Bioelectromagnetics 22:219–223 (2001)

Effects of 5 s Exposures to a 50 μT, 20 Hz Magnetic Field on Skin Conductance and Ratings of Affect and Arousal

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This study investigated the effect of a weak magnetic field (50 μT, 20 Hz sinusoidal, 5 s duration) on concurrent perceptions of visual stimuli. Subjects were seated between Helmholtz coils and gave post-exposure ratings for the affective content and arousing nature of presented images. They were blind as to the presence or absence of a simultaneously presented field. Skin conductance and arousal ratings did not show significant differences between experimental and control conditions, but the affective content rating did ($P = 0.041$), with the images viewed under field exposure being rated as having a more positive affect. Such measures might thus be useful as additional indicators of magnetic field detection. A post-hoc analysis of skin conductance profiles showed that 48% of subjects exhibited a lowering of skin conductance during field exposure, 34% exhibited no apparent reaction, and 17% exhibited an increase. Overall ratings given by each of the groups appeared to relate to these physiological profiles. Bioelectromagnetics 22:219–223, 2001. © 2001 Wiley-Liss, Inc.

Key words: intermittent magnetic field; extremely low frequency; electromagnetic field detection.

INTRODUCTION

Application of extremely low frequency (ELF) electromagnetic fields has been associated with a variety of behavioral and physiological effects in humans, ranging from alterations in reaction time [Friedman et al., 1967] and pain-perception [Papi et al., 1995] to large-scale affective disorders [Sandyk et al., 1991]. Many of these studies concentrated on fields at power-line frequencies, but some have focussed on the naturally-occurring, lower frequencies associated with atmospheric and geomagnetic field activity. For example, field activity has been reported to correlate with subjective experiences of detachment [Persinger, 1995], mood [Persinger and Levesque, 1983], and visual hallucinations [Randall and Randall, 1991]. There is also evidence that fields in the frequency range corresponding to electroencephalogram recording of human brain activity act to alter the brain's intrinsic electrical activity [Bell et al., 1994], suggesting that certain frequencies might correspond to specific physiological or behavioral processes.

In a pilot study, Stevens [1997] showed that exposure to a 50 μT magnetic field at frequencies up to 40 Hz resulted in a lowered level of skin conductance. Such a change would normally be taken to indicate that the person was experiencing a lowered level of general arousal relating to the current situation. However, subjects did not show an awareness of this change. The current study was thus conducted to see if there might be observable effects on behavior by asking subjects to rate some standard visual stimuli during exposure to an applied magnetic field. Skin conductance was chosen as the primary measure because it is a good general indicator of a subject's state of arousal and is reliably associated with behavioral differences. Skin conductance changes are normally taken to indicate either different levels of situational arousal of the autonomic system or of the responsiveness of an individual to stimuli [Cacioppo and Tassinary, 1995]. A change in skin conductance during field exposure would, therefore, indicate a different level of arousal, which should be reflected in the subject's observed behavior.

Now, if the subjects were not aware that a magnetic field was present, they might attribute any field-induced change in arousal to their current

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Contract grant sponsor: Fundação Bial, Porto, Portugal; Contract grant number: 7/96.

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Received for review 20 October 1999; Final revision received 28 June 2000

perception—in this case, a visual image. By measuring their ratings for arousal and affect of that picture, it was hoped that a behavioral indicator of magnetic field presence would be found that could be compared to the physiological responses. The current set-up would not indicate in which area of the body the applied field was having an effect, but might demonstrate the types of changes which might be seen in an individual exposed to similar magnetic fields in the environment. The 20 Hz, 50 μT field chosen for use in this study lies within both the frequency range of natural fluctuations and that of the human brain, but was greater in magnitude than either (being on the order of strength of all components of the earth's field) to maximize any potential effects on the subjects.

METHOD

Subjects

Twenty-nine (20 male, 9 female) self-selected subjects with ages of 18–35 years participated in the study. Recruitment was via poster and word of mouth. All were fully informed about the nature of the study and signed a consent form indicating that they had no personal or family history of epilepsy-related symptoms, understood that the fields used might transiently affect their physiology, and knew that they were free to interrupt or terminate the experiment.

