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Short communication

Human exposure to 60-Hz magnetic fields: neurophysiological effects

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Abstract

The neurophysiological effects of exposure to power-frequency magnetic fields at two occupationally-relevant intensities were evaluated in a single-blind study with 18 male and 18 female volunteers. Auditory brainstem (BAEP) and somatosensory (SEP) evoked potentials were recorded before, during and after field exposure (duration = 45 min, frequency = 60 Hz, field intensities = 14.1 or 28.3 microtesla, μT), or an equivalent sham-exposure control period. Visual event-related potentials (VEP) to pattern reversal stimuli were also recorded before and after the exposure period. Field exposure had no differential effects on the BAEP, the VEP, or on SEP measures of central conduction time. Men and women showed a similar lack of sensitivity to exposure. The present results do not support the mechanistic hypothesis that the transmission of sensory information to appropriate cortical centers is delayed or distorted by exposure to power-frequency magnetic fields at occupational intensities.

Keywords: EMF; ELF; EEG; Evoked potential; Human; Gender

1. Introduction

Electric power transmission and distribution systems are becoming increasingly prevalent in the environment. This has raised public health concerns and accelerated research to identify possible biological effects associated with exposure to power-frequency electric and magnetic fields (NRC, 1996; Valberg et al., 1997; Portier and Wolfe, 1998). The brain and central nervous system are considered to be among the most likely sites of interaction between biological systems and power-frequency fields. The electric field in-

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duced in the brain by exposure provides a plausible biophysical mechanism for the modulation of neuronal activity or function. Gailey et al. (1997) estimated that induced electric fields of at least 1-mV/m in magnitude are needed for biological responses to occur. Calculations derived from the recent dosimetric model of Dawson et al. (1997) indicate that attainment of this threshold is quite feasible under various occupational exposure scenarios. Few electrophysiological studies of animal nervous system activity have been reported, however, and surprisingly little is known about exposure effects on electroencephalographic (EEG) measures of human sensory and cognitive function.

Early rodent and in vitro studies (see Cook et al., 1992) demonstrate that field exposure can influence synaptic function, conduction velocity in peripheral nerves, neuronal excitability, and the analgesic effects of opiates. The relevance of such studies to typical human exposure conditions is unknown, however, due to the use of anesthetized animals, isolated physiological preparations or very high exposure intensities. The study by Dowman et al. (1989) is the only one to evaluate exposure effects at occupationally relevant intensities on sensory evoked potential (EP) measures in a primate (the monkey, *Macaca nemistrina)*. Test subjects were chronically (18 h/day for 3 weeks) exposed to combined electric and magnetic fields at three intensities, and EPs from auditory, somatosensory and visual pathways were recorded periodically when the fields were switched off. Exposure had no effect on early or mid-latency EP component measures in any pathway. At the two higher intensities evaluated, however, exposure was associated with reduced amplitude of two late somatosensory (SEP) components (P21-N45, N45-P70). The functional significance of this reduction is unknown.

No information is available about possible effects on EP sensory measures in humans during exposure. Graham and colleagues, however, performed a series of human exposure studies to evaluate effects on longer-latency 'cognitive' event-related potential measures (Graham et al., 1987, 1994; Cook et al., 1992). Men were exposed, under double-blind control conditions, to 60-Hz electric and magnetic fields for up to 6 h at three occupationally relevant intensities. Visual (VEP) and auditory (AEP) event-related potentials were recorded before, during and after exposure while subjects performed the Oddball Task. Replicable field-related effects were found only for the AEP. Exposure was associated with alterations in P300, a primary cognitive component of the AEP. In the context of the Oddball Task, the observed changes suggest that stimulus evaluation time was slowed during exposure. These effects were noted within the first 45-min after exposure was initiated. Lyskov et al. (1993) also reported reductions in N100 amplitude of the AEP when testing humans immediately after brief (<60 min) exposure to 45-Hz magnetic fields.

