Potential Emotional and Cognitive Disorders Associated with Exposure to EMFs

A REVIEW

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Environmental and occupational hazards or stressors that may cause sickness, impaired health, or significant discomfort in workers or the general population are generally classified as hazardous chemicals, physical stressors, biological agents, ergonomic factors, mechanical agents, or psychosocial factors (Plog, 1996). Technological advances and the resulting changes in working conditions and the environment create new hazards or stressors. These stressors can produce new or unexpected biological and psychosocial responses.

One of the most obvious changes is the introduction of numerous electrical equipment and modern communication devices into the workplace and other aspects of modern life. This trend has increased the exposure of workers and the public to electromagnetic fields (EMFs) (World Health Organization [WHO], 1984), a potential physical stressor.

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The purpose of this article is to review potential emotional and cognitive disorders associated with EMFs. Because most of the studies published have examined the effects at power line frequency (50 Hz or 60 Hz), the sources cited describe observations of EMFs of this frequency, unless otherwise specified.

ELECTROMAGNETIC SPECTRUM AND ELECTRIC AND MAGNETIC FIELDS

Visible light is a very narrow segment of the electromagnetic spectrum. Separate colors become perceptible due to different frequencies in the spectrum of visible light. Similarly, the electromagnetic spectrum encompasses a broad range of frequencies, including gamma and x-rays, ultraviolet radiation, visible light, infrared radiation, laser beams, microwaves, and television, radio, and radar system transmissions. The electromagnetic spectrum also encompasses subradio and extremely low frequencies (ELF). ELF is the term commonly applied to frequencies of 30 Hz to 300 Hz. However, the definition of ELF may extend from direct electric current (0 Hz) to 30 kHz. ELF includes electric power line frequency of 60 Hz in North America and 50 Hz elsewhere (Michaelson, 1982).

Frequency (f, in Hz) and wavelength (λ, in m) of an electromagnetic wave are inversely related by the speed of light ($c = 3 \times 10^8$, in m/s): $c = f\lambda$. For example, the wavelength of power line frequency of 60 Hz is 5×10^6 m (3,108 miles), and the wavelength of electromagnetic energy used in microwave ovens normally used in the kitchen, which have a frequency of 2,450 MHz or $2,450 \times 10^6$ Hz, is 0.122 m (about 5 inches).

Electromagnetic energy is composed of electric fields (EFs) and magnetic fields (MFs). This type of energy is basically emitted from a radiating source or an antenna. In the home or workplace, ELF EMFs are generated by using any type of electrical equipment. If the distance (d) from a source of electromagnetic energy becomes relatively large compared to the wavelength of the electromagnetic energy, $d > \lambda/6$, the EFs and MFs will be linked. Together, they create radiating EMFs. In a radiating EMF, electric fields and magnetic fields coexist. A changing electric field is accompanied by changing magnetic fields and a changing magnetic field is accompanied by changing electric field. When the distance from the source is relatively small compared to the wavelength, the EFs and MFs are not linked together. In such a case, the electric fields and magnetic fields have separate and independent properties. Because the wavelength related to EMFs of power lines is very long (3,108 miles), EMFs generated by most electrical equipment energized by power lines can be treated as separate and independent EFs and MFs in any related measurement or discussion (Akbar-Khanzadeh, 1994; Hitchcock, 1995).

HEALTH EFFECTS OF EMFS

Numerous reviews about the health effects of EMFs have been published (Anderson, 1993; Goodman, 1995; Knave, 1994). Recent reviews discuss potential associations with cancer of all sites, particularly leukemia, non-Hodgkin's lymphoma, lymphoma, cancers of the lung, brain, nervous system and pancreas, as well as spontaneous abortions, developmental abnormalities, and cognitive disorders (Adey, 1990; Bates, 1991; Knave, 1994; Savitz, 1993; Wilson, 1993). Several investigators have proposed that cognitive and behavioral manifestations might result from neurohormonal responses to EMF exposure (Cook, 1992; Groh, 1990; Wilson, 1988).