Apparatus

Electromagnetic fields were generated via Helmholtz coils, 0.65 m in radius with 256 turns of copper wire, modeled after those used by Bell and Marino [1989]. A current of 0.14 A, sinusoidally modulated at 20 Hz, was provided via the amplified output of a computer sound card. The generation of a 50 μT magnetic field was verified before the start of each session using a fluxgate magnetometer (model 428C, Applied Physics Systems, Mountain View, CA). The axis of the coils was oriented in an east–west direction in a sound-attenuated room. Subjects were seated between the coils, facing south, in a padded, all-plastic chair that offered full back, head, and arm support. Their heads and upper chest were within the magnetic-field region, calculated to be uniform within 5% of its predetermined value. For details of the field distribution, see Bell and Marino [1989]. During an experimental session, the only other equipment in the room was a 17 inch computer monitor used to display the images. This was situated in front of the subject, 1.5 m away from the outer edge of the coils. No pickup on the monitor screen of the magnetic field could be discerned at this distance, the monitor's audio speakers were unplugged to avoid pick-up, and no other potential cues associated with field presence could be identified.

Skin conductance (μS) was recorded using 78.5 mm^2 round Ag–AgCl electrodes with a water-based cream, placed on the second phalanx of the index and second fingers of the nondominant hand. A physiological data system (model I410, J&J Engineering, Poulsbo, WA) was interfaced to a high-speed serial port on a 100 MHz Pentium PC. Data were sequentially sampled at 1024 Hz, and time-averaged samples were saved to disk at 16 Hz. To ensure that there was no detectable direct pick-up of the electromagnetic fields by the physiology leads, test runs were conducted with electrodes connected via a 100 kΩ resistor, representing a mid-range value of the typical resistance of human skin, and recordings taken during field exposure. No field-related response was observed.

Visual Stimuli

Twenty GIF images, presented full-screen at a resolution of 300 × 200 pixels were used, evenly covering a range of affect and arousal ratings. The content of these images was selected to correspond to some of those rated in the International Affective Picture System [Davis et al., 1995]. Images were presented for 5 s, appearing 1 s after the rating for the previous image had been entered by the subject. Subjects were allowed as much time as they wanted to enter the ratings.

Procedure

Subjects were seated and the physiology electrodes were attached. They were told that they would be presented with 20 images while their physiology was recorded. The experimenter then left the room for the duration of the experiment. Images were presented in a pseudo-random order by the controlling computer. After each image, subjects were instructed by the computer to give ratings for the level of arousal and affect which they associated with that image. They responded by using a joystick (operated by their dominant hand) to move an on-screen sliding scale, labeled 'calming–neutral–arousing' and 'unpleasant–neutral–pleasant' for the arousal and affect scales, respectively. The computer then scaled these positional ratings from 0 to 100. The presence or absence of a field during each image viewing was based on a 50% probability pseudo-random decision, giving an average of 10 images per subject being viewed simultaneously with field exposure and 10 without. Overall, this resulted in 138 pleasant and 162 unpleasant pictures being viewed in the control condition, 144 pleasant and 156 unpleasant in the experimental condition.

Analysis

Raw skin conductance readings for each subject were converted to standardized z-scores i.e., expressed in units of each subject's standard deviation:

$$z_n = \frac{x_n - \overline{x}_n}{\sigma_n}$$

This technique allows between-subject comparison and reportedly gives a robust measure for subsequent analysis [Sersen et al., 1978]. Z-scores were then averaged over the 5 s period in which an EMF might be present and the variance calculated, giving two values (mean level and variance of skin conductance z-scores) per subject for every stimulus-presentation period. Comparison of means and variances was performed using a Wilcoxon matched-pairs signed-ranks test. This was one-tailed since, based on earlier pilot studies [Stevens, 1997], it was predicted that the presence of the field would result in a lowered level and a decrease in the variability of each subject's skin conductance.

The mean ratings for each of the 20 images were compared for field exposure vs. no field exposure using a Mann–Whitney unmatched-pairs test. This test was used because a comparison was being made between the average ratings of two different sets of subjects. To avoid problems with habituation, no single image was rated by the same subject under both conditions. Instead, the "field present" image ratings for one set of subjects was compared with the "no field" image ratings for the set of subjects in the field condition. This was necessary because if the same subject was shown the same image under both conditions, the lack of novelty in the second viewing could have introduced an affected response.

Post-hoc, the 5 s skin conductance recordings were sorted into one of three categories: lowered skin conductance during field exposure, heightened skin conductance under field exposure, or no obvious response. Average profiles for each category were produced, and the average ratings given to the images for each profile were compared.