One possible mechanism for these reported effects on the AEP is a slowing or alteration of neural transit time. In other words, exposure may act to delay or distort the transmission of essential sensory information to appropriate brain stem and/or cortical centers. In light of the Dowman et al. (1989) results, it was also of interest to measure the SEP in humans during field exposure. Thus, the present study compared measures of the Brainstem Auditory EP (BAEP) and SEP collected before, during and after field exposure. Data were also collected on the VEP in response to pattern reversal stimuli to provide additional basic information about the influence of exposure on the visual system.

2. Materials and methods

2.1. Subjects

Thirty-six, healthy volunteers (18 men/18 women, ages 18–27 years; mean = 20 years, S.D. = 1.6 years) participated in the study. All were right-handed, none had chronic disease or disability, and none were taking medications. Women were included because so little is known about possible effects in women. The study was approved by the institute's review board and written informed consent was obtained.

2.2. Procedures

Equal numbers of men and women were randomly assigned to each of three test groups. One group was exposed for 45 min to a 60-Hz circularly-polarized magnetic field (resultant flux density = 14.1 microtesla, μT). A second group was similarly exposed but at a higher intensity (resultant flux density = 28.3 μT). These intensities were used by Graham et al. in their studies of the AEP, and they are within the range of occupational exposures associated with electric utility operations and the use of industrial machinery or power equipment. In addition, calculations based on the Dawson et al. (1997) model indicate that exposure to the 28.3-μT magnetic field would induce an electric field of approximately 1.8 mV/m in cortical areas of the brain. The third group was a sham exposure control group. Volunteers in this group participated in all aspects of the study protocol, but were not exposed to 60-Hz magnetic fields above the ambient background measured in the laboratory (≤ 0.2 μT). This intensity is characteristic of residential exposures.

BAEP and SEP data were collected before, during and after the exposure period. VEP data were collected before and after exposure, but not during exposure because magnetic field activation distorted the image on the monitor and interfered with the presentation of the checkerboard pattern stimuli. After collection of pre-exposure measures, the field generation system was activated to present either field or sham exposure conditions for 45 min. Subjects read during the exposure period, but were not allowed to nap or sleep. At 15 min into the exposure period, BAEP and SEP data were again collected. Subjects then continued reading until the end of the period, after which post-exposure measures were collected.

2.3. Exposure facility

Facility characteristics are described in Cohen et al. (1992). The subject sat in a wooden chair in the center of the exposure room (a cube 2.45-m on a side). Magnetic field generation systems were located out of sight behind the walls and above the ceiling of the exposure room. Field generation coils were not energized in the control condition. In the two exposure conditions, the uniform (4–7%) magnetic field was presented intermittently over the 45-min exposure period (the field cycled on and off at 15-s intervals). Circularly-polarized fields were presented intermittently at the selected duration and intensities because such exposure conditions were previously associated with physiological effects in humans (Cook et al., 1992; Graham et al., 1994; Sastre et al., 1998). The facility's blinded control system was used to prevent subjects from knowing when field or sham exposure conditions were in effect.

2.4. Measures

EEG measures were recorded using a NeuroScan EEG/EP System (Neurosoft, Inc., Sterling, VA). Recording techniques followed NeuroScan recommendations, and scoring methods followed IFCN guidelines (Newar et al., 1994a,b). Ag/AgCl surface electrodes were attached, using Grass EEG electrode cream and electrode gel as the contact medium, to standard scalp sites at Cz, Oz, C4′, and left (M1) and right (M2) mastoids (10–20 system). Electrode resistance was kept below 5 kΩ. The electrooculogram (EOG) was recorded from placements above and at the outer canthus of the left eye for on-line artifact rejection.