The relationships between exposure to EMFs and psychosocial or biological responses reported by some independent investigators suggest that a subtle, complex association might exist. For example, studies examining the relationship between exposure to video display units (VDUs) with frequencies up to 400 KHz (Oftedal, 1995), and physiological strain such as facial skin symptoms (i.e., burning sensation, stinging, itching, tenderness or pain, redness) reveal a possible association between the exposure and strain. This association could be due to actual exposure to harmful agents produced by VDUs, as well as to psychosocial stressors created by the organizational structure of the modern workplace (Smith, 1981). The strain responses due to working with VDUs might also reflect associations with exposure to EMFs. Other investigators have examined subjective symptoms such as wakefulness and stress, and have measured reaction time in electrical utility workers who are also exposed to EMFs and found no adverse responses (Gamberale, 1989).

IN VITRO AND NON-HUMAN DATA

Cellular Mechanisms

Goodman (1995) recently reviewed several prevalent theories of the cellular mechanisms by which EMFs might produce reactions. Possible mechanisms include:

- Interactions with plasma membranes, including the creation of unhydrated ions moving in membrane channels.
- Alterations in responses to hormones.
- Changes in enzyme activity.
- Alterations in rates of metabolism.
- Interactions of electric fields or currents with cells to induce an electric charge or polarization.

According to Luben (1991), EMFs might interfere with the enhancing effect of parathyroid hormone on adenylate cyclase activity, resulting in decreased extracellular calcium concentrations. Bloom (1980) and Seegal (1989) observed decreases in dopamine concentrations resulting from EMFs ranging between 3 kilovolts per meter (kV/m) and 0.1gauss (G) to 30 kV/m and 0.9 G, which would contribute to a reduction in adenylate cyclase activity with a consequential decrease in extracellular calcium concentration.

Because the levels of calcium did not decrease in magnitude with increasing exposure to EMFs, the authors' findings may be questionable. The increased levels of extracellular calcium in response to electric field exposures (15 Hz, 42.5V/m; 45-105 Hz, 42.5 V/m; 50 Hz, 45-50 V/m; 60Hz, 35-40 V/m) are not consistent with an association between EMF exposure and decreased adenylate cyclase activity, resulting in decreased extracellular calcium concentration (Blackman, 1990, 1985). Weaver (1992) offers models suggesting that EMFs might alter the configuration of the proteins and enzymes of the cell membrane and inhibit functioning of Na-KATPase. Na-KATPase is an enzyme essential for utilization of ATP at the cell membrane and maintaining cellular sodium and potassium homeostasis (Blank, 1990). Changes in cellular sodium and potassium concentrations in the cell are essential for the transmission of electrical impulses through the nervous system (Hille, 1989). Exposure to EMFs might alter emotional and cognitive states through these changes.

Data Supporting an Association With Depression

Although a consistent mechanism of action has not been identified for exposure to EMFs, a review by Wilson (1988) shows that findings in several animals including rats, guinea pigs, and monkeys are indicative of a relationship between exposure to EMFs and depression. Exposure to EMFs decreases the concentrations of serotonin and melatonin in the blood (Welker, 1983, rotated MFs of 0.5-1.23 G; Wilson, 1986, EFs of 39 kV/m). Reduced levels of blood serotonin and melatonin are proposed to be related to depression (Schaffer, 1981). The decreases in serotonin and melatonin concentrations observed by Wilson (1986) became more pronounced with increasing duration of exposure.

Exposure to EMFs (3 kV/m and 0.1 G, 30 kV/m and 0.9 G) decreases the concentrations of homovanillic acid, a metabolite of dopamine (a precursor of norepinephrine) and of 5-hydroxyindolacetic acid, a metabolite of serotonin (Seegal, 1989). These findings further support an association between exposure to EMFs and depression

(Wilson, 1988). Several medications found to be effective in the treatment of depression increase brain concentrations of norepinephrine (Malenka, 1989). Thus, deficits of norepinephrine in the brain might contribute to the development of depression.