RESULTS

Neither the skin conductance measures (Table 1) nor the arousal ratings (Table 2) showed statistically significant differences between experimental and control conditions. However, the affect ratings differed significantly ($P = 0.041$) between conditions, with the images viewed under field exposure being rated as having a more positive affect.

There appeared to be three broad categories of response to the presence of the field (Fig. 1). Forty-eight percent of the subjects ($N = 14$) showed a lowered skin conductance (group L) during field exposure. Thirty-four percent ($N = 10$) of subjects showed no apparent reaction (group N), and seventeen percent ($N = 5$) showed a reversed reaction (group H), with increased skin conductance during field exposure. Within these subgroups, the affect and arousal ratings again differed between field exposure conditions (Table 3). Both group L and group N gave higher affect ratings under field exposure whereas group H gave slightly lower ratings under field exposure. All of the subgroups gave lowered arousal ratings under field exposure, this being greatest for group H and smallest for group N.

DISCUSSION

The present findings show that blind exposure to a 50 µT, 20 Hz magnetic field significantly increased the value of the affect rating of a concurrently viewed image. That is, images viewed during field exposure, irrespective of content, tended to be rated as being

TABLE 1. Effect of Exposure to a 50 µT, 20 Hz Electromagnetic Field (Experimental) and to a Sham Exposure (Control) on Skin Conductance Measure

Measure	Number of subjects	Control	Experimental	Wilcoxon test
Skin conductance (z-score)	29	−0.233	−0.318	$P = 0.113$ (1-tailed)
Skin conductance (variances)	29	0.115	0.137	$P = 0.052$ (1-tailed)

TABLE 2. Effects of Exposure to a 50 µT, 20 Hz Electromagnetic Field (Experimental) and to a Sham Exposure (Control) on Image Ratings of Affect and Arousal

Rating	Number of images	Control	Experimental	Mann–Whitney Test
Affect	20	49.0	53.8	$P = 0.040$ (2-tailed)
Arousal	20	50.1	46.7	$P = 0.080$ (2-tailed)