Stimuli for the BAEP consisted of 0.1 ms, 90 dB clicks delivered at an inter-stimulus interval of 50 ms through a foam tube-phone inserted in the left ear. The subject was instructed to sit quietly with eyes closed and listen to the clicks. Ipsilateral EEG (Cz-M1) was sampled at 20 kHz in 20-ms epochs around each stimulus (pre-stimulus baseline = 5 ms). The NeuroScan system performed online comparisons of signal/noise ratios calculated over blocks of 256 responses to determine the total number of responses needed to produce a quality waveform. Amplification and filter settings were 100 K and 150–1500 Hz, respectively. Analysis evaluated differences in inter-peak latency between Waves I, III and V. These respectively track neural transmission from excitation at the auditory portion of the 8th cranial nerve, through the pons and into the inferior colliculus in the midbrain.

Stimuli for the SEP consisted of 0.2-ms square-wave pulses, delivered at 5/s through the stimulator electrode applied longitudinally over the median nerve at the left wrist (Grass square pulse stimulator and transformer-coupled stimulus isolation unit, models S48 and SIU8T, Grass Instruments, Quincy, MA). Intensity was adjusted to produce a visible thumb twitch. EEG over the contralateral somatosensory cortex (C4′ referenced to M1–M2) was sampled at 20-kHz in 110-ms epochs around each stimulus (pre-stimulus baseline = 10 ms), and averaged over 500 trials. Amplification and filter setting were 1 K and 5–3000 Hz, respectively. Analysis focused on evaluation of inter-peak latency differences in central conduction time (P14, N20), generally taken as the time between the cervico-medullary junction and the primary somatosensory cortex.

The VEP stimulus consisted of a maximum contrast, 23-bar, B/W checkerboard pattern that reversed at 0.5 Hz on a 17-inch PC monitor placed 65 cm from the nasion of the subject (visual angle subtended = 57°). The subject was instructed to focus on a blue dot in the center of the monitor. The EEG (Oz referenced to M1–M2) was sampled at 512 Hz in 200-ms epochs around each pattern reversal (pre-stimulus baseline = 50 ms), and averaged online until 200 artifact-free trials were collected. Artifacts were defined as epochs with values > 100 μV. Amplification and filter settings were 1 K and 1–40 Hz, respectively. Latency differences in the N70 and P100 components were evaluated.

The ability of subjects to consciously perceive the presence of the magnetic field was assessed by having them complete the Field Status Questionnaire (FSQ, Cook et al., 1992) at the end of the test session. Subjects answered three questions: ‘In your judgment, was the field on or off?’, ‘How