Exposure to EMFs changes circadian rhythms (Aschoff, 1965). Changes include shortening the normal circadian period (Wever, 1973) and altering the rhythms in melatonin production (Wilson, 1988). Because desynchronization of circadian rhythms and reduced serum levels of melatonin are often associated with depression (Thompson, 1984), Groh (1990) proposes that the depressive effect associated with EMFs might be due to alterations in circadian rhythms. Ehret (1981) reported that circadian rhythm disruptions, such as those that may occur in night shiftwork, are related to fatigue or disorders of normal sleep/wake patterns, and Wehr (1979) found an association between disruptions in circadian rhythms and psychoses. Thus, EMF induced alterations in circadian rhythms might result in fatigue or psychosis. However, it should be pointed out that the association between EMF and circadian rhythm has not been fully developed.

Reviews by Reiter (1990) and Wilson (1988) conclude that exposure to EMFs might interfere with the synchronizing activity of the pineal gland and melatonin and alter brown fat physiology, adrenal metabolism, and insulin regulation. The resulting disruptions to glucose and hormonal homeostasis might cause altered functioning of the brain.

Other Psychological Effects

Another potential psychological outcome of exposure to EMFs (0.5 Hz, 1.5-90 G) is its inhibitory effect on morphine induced analgesia as observed in mice (Kavaliers, 1986). This effect was observed in only one of two strains of mice studied, and lacked consistent findings in the same species. The nature of this response is in a manner compatible with a calcium mediated response, and the depressed analgesic response might reflect interference with the release of endorphins, which are associated with the emotional state of well being induced by morphine (Jaffe, 1980). In contrast, Lai (1992) found that exposures to EMFs in the range of microwaves (2,450 MHZ, 1 mW/cm^2 power density) decreased cholinergic activity in the hippocampus mediated through opioid receptors. Equivalent responses were not observed in the frontal cortex. In addition, the lack of compatible findings suggests that responses to EMFs mediated through opioid receptors are selective and site dependent. Changes agreeable with opioid agonistic effects include euphoria, which is not consistent with a depressive effect, and drowsiness, which is characteristic of depression (Jaffe, 1980).

Other possible mechanisms of action of EMFs on the neurobiological state have been suggested. Azana (1994) reviewed available data concluding that most of the responses observed might be due to electrochemical changes occurring on cell membranes. Electrochemical changes will alter conductivity, changes in enzyme activity and reconfiguration of proteins involved in ion transport. Blackman (1990) reported an EMF related (45, 60, 75, 90, 105 Hz, unspecified field intensities) increase in calcium release from the brains of chickens and chick embryos, possibly mediated through effects on cell membranes. Shivers (1987) found measurable increase in the blood-brain permeability due to MF exposures of rats to magnetic resonance imaging (MRI) procedures. These changes might result in altered concentrations of nutrients and of xenobiotics, which could compromise the homeostatic state necessary for emotional and mental well being. Blank (1993, 1994) reported changes in the distribution patterns of proteins synthesized by Sciara salivary glands in response to EMFs (60 Hz, 0.008 8 G) are strongly similar to changes associated with heat stress. These researchers believe in a separate sensor with its own sensitivity for each of the magnetic and thermal stressors. Because exposure to heat stress results in altered mental and emotional states, it is reasonable to assume that exposure to magnetic fields would have a similar outcome.

While data exist relating EMFs exposure to alterations in brain physiology, results of animal studies of EMF related changes in brain activity and function are inconsistent. Levine (1994) found that a decrease in the navigational ability of mice, which was measured as ability to distinguish left and right stimuli, occurred immediately after exposures to EMFs (MRI source, 3,000 G). During subsequent trials, the performance of the non-exposed mice improved, but no change in performance in the exposed mice was observed. The authors did not vary the stimuli during a given trial, and the difference between the exposed and non-exposed groups might reflect deficits in memory rather than deficits in ability to distinguish stimuli. Dowman (1989) found no effect on early or mid-latency evoked potential components of electroencephalogram (EEG) measurements in primates. However, the researchers did observe that a decrease in the amplitude of the late latency evoked potential due to exposure to different combinations of EFs and MFs (3 kV/m and 0.1G; 10 kV/m and 0.3 G; 30 kV/m and 0.9 G). Because the authors measured potentials only when the animals were not exposed, whether a change in potential occurs during actual exposure cannot be predicted.