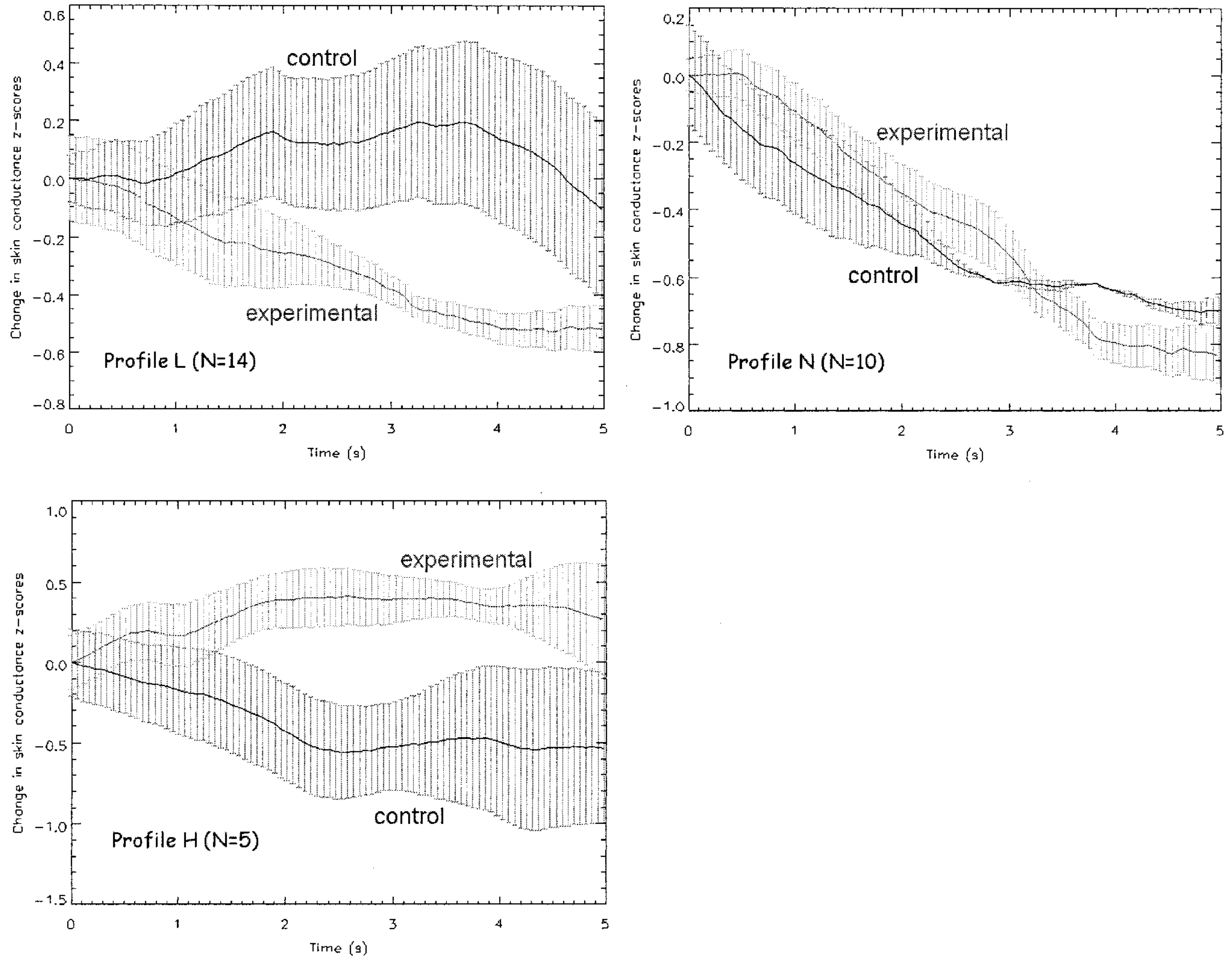

Fig. 1. Averaged skin conductance z-score profiles for subsets of subjects, during field exposure (experimental) and null exposure (control) periods.

more pleasant than those viewed in the control condition. This effect appears to be due to the applied field, since there were no apparent sensory cues alerting subjects to its presence and the random selection of images in each condition actually resulted in there being slightly more unpleasant than pleasant pictures in the field exposure condition. If there were a bias due to the presentation order, then it would have been acting opposite to the overall effect seen. It is not known whether the field acted to affect the subjects'

TABLE 3. Effects of Exposure to a 50 μT, 20 Hz Electromagnetic Field (Experimental) and to a Sham Exposure (Control) on Image Ratings of Affect and Arousal, Split by Skin Conductance Response Subgroups

		Affect ratings		Arousal ratings	
Subgroup	N	Control	Experimental	Control	Experimental
L	14	45.4	51.2	53.4	45.3
N	10	45.3	50.3	59.7	52.1
H	5	43.7	42.9	63.4	45.1

physiologies directly or their emotional response to the images, but the present results indicate that the subjects were reacting to the presence of the magnetic field by exhibiting significant behavioral changes.

A post-hoc analysis divided the subjects into three subgroups based on the pattern of their averaged skin conductance response to the presence of the magnetic field. The largest subgroup (L) exhibited a lowered skin conductance when the field was present and were also the group which showed the biggest difference in affect ratings for the images between control and experimental conditions. Additionally, they were the only ones to show the expected *rise* in skin conductance in reaction to the presentation of the visual stimuli throughout the session. This implies that individuals in this subgroup had labile physiologies, since such people habituate only slowly to repeated, simple stimuli and continue to show large skin conductance responses. If so, this would be consistent with other findings [Cacioppo and Tassinary, 1995], wherein labile subjects perform best at the detection of weak signals. In this case, the weak magnetic field would represent a detectable signal, albeit one with no useable information content. The effects of that detection appear to have been incorporated into the subjects' responses, being transferred onto a concurrent, conscious perception (the affective rating of a visual stimulus), an effect seen in a variety of other cases involving the detection of weak or ambiguous signals [Lange et al., 1996].

It should be noted that the "no obvious response" subgroup (N) showed almost as great a difference in their affect ratings as the lowered-response group, possibly indicating that they were showing a skin conductance response in the same direction but of much lower magnitude. However, the subgroup (H) showing an increased (i.e., reversed) skin conductance response to the magnetic field, also exhibited a decrease in affect ratings between conditions. This lends some support to the idea that the change in physiology did relate to a subject's emotional rating of the concurrently present image

If the observed subgroupings do relate to physiological lability then this will help explain why human bioelectromagnetic studies often find conflicting results. The present results show a reversed effect depending on the direction of skin conductance response, so a study using unselected subjects might find any effect that did occur was cancelled out across differently responding subgroups of subjects. Future studies would, therefore, benefit from dividing subjects into groups based on the degree of their resting physiological activity and then predicting differences in their responses in subsequent tasks under magnetic field exposure.

ACKNOWLEDGMENTS

This work was supported by Fundação Bial, Porto, Portugal under grant number 7/96.

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