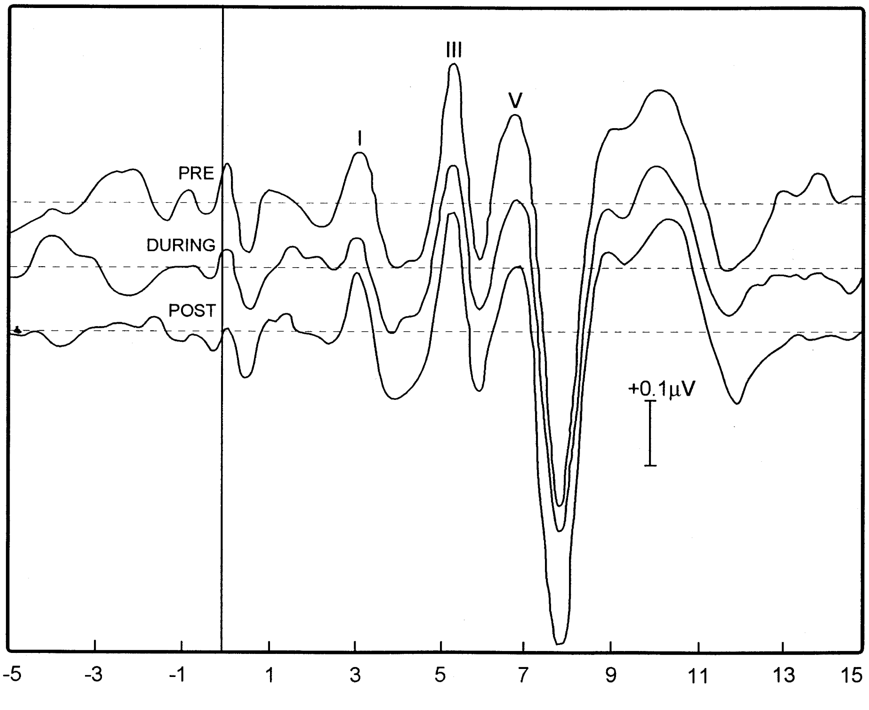

Fig. 1. Grand average ($N = 36$) brainstem auditory evoked potentials (BAEP) recorded before, during and after exposure for 45 min to 60-Hz magnetic fields at occupational intensity levels. Exposure had no effect on the latency of Waves I, III and V.

confident are you of this judgment (a 1–5 scale)?' and 'What are you basing this judgment on?'

Analysis of variance for mixed designs was the primary analysis technique employed. Factors in the analysis were group (sham, 14.1 μT, 28.3 μT), test period (pre-, during, post-), gender, and parameters that varied as a function of the measure analyzed. Group and gender were between-subjects factors; the rest were within-subject factors. Significant interactions were further examined with simple effects tests. The Huhyn-Feldt correction was used to correct for lack of sphericity due to repeated measures. Effects at $P \leq 0.05$ were considered significant.

3. Results

Analysis of FSQ rating data indicated that subjects were unable to judge when the magnetic fields were active ($\chi^2 = 3.59$ (df 2), $P < 0.20$). This finding confirms the effectiveness of the single-blind control procedures. As illustrated in Fig. 1, no field-related latency differences were found between Waves I, III and V of the BAEP as a function of group, test period or gender. For the VEP, no field-related effects were found for N70 or P100 amplitude or latency (see Fig. 2). Analysis of SEP inter-peak latency measures of central conduction time (P14, N20) also revealed no field-related differences as a function of group, test period or gender. Following Dowman et al. (1989), amplitude measures of the late SEP components were also examined. The P21-N45 amplitude difference was not influenced by exposure; however, an interaction effect ($F_{4,46} = 4.68$, $P = 0.003$) was found between group and test period for the N45-P70 amplitude difference. Fig. 3 illustrates this statistical interaction. Amplitude was reduced only for the group exposed to the lower intensity magnetic field and only during the exposure period ($F_{2,16} = 5,19$, $P = 0.03$). For these rea-