HUMAN EFFECTS

Current Opinions

Reviews of potential effects on emotional state and cognition resulting from EMFs have reached conflicting conclusions. Gamberale (1990) provided a review of the human studies and concluded that EMFs associated with transmission lines do not cause psychological effects to be considered as health hazards. This investigator nevertheless cited two English studies of subjects exposed to an electric field (36 kV/m) which brought about changes in mood and performance decrement in a reasoning task. Knave (1994) reviewed studies on EMFs and health effects, including neurobehavioral reactions, and concluded that the study results were not generally clear or consistent to constitute a sound basis for restricting exposure. Wilson (1988) reviewed epidemiologic studies and suggested that long term exposure to EMFs may cause pineal dysfunction and contribute to the onset of depression or exacerbate existing depressive disorders. Some of the findings of the studies, which report no definite association between exposure to EMFs and measurable adverse health effects, suggest that cognitive and emotional responses might result from the exposure.

Suicide

Studies of suicide and exposure to EMFs have yielded disparate findings. Baris (1990) found no excess of suicide notations on the death certificates of British subjects described as electrical utility workers. A recent study reporting suicide in Canadian electrical utility workers (Baris, 1996) found a potential association between suicide and the geometric mean (GM) of the levels of exposure to electric fields. The exposure of study subjects was estimated from their job histories and determination of personal exposure of current workers with similar job activities to those of study subjects. Because the most pronounced increase in risk of suicide occurred in subjects in a medium exposure group (GM = 23.1 - 40.3 V/m) rather than in a high exposure group (GM = 136.1 - 308.6 V/m), these findings are hard to explain unless the health effect is not dose related. Perry (1981) reported an association between residential exposure to MFs and suicide. The "mean $\pm$ standard deviation" of magnetic field strength for the suicide addresses was "867 + 1,320 μG," which was significantly higher than of "709 + 1,110 μG" for the controls. Because exposure was ascertained after the occurrence of a suicide and measured at the entrances to the residence of the subjects rather than by actual measurements of personal exposure, the findings of Perry (1981) may be questionable. Therefore, current findings on the association between suicide and EMFs are inconclusive.

Depression

Dowson (1988) used a questionnaire to study subjects residing in an area near overhead power lines of 132 kV compared to a control group selected in an area 3 miles distance, where the field intensity was much lower. The study subjects experienced a higher self reported prevalence of headache and depression than did the control group. Perry (1988) found a higher prevalence of depressive illness in persons living near the main electrical supply cable for their block versus persons living further from the cable. A study of the relationship between depression and headaches with residence near a high power transmission line by Poole (1993) also showed that exposure to EMFs might be associated with depression. Poole (1993) reported that this association was due neither to awareness of the exposure nor to other risk factors for depression. When confounding factors were included in the analysis, no association with headaches was found. These studies support Wilson's (1988) hypothesis that depression might result from exposure to EMFs. However, the lack of actual measurements of exposure precludes a conclusion that a significant causal relationship between EMF exposure and depression really exists.

Other studies do not support an association between depression and EMFs. Studies by Prato (1988-1989) found no association between exposure to EMFs (MRI, exposures of unspecified intensity) and serum melatonin concentrations. Because this study examined only four subjects, the findings are not conclusive. A study by McMahan (1994) showed no relationship between exposure to EMFs and depressive symptomatology in 152 women. Therefore, current available findings signify that further work is appropriate.

