Influence of 50 Hz-1 mT magnetic field on human median nerve

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In this study, human median nerve was exposed to power frequency magnetic fields in order to provide clarification for possibly changeable nerve conduction mechanism. The nerve was exposed to 50 Hz magnetic field by utilizing a special Helmholtz applicator. The experiments were carried out with six healthy human-volunteers. Median motor distal amplitude/proximal amplitude ratios were recorded from adult human median nerve pre-exposure, during, and post-exposure to a 50 Hz, 1 mT magnetic field. The result of 18 measurements shows that median motor distal amplitude/proximal amplitude ratio significantly decreases in pre-exposure state as compare to post exposure of which. The results of this study may be useful for some nerve rehabilitation, excitation, and stimulation in more effective/safe physical therapy. Additionally, 50 Hz, 1 mT sinusoidal magnetic field should not be recognizing as safe for conduction mechanism on a nerve. These mechanisms would be cleared by new advanced engineering models in other future works.

Keywords Low-level magnetic field, Distal amplitude, Proximal amplitude, Median nerve

INTRODUCTION

Many biological processes are affected by magnetic fields. Hence, incremental internal fields generated by external magnetic fields can be expected to affect that biology. With some exceptions, most of the present interest in the effects of exogenous static and low-frequency magnetic fields centers on three intensity regions (Sommerfeld, 1952). There are concerns that 50–60 Hz power distribution fields as small as 0.2 μT, may affect the health of populations (Lin and Gandhi, 1996). Alternative current (AC) fields that are larger than 1 mT with frequencies of a few kHz or less may have therapeutic value with respect to the healing of bone fractures and soft-tissue injuries (Foster and Schwan, 1996). The very large slowly varying fields of the order of 2 T used in magnetic resonance imaging might affect the physiology of the patients.

For either the direct magnetic fields or the magnetically induced electric fields to affect the biology of living systems, the interactions with such systems must generally be larger then the interactions with endogenous physiological and thermal noise. This constraint seems to exclude the possibility that the environmental fields less than 1 μT from the electric power distribution system affect health and places important constraints on the minimal fields that can be expected to have therapeutic value.

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The ability to simulate biological structures with currents induced by low-frequency magnetic fields has long been known. The magnitude and change of stimulus is communicated to the central nervous system by the frequency and number of impulses in the nerve cells. The use of magnetic fields and direct current stimulation for treatment of nonunion fractures is a major advance in the orthopedic surgery. Basset (1982) achieved a success rate of 80%. Adey and Bawin (1977) observed that ELF fields amplitude modulated at brain wave frequencies have strongly influenced spontaneous and conditioned EEG patterns in the cat. He proposed that the weak electrical forces induced in the brain were modifying the excitability of the central neurons and that these changes were reflected in the recorded transient EEG episodes (Bawin et al., 1975).

Schwan (1985) observed that larger cells are more sensitive to an external field than smaller ones provided that the applied frequency is low enough to make the membrane impedance large. He also concluded that at high frequencies the likelihood of any direct interaction of magnetic fields with biological membranes is small. At frequencies 100 Hz or less, Adey and Bawin (1977) suggested a direct interaction with the central nervous system. These might have been caused by direct interaction with central nervous system (Adey and Bawin, 1977).

Variations in the intracellular action potentials with recording temperature and axon conduction velocity were also incorporated into the volume conduction calculation. Also, action signal propagation that exhibits a variation in the shape of signals along the sample (non uniform propagation) is difficult to measure using the traditional electric methods (Wijesinghe, 2010).

NERVOUS SYSTEM

Many of the biological effect which has been reported in animals or humans exposed to extremely low-frequency B or E fields appear to be associated with the nervous system. Such system responsiveness to fields might be anticipated since the nervous system plays a basic role in the interaction of animals with their environment. Indeed, other biological systems may be influenced indirectly by EMF exposure through neural/hormonal functions. Reported nervous system effects from EMF exposures include: changes in behavioral and activity response; chemical changes in nerve cells; changes in the excitability of nerves; altered neurotransmitter and neurohormone levels; and disruption of biological rhythms.

Among the most sensitive measures of perturbation in a biological system are tests which determine modifications in the behavioral patterns of animals. Behavioral studies in several species provide evidence of E field perception, as well as indications that behavior can be altered by exposure. The threshold of detection of 60-Hz E fields has been reported to be between 4 and 10 kV/m in rats (Stern et al., 1983). E-field thresholds in other animal species, including mice (Sander et al., 1982), pigs (Graves et al., 1978), and birds (Lovely et al., 1992), have been reported in the 25- to 35-kV/m range. Perception of B fields has not been observed in the mT range (Barlow et al., 1947), however visual perception in the form of phosphenes was demonstrated with B fields above 20 mT in humans (Lovsund et al., 1980; Hjeresen et al., 1980). Avoidance behavior of animals has been investigated at several E-field strengths. With some exceptions, animals generally avoid exposure to E fields over 50-75 kV/m (Lovely, 1988). Under those levels, changes in physical activity responses have been reported although the changes are usually transitory (Tenforde, 1986). Effects of B fields on behavior are curious in that several investigations performed at low field intensities showed behavioral alterations.
(Anderson, 1990). In contrast, studies conducted at higher B field intensities demonstrated no evidence of effects on animal behavior.