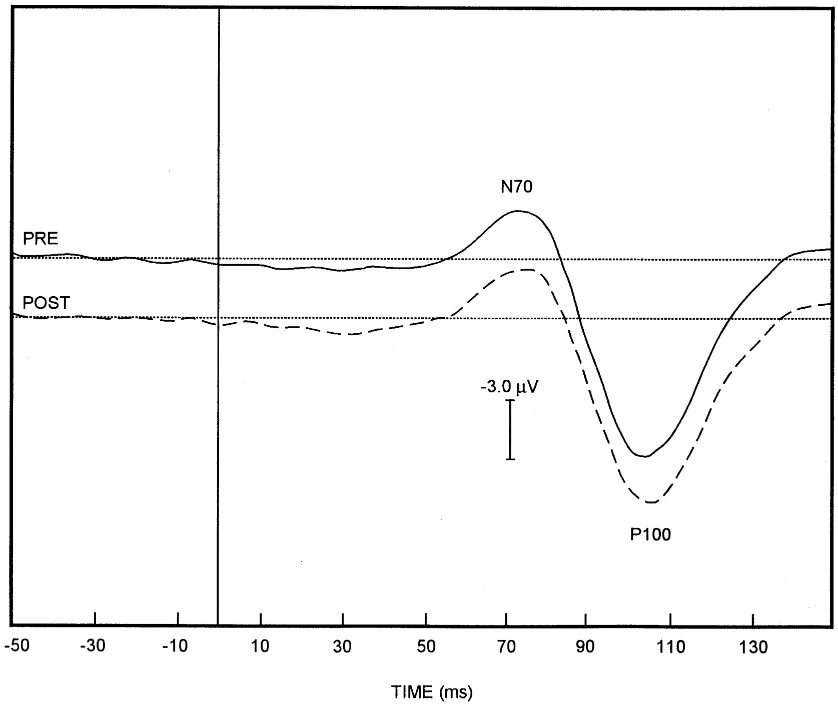

Fig. 2. Grand average ($N = 36$) visual event-related potentials (VEP) recorded before and after exposure for 45 min to 60-Hz magnetic fields at occupational intensity levels. Exposure had no effect on the latency or amplitude of component measures (N70, P100).

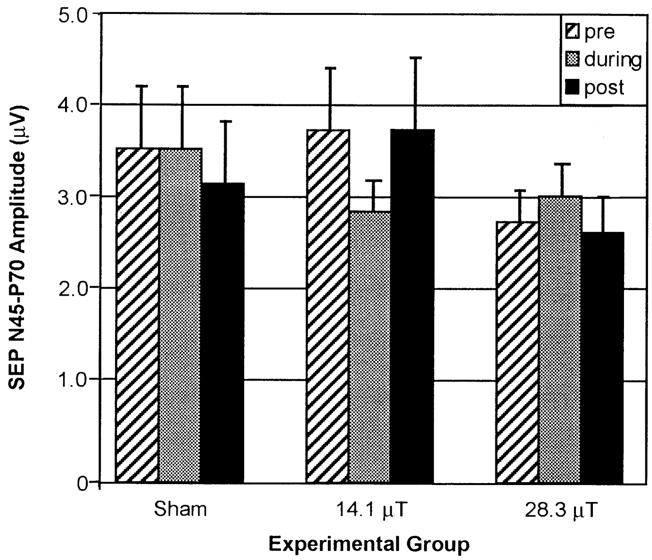

Fig. 3. Comparison of N45-P70 component amplitudes (mean ± S.E.M.) of the somatosensory evoked potential (SEP) plotted for the sham exposure control group and the two magnetic field intensity exposure groups. Amplitude was reduced only for the group exposed to the lower intensity field, and only when measured during exposure.

sons, and because of unexplained amplitude variation in the sham control group, we doubt that the finding has functional significance.

4. Discussion

These results do not support the hypothesis that transmission of sensory information to appropriate brain stem and/or cortical centers is delayed or distorted by exposure to power-frequency magnetic fields at occupational intensities. Thus, the AEP alterations reported earlier by Graham et al. and by Lyskov et al. (1993) can not be accounted for by a slowing or alteration of neural transit time in auditory pathways. It is possible that the observed effect on AEP measures may be related to shifts in physiological arousal and attention during the extensive testing protocols used. The lack of effects seen for the VEP replicate our earlier negative VEP results and also those of Silny (1986) in human exposure studies with 50-Hz magnetic fields. We have little confidence in the amplitude reduction found for the late N45-P70 component of the SEP. This reduction was limited to the group exposed to the lower intensity field, and no similar pattern was seen in the more highly exposed group. Gender also was not a significant factor in this study; although gender main effects were found, as is usual with the measures analyzed. Neither men nor women were sensitive to the presence of the magnetic fields.

Exposure duration in this study was relatively brief, and others have suggested the need to examine more chronic conditions that parallel the typical experience of many people (Portier and Wolfe, 1998). A related issue is the possibility that EEG disturbances may arise from exposure to the more complex magnetic fields found in the man-made environment. The results of occupational exposure studies performed to date, however, provide little support for these suggestions (Gamberale et al., 1989). EEG effects have been observed primarily in the laboratory, not in the ambient environment. From a basic research point of view, this suggests a need for additional work to better understand the relationship between exposure and brain electrical activity underlying human sensory and cognitive function. From a public health perspective, however, the changes observed to date appear to be within normal ranges for the EEG parameters assessed and do not indicate any immediate cause for public concern.

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