Other Emotional Responses

Further evidence of an association between exposure to job stressors, which indirectly included EMFs, and increased emotional responses (such as irritability) and psychological mood state (anxiety, depression, anger, vigor, fatigue, and confusion) can be found in a study by Smith (1981). The authors compared clerical workers who used VDUs with professional workers using VDUs and clerical workers who did not use these devices. The highest levels of strain were reported by the clerical workers using VDUs, and the levels of strain found in clerical workers who did not use VDUs were greater than those found in professional users of VDUs. The authors reported that exposures to non-VDU related stressors experienced by the two groups of clerical workers were similar. This suggests that sources of stress associated with non-professional employment might be confounded by exposures to EMFs. Some of the stressors found to be associated with musculoskeletal disorders of the upper extremities in VDU workers were fear of being displaced by computers, increasing work pressures, and surges in workload. Routine tasks lacking decision making opportunities, high information processing demands, jobs requiring a variety of tasks, and lack of a production standard also were found to contribute to the job stress experienced by VDU workers (Hales, 1994).

A study by Norback (1991) suggests that physical symptoms associated with psychosocial stressors might also be associated with exposure to EMFs. Examining risk factors for sick building syndrome in Swedish office workers, the authors found that an association between work with VDUs and eye and skin symptoms was significant when controlling for atopy, allergy to nickel, static electricity, and psychosocial factors.

In addition to emotional responses, effects on EEGs have been reported by several investigators. Bell (1991) reported that less power in the EEG was observed in 7 of 14 subjects studied in the presence of an MF (unspecified frequency, 0.25- 0.50 G). A study by Cook (1992) showed exposure to the combined EFs (9 kV/m) and MFs (0.2 G) significantly increased the P300 component of the auditory event related brain potential and slowed heart rate. The effects observed by Cook (1992) were greatest soon after the fields were turned on, and again when the fields were turned off. In a similar study, Graham (1994) reported significant increase in the latency and amplitude of event related brain potential and slowing heart rate in subjects exposed to medium levels of EFs and MFs (9 kV/m, 0.2 G). Exposure at the lower fields (6 kV/m, 0.1 G) or higher field levels (12 kV/m, 0.3 G) showed no effects on EEG activity or cardiac measures. These studies establish a definitive association between EMFs and the physiological responses, but they do not support any dose-response relationship. In contrast to the findings of Cook (1992) and Graham (1994), Lyskov (1993) reported a decrease in the amplitude and latency of the P300 component resulting from exposure of 14 subjects to a 45 Hz, 12.6 G magnetic field. Stoops (1979) found no effect of EMFs (unspecified frequency, 400kV/m) on neurologic activity in electrical workers (Anderson, 1990). However, the number of subjects studied was relatively small. Buettner (1992) measured brain stem auditory potentials and somatosensory evoked potentials and found no long term effect from exposure to a static MF (MRI exposure, 15,000 G). Because the number of subjects studied was low, these results are not conclusive. The inconsistency of the findings of studies examining the effect of EMFs on EEGs suggests further research is indicated.

Reports on cognitive effects resulting from EMFs are inconsistent. Cook (1992) found that subjects exposed to EMFs (9 kV/m and 0.20 G) made fewer errors in the choice reaction time test, which measures ability to make low level decisions under pressure. The results of several other tests, including time estimation, vigilance, digit span, and reaction time in event related brain potential tasks were not affected by the EMF exposures. Graham (1994) reported a slowing of reaction time associated with exposure to EMFs (6 kV/m 0.10 G). However, this response may not be dose dependent because it was not found with exposure to stronger fields (Graham, 1994). Sweetland (1987) reported no difference in performance on digital span tests or increased anxiety in subjects exposed to EMFs (MRI, exposure to unspecified intensity) versus unexposed controls. The subjects examined by Sweetland ranged between 18 and 63 years of age, and the authors did not adjust for potential differences in age among the groups studied.

Stollery (1986) reported that exposure to EFs (50 Hz, 36 kV/m) did alter human performance and subjects in the study showed a decrease in arousal level. Stollery (1987) also found that vigilance and concentration were not influenced by exposure of 76 subjects to EFs (50 Hz, 36 kV/m), nor do their results support the hypothesis of a stress reaction. Several clinical studies by Hauf (1982), conducted on more than 100 subjects, found no effect of EFs (50 Hz; 1, 15 or 20 kV/m) on behavior or EEG patterns (Anderson, 1990). However, Hauf did observe a decreased reaction time, as well as an increase in norepinephrine, in exposed subjects (Anderson, 1990). Gamberale (1989) and Knave (1979) also found no EMF related adverse effects on reaction time, vigilance, short term memory, or perception in electrical utility linemen. The lack of positive findings in electrical utility workers might reflect a healthy worker effect from employees affected by the exposure ceasing employment in the electrical utility industry.