A number of studies have investigated the central nervous system (CNS) for changes in various chemicals in the brain upon exposure to EMF. In general, these studies report small, albeit highly variable, changes in certain neurotransmitters (Wilson et al., 1999). The data provide limited evidence that exposure to E fields in the power frequency range may cause slight changes in nervous system function. The number of experiments is not large, and there are significant questions about the strength and validity of several of the studies. Recent experiments suggest significant changes in norepinephrine content in specific brain regions of the hamster exposed to 60-Hz magnetic fields (Jaffe et al., 1983).

In the area of neurophysiology, a confusing array of studies claim both effects and no effects of EMF exposure. A case in point is the commonly used measure of general CNS activity, the electroencephalogram (EEG), where significant alterations were reported in some studies but not in others (Wilson et al., 1999). In an assessment of a more specific electrical signaling of the brain, evoked responses, no effects caused by exposure to E fields were observed in visual evoked response; however, changes have been demonstrated in somatosensory evoked response (Wolpaw et al., 1987).

**EFFECT OF STIMULATION ON NEURONS**

The magnitude and stimulus is communicated to the central nervous system by the frequency and number of impulses in the nerve cells. Information about a stimulus is thus pulse coded. Nerve axons are roughly circular in cross section and are hundreds or thousands of times longer than they are wide. The potential changes at one site along a nerve cell are accompanied by current flow across the membrane at that point. Most nerve cells in the resting state exhibit a steady potential difference of about 75 mV across the membrane, the inside being negative to the outside. The action potential has the unique ability to reestablish itself in immediately adjacent membrane regions.

The currents generated by the impulse itself are responsible for its renewed appearance along the nerve. The finite duration of the action potential and its recovery process fix the limit at about 1,000 impulses per second. At the same time, the threshold of the receptor must be sufficiently low so that small changes in the available energy can be detected. A lower limit of 1 impulse per second can be chosen as a meaningful threshold frequency. Thus, a range between 1 and 1,000 impulses per second seems a reasonable approximation where the nerve cell is likely to respond to external stimuli. The frequency of the propagated action potential is critically dependent upon the magnitude of the receptor potential. Several sensory systems show that the application of a stimulus causes an increase in the conductance of the cell membrane.

**METHODOLOGY**

**Subjects**

The experiments were carried out on 6 normal volunteers, aged between 28 and 52 (mean = 35). This study was approved by the ethics committee of the Suleyman Demirel University Medical Sciences Research Center. The subjects were healthy, without any medical disorders and medications. The subjects were sitting in relaxed position; any physical activity was excluded during the experiment. The right *nervus medianus* motor nerve fibers were under test in the study.

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MAGNETIC FIELD EXPOSURE SYSTEM

Magnetic field density between coils was set to 1 mT by using to set the output voltage of 25 Volts from 50 Hz alternating current source (Philip Harris, Shenstone, UK). The magnetic field during exposure was controlled by input current to the Helmholtz coils and measuring the magnetic flux density with a magnetic field probe (Philip Harris, Shenstone, UK). Induced RMS voltage across the output leads of probe was monitored by using digital voltmeter (Chauvin Arnoux Max 3000 TRMS, Paris, France). A field of 1 mT, as calculated from voltages induced in pick-up standardized coil probe, placed midfield, was generated in a pair of Helmholtz coils 10 cm in diameter, with 220 turns of 0.8 mm gauge copper wire each. The coils were placed parallel to the table so the magnetic field has to be vertical oriented. The coils were mounted on a plastic framework, 15 cm apart, and connected in series to a generator delivering a sine wave output current of 0.875 Arms at 50 Hz.

PROTOCOL

This study was performed at Electrophysiology laboratory of Neurology Department of Medical Faculty in Suleyman Demirel University. In this study, three main states were conducted: pre-exposure (first), during exposure (second), and post-exposure (third) treatments. These experimental applications (treatments) were performed to test a magnetic field’s ability to alter the motor distal amplitude/proximal amplitude ratio of a human median nerve. The ambient temperature and relative humidity percent of the room housing this facility were maintained at 28 ± 2 °C and 55% ± 5, respectively.

FIGURE 1 Distal application to the subject’s arm. For shunt polarization of axial magnetic field vector to the nerve fiber, the arm was placed in the axial position to the Helmholtz set.
The median nerve from the right arm was stimulated concurrently on proximal (elbow) and distal (wrist) regions, using square-shaped supra-maximal pulses with 0.2 ms and 2 Hz. The motor responses were recorded from the *Abductor Pollicis Brevis* (APB) muscle, using surface electrodes. Recordings were made on a Nihon-Kohden Neuropack 4 digital electromyography with its tune to the 10 kHz sampling rate. Fig 1 and 2 show median nerve excitation in distal and proximal areas, respectively.

