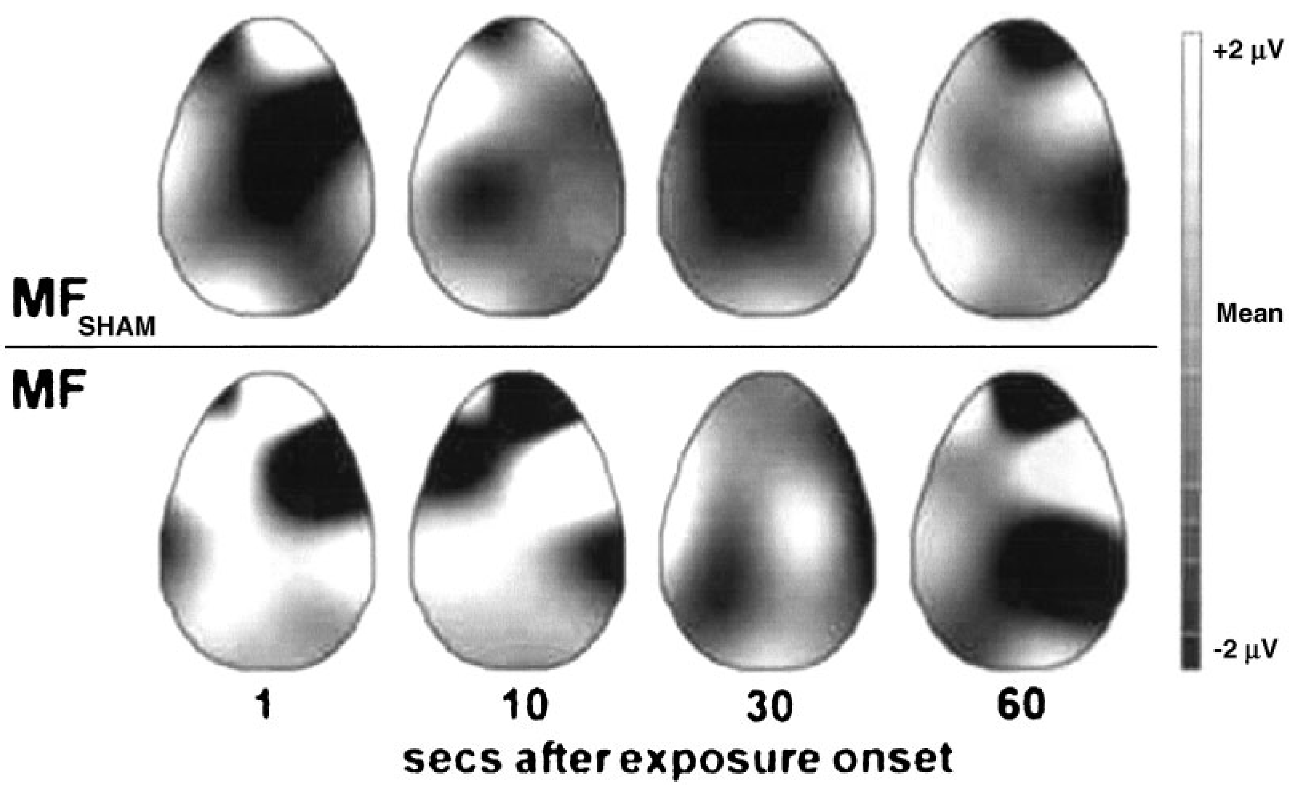

Fig. 1. Topographies of global field power, averaged over all subjects, for 1, 10, 30 and 60 s of either sham exposure (top) or magnetic field (MF) exposure (bottom) conditions.

experience was not directly mapped onto the underlying physiological effects.

DISCUSSION

Based on previous findings showing that participants gave affective responses when exposed to weak, low-frequency MFs, this study attempted to differentiate between two potential processes by which this might occur: direct activation of neural structures relating to 'emotive circuits' or subjective interpretation of more general physiological responses to the ambient field. Subjects were exposed to MFs at sinusoidal frequencies corresponding to the peak frequency of their EEG during autobiographical recall of emotional states. Their EEG and self-report responses were then compared to those obtained during sham field exposure, the exposure schedule being pseudo randomised and double blind. After MF exposure, participants' choice of emotion-related words indicated a shift towards more positive emotional state than the negative overall state that reported in the sham condition. This was associated with a significant decrease in cortical activity (based on EEG GFP) but the EEG alpha FA measures showed no significant difference.

Given that the EEG-emotion literature suggests [Hagemann et al., 1998] frontal alpha power in the F3 and F4 electrodes tends to be asymmetrical when a subject experiences an emotional state—positive emotions show positive asymmetry (decreased alpha/ increased cortical activity in the left frontal cortex) and negative emotions show a negative asymmetry (decreased alpha/increased cortical activity in the right frontal cortex)—this does not support the idea that the experienced affective state was the result of a direct activation of emotional circuits. Instead, it suggests that any change in reported affect was due to the participant interpreting the MF-induced change in cortical arousal as an emotional event, opting in the absence of any contrary external cues to interpret the lower arousal state as being a more positive emotional state.

If this is the case, then it has similarities with the original James-Lange view of emotion as a deductive process based on the perception of bodily or behavioural change [Gross, 1992]. Although this view is inadequate to explain all emotional experience, the basic premise still applies where there are ambiguous stimuli coupled with external cues [e.g., Shachter and Singer, 1962]. Weak MF stimuli could certainly count as ambiguous stimulus given that they do not appear to be directly detectable at a conscious level [Stevens, 1997] and are not mediated by any known sensory pathway yet do perturb physiological processes in a measurable way.

If the ultimate behavioural effect is indeed one of interpretation rather than directly causal, then this has strong implications for any epidemiological studies looking at behavioural effects and potential hazards of environmental MFs. Researchers should take care to ensure that behavioural effects were directly related to field exposure and not secondary interpreted effects, possibly by taking concurrent relevant physiological measures as in this study. Efforts should also be made to minimise, or at least standardise between conditions, any potential environmental cues that could bias participant responses. More generally, given that the field intensities (5 μT) and frequency characteristics (8.3–12.2 Hz, sinusoidal) of the MFs used in this study could be reproduced by commonly found electrical equipment and possibly by natural sources, the findings reported here could underlie a variety of anomalous experiences, ranging from 'paranormal' experiences linked to geographical sites [e.g., Wiseman et al., 2003; Braithwaite, 2004] to the relatively strong symptoms reported by self-identified 'electrosensitive' people [Leitgeb and Schröttner, 2003]; in both cases, the diversity of reported effect could relate to the particular interpretive cues available at the MF exposure location and the subjective interpretation of them, rather than being a direct result of the MF itself.

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