The inconsistency of the findings at various frequencies might be explained by non-linear dose-response relationships. Depending on the molecular structure of the material such as those in the living cells, in some frequencies of EMFs the exposure intensities are amplified (resonant like mechanism resulting in enhanced responses) and in other frequencies the exposure intensities are abridged. However, data supporting a resonance like mechanism of action have not been consistently reproduced (Goodman, 1995).

The inconsistency also may be explained by the lack of a dose-response relationship for exposures of varying intensities to the same frequency. As noted by Graham (1994), "if this is in fact the case, then perhaps some previous negative research results may have been due to exposure levels that were too high or too low." Changes in free radicals from the triplet state to the reactive singlet state induced by EMFs might be frequency dependent (McLauchlan, 1992) and intensity dependent, with a greater net change to the singlet state from low intensity EMFs compared to EMFs of greater intensity (Adey, 1993).

CONCLUSIONS

The evidence linking adverse cognitive and emotional responses to exposures to EMFs is inconsistent. The disease most likely to be associated with the exposure is depression, and published studies have found neither a consistent association nor a simple dose-response relationship. However, findings of EMF induced changes in serum concentrations of neurotransmitters and hormones associated with depression lend biologic plausibility to the association between the exposure and this mental condition.

Studies of the effects of exposures to EMFs on cognition have also yielded inconsistent results. To date, no plausible mechanism of action has been proposed. Studies of office workers using VDUs suggest that exposure to EMFs might be associated with emotional responses, but different investigators have reported disparate responses.

The relationship between exposure to EMFs and psychosocial responses is not a simple one that meets the conventional causality criteria of strength, consistency, or dose-response. The inconsistency in results and lack of a simple dose-response relationship suggest that the potential association between EMFs and cognitive and emotional responses is complex, possibly restricted to specific exposure frequencies and intensities and confounded by exposure to other stressors. Further work to examine the association between EMFs and cognitive and emotional responses by specific electromagnetic frequencies and intensities in the context of known sources of stress is indicated.

REFERENCES

Adey, W.R. (1990). Joint actions of environmental non-ionizing electromagnetic fields and chemical pollution in cancer promotion. *Environmental Health Perspectives, 86*, 297-305.

Adey, W.R. (1993). Biological effects of electromagnetic fields. *Journal of Cellular Biochemistry, 51*, 410-416.

Akbar-Khanzadeh, F. (1994). Electro-magnetic fields. The Fourth

National Symposium and Trade Exhibition on Health Care Safety and the Environment, Lake Buena Vista, FL, *Proceedings Book 1994—Part 2* (pp. 1127-1163). Chicago: The American Hospital Association.

Anderson, L.E. (1990). Interaction of ELF electric and magnetic fields with neural and neuroendocrine systems. In B.W. Wilson, R.G. Stevens, & L.E. Anderson (Ed.). *Extremely low-frequency electromagnetic fields: The question of cancer* (pp. 139-157). Columbus, Ohio: Batelle Press.

Anderson, L.E. (1993). Biological effects of extremely low-frequency electromagnetic fields: In vivo studies. *American Industrial Hygiene Association Journal, 54,* 186-196.

Aschoff, J. (1965). Circadian rhythms in man. *Science, 148,* 1427-1432.

Azana, M.J., & Del Moral, A. (1994). Cell membrane biochemistry and neurobiological approach to biomagnetism. *Progress in Neurobiology, 44,* 517-601.

Baris, D., & Armstrong, B. (1990). Suicide among electric utility workers in England and Wales. *British Journal of Industrial Medicine, 47,* 788-792.