As performed in the clinical routine recordings, the values of distal and proximal amplitudes from median nerve were obtained as mentioned above. Just after this recording procedure, magnetic field source was kept as switched on for the first 5-min exposure duration. After this process, a new recording was performed. Then, the exposure process was ended. After the 5-minute rest duration, the last recording was performed. Entire process was applied to all subjects.

**FIGURE 2** Proximal application to the subject’s arm.

**TABLE 1** Obtained parametric values of motor distal amplitude/proximal amplitude ratio of human median nerve of pre-exposure, during and post exposure groups

| Subject number | Pre-exposure motor distal amplitude/proximal amplitude | During motor distal amplitude/proximal amplitude | Post-exposure motor distal amplitude/proximal amplitude |
|----------------|--------------------------------------------------------|--------------------------------------------------|--------------------------------------------------------|
| 1              | 1.140                                                  | 1.115                                            | 1.088                                                 |
| 2              | 1.252                                                  | 1.122                                            | 1.139                                                 |
| 3              | 1.170                                                  | 1.053                                            | 1.030                                                 |
| 4              | 1                                                      | 1.018                                            | 0.925                                                 |
| 5              | 0.948                                                  | 0.986                                            | 0.934                                                 |
| 6              | 0.980                                                  | 1                                                 | 0.987                                                 |
| Average ± Standard Deviation | 1.08 ± 0.122                                     | 1.04 ± 0.058                                      | 1.01 ± 0.085                                         |

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DATA ANALYSES

The statistical analysis for the calculated motor distal amplitude/proximal amplitude ratio was done in order that the mean values and standard deviation of the data were obtained. The two-tailed paired Student t test was used to compare the data in case of measurement. The p values lower than 0.05 were considered significant.

RESULTS

As seen from Table 1, the average value of rate of distal/proximal magnitudes were $1.08 \pm 0.122$ in the first treatment, $1.08 \pm 0.122$ in the second, and $1.01 \pm 0.085$ in the third application. From Table 1, the p values can be obtained as seen in the Table 2.

Statistical wise, p values of first to third application are significant whereas the values of first to second, and second to third as insignificant. Graphical representation of standard deviation and average values of motor distal to proximal magnitudes can be seen in Fig 3.

After the exposing of human median nerve to 50 Hz-1 mT magnetic field, all measures were taken by using 4-channel NCS/EMG/EPS (Nihon Kohden Neuropack Corporation, Tokyo, Japan). Some interesting results were observed: obtained values of motor distal magnitude to proximal amplitude rate of post-exposure were low comparing to pre-exposure values significant ($p = 0.03$).

DISCUSSION

In studying membrane potential and voltage-gated ionic channels, two possible mechanisms explaining the effects of magnetic fields on action potentials seem most logical. One possible mechanism involves the effects of magnetic fields on the phosphorylation of specific sites on the voltage-gated sodium channel. Several articles have suggested that magnetic fields may influence the rate of phosphorylation of specific protein kinases (Sun et al., 2002). The presence of paramagnetic molecules such as magnesium and manganese may alter the proper

| Motor distal amplitude/proximal amplitude ratio | p value |
|------------------------------------------------|---------|
| Pre-exposure and during application           | 0.325   |
| During and post-exposure application          | 0.090   |
| Pre-exposure and post-exposure application    | 0.037   |

FIGURE 3 Motor distal amplitude/proximal amplitude ratio of average and standard deviation.
functioning of the protein kinases; thus, increasing the rate of phosphorylation. The sites of phosphorylation in the voltage-gated sodium channels are located between the first and second domains, where some research suggests that the protein sequence controls the acceleration of slow inactivation (Goldin, 2003). Furthermore, studies have been shown that slow inactivation greatly influences the firing of action potentials (Denac et al., 2000).

This could mechanistically explain the results of Cavopol et al. (1995) that the number of action potentials elicited decreases under the presence of a quadrupole. In this experiment, no conclusions regarding magnetic fields potential influence on slow inactivation can be made due to the variables measured. The second possible mechanism by which magnetic fields may have an influence on action potentials involves the voltage sensor. Furthermore, it is uncertain as to how magnetic fields may influence the voltage sensor. If indeed magnets affect the voltage sensor, all of the measured variables, except the duration of the action potential, would change due to the action of the voltage sensor.

The increase in amplitude suggests that the magnetic field exposure increased the number of voltage gates opened. In other words, the magnets may have caused more voltage sensors to respond to the applied stimulus. The increase in activation time suggests that the magnetic fields produce a force which prevents the movement outward of the voltage sensor and thus the opening of the activation gate. Rosen also reports an increase in activation time due to the presence of static magnetic fields (Rosen, 2003). We think these possible mechanisms act a key role in our study, as previously mentioned mechanisms represent potential areas of research in trying to identify any possible effects of magnetic fields on the human nervous system. Some different frequencies, field intensities, and wave shapes might be used by future researchers.

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Declaration of interest

The authors report no conflicts of interest. The authors alone are responsible for the content and writing of this article.

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