Baris D., Armstrong, B.G., Deadman, J., & Theriault, G. (1996). A case cohort study of suicide in relation to exposure to electric and magnetic fields among electrical utility workers. *Occupational and Environmental Medicine, 53,* 17-54.

Bates, M.N. (1991). Extremely low frequency electromagnetic fields and cancer: The epidemiologic evidence. *Environmental Health Perspectives, 95,* 147-156.

Bell, G.B., Marino, A.A., Chesson, A.L., & Struve, F.A. (1991). Human sensitivity to weak magnetic fields. *Lancet, 338,* 1521-1522.

Blackman, C.F., Benane, S.G., House, D.E., & Joines, W.T. (1985). Effects of ELF (1-1120 Hz) and modulated (50 Hz) RF fields on the efflux of calcium ions from brain tissue in vitro. *Bioelectromagnetics, 6,* 1-11.

Blackman, C.L. (1990). ELF effects on calcium homeostasis. In: B.W. Wilson, R.G. Stevens, & L.E. Anderson (Ed.). *Extremely low-frequency electromagnetic fields: The question of cancer* (pp. 187-208). Columbus, Ohio: Batelle Press.

Blank, M., Korkova, O., & Goodman, R. (1993). Similarities in the proteins synthesized by Sciaria salivary gland cells in response to electromagnetic fields and to heat shock. *Bioelectrochemistry and Bioenergetics, 31,* 27-38.

Blank, M., Khorkova, O., & Goodman, R. (1994). Changes in polypeptide distribution stimulated by different levels of electromagnetic and thermal stress. *Bioelectrochemistry and Bioenergetics, 33,* 109-114.

Blank M., & Soo, L. (1990). Ion activation of the Na,K-ATPase in alternating currents. *Bioelectrochemistry and Bioenergetics, 24,* 51-61.

Bloom, F.E. (1980). Neurohumoral transmission and the central nervous system. In A.G. Gilman, L.S. Goodman, & A. Gilman (Ed.). *The pharmacological basis of therapeutics* (pp. 235-257). New York: MacMillan.

Buettner, U.W. (1992). Human interactions with ultra high fields. *Annals of the New York Academy of Sciences, 649,* 59-66.

Cook, M.R., Graham, C., Cohen, H.D., & Gerkovich, M.M. (1992). A replication study of human exposure to 60-Hz fields: Effects on neurobehavioral measures. *Bioelectromagnetics, 13,* 261-285.

Dowman, R., Wolpaw, J.R., Seegal, R.F., & Satya-Murti, S. (1989). Chronic exposure of primates to 60-Hz electric and magnetic fields: Neurophysiologic effects. *Bioelectromagnetics, 10,* 303-317.

Dowson, D.I., & Lewith G.T. (1988). Overhead high-voltage cables and recurrent headache and depressions. *The Practitioner, 232,* 435-436.

Ehret, C.F. (1981). New approaches to chronohygiene for the shift worker in the nuclear power industry in night- and shift-work. In: A. Reinberg, N. Vieux, & T. Andlauer. (Eds.). *Biological and social aspects* (pp. 263-270). Oxford: Pergamon Press.

Gamberale, F. (1990). Physiological and psychological effects of exposure to extremely low frequency electric and magnetic fields on humans. *Scandinavian Journal of Work and Environmental Health, 16* (Suppl.), 51-54.

Gamberale, F., Olson, B.A., Eneroth, P., Lindh, T., & Wennberg, A. (1989). Acute effects of ELF electromagnetic fields: A field study of linesmen working with 400 kV power lines. *British Journal of Industrial Medicine, 46,* 729-737.

Goodman, E.M., Greenbaum, B., & Marron, M.T. (1995). Effects of electromagnetic fields on molecules and cells. *International Review of Cytology, 158,* 279-338.

Graham, C., Cook, M.R., Cohen, H.D., & Gerkovich, M.M. (1994). Dose response study of human exposure to 60 Hz electric and magnetic fields. *Bioelectromagnetics, 15,* 447-463.

Groh, K.R., Readey, M.A., & Ehret, C.F. (1990). Chronobiological effects of electric fields. In B.W. Wilson, R.G. Stevens, & L.E. Anderson (Ed.). Extremely low frequency electromagnetic fields: *The question of cancer* (pp. 47-86). Columbus, Ohio: Batelle Press.

Hales, T.R., Sauter, S.L., Peterson, M.R., Fine, L.J., Putz-Anderson, V., Schleifer, L.F., Ochs, T.T., & Bernard, B.P. (1994). Musculoskeletal disorders among visual display terminal users in a telecommunications company. *Ergonomics, 37,* 1603-1621.

Hauf, R. (1982). Electric and magnetic fields at power frequencies, with particular reference to 50 and 60 Hz. In M.J. Seuss (Ed.). *Nonionizing radiation protection* (pp. 175-197). Copenhagen: World Health Organization.

Hille, B., & Catterall, W.A. (1989). Electrical excitability and ionic channels. In G.J. Siegel, B.W. Arganoff, R.W. Albers, P.B. Molinoff (Eds.). *Basic neurochemistry: Molecular, cellular and medical aspects, 4th ed.* (pp. 71-90). New York: Raven Press.

Hitchcock, R.T., & Patterson, R.M. (1995). Radio-frequency and ELF electromagnetic energies: *A handbook for health professionals.* New York: Van Nostrand Reinhold.

Jaffe, J.H., & Martin, W.R. (1980). Opioid analgesics and antagonists. In: A.G. Gilman, L.S. Goodman, & A. Gilman (Ed.). *The pharmacological basis of therapeutics* (pp. 494-534). New York: MacMillan.

Kavaliers, M., & Ossenkopp, K.P. (1986). Magnetic field inhibition of morphine-induced analgesia and behavioral activity in mice: Evidence for involvement of calcium ions. *Brain Research, 379,* 30-38.

Knave, B. (1994). Electric and magnetic fields and health outcomes—An overview. *Scandinavian Journal of Work and Environmental Health, 20,* 78-89.

Knave, B., Gamberale, F., Bergstrom, S., Birke, E., Iregren, A., Kolmodiv-Herman, B., & Wennberg A. (1979). Long-term exposure to electric fields. A cross-sectional epidemiologic investigation of occupationally exposed industrial workers in high-voltage substations. *Electra, 65,* 41-54.

Lai, H., Carino, A., Horita, A., & Guy, A.W. (1992). Opiate receptor subtypes that mediate a microwave-induced decrease in central cholinergic activity in the rat. *Bioelectromagnetics, 13,* 237-246.

Levine, R.L., & Bluni, T.D. (1994). Magnetic field effects on spatial discrimination learning in mice. *Physiology and Behavior, 55,* 465-467.

Luben, R.A. (1991). Effects of low-energy electromagnetic fields (pulsed and DC) on membrane signal transduction processes in biological systems. *Health Physics, 61,* 15-28.

Lyskov, E., Juutilainen, J., Jousmaki, V., Hannien, O., Medvedev, S., & Partanen, J. (1993). Influence of short-term exposure of magnetic field on the bioelectrical processes of the brain and performance. International *Journal of Psychophysiology, 14,* 227-231.

Malenka R.C., Hamblin M.W., & Barchas J.D. (1989). Biochemical hypotheses of affective disorders and anxiety. In: G.J. Siegel, B.W. Arganoff, R.W. Albers, & P.B. Molinoff (Eds.). *Basis neurochemistry: Molecular, cellular and medical aspects, 4th ed.* (pp. 877-891). New York: Raven Press.

McLauchlan, K. (1992). Are environmental magnetic fields dangerous? *Physics World, January,* 41-45.

McMahan, S., Ericson, J., & Meyer, J. (1994). Depressive symptomatology in women and residential proximity to high-voltage transmission lines. *American Journal of Epidemiology, 139,* 58-63.

Michaelson, S.M. (1982). Microwave and radiofrequency radiation. In: M.J. Suess (Ed.). *Nonionizing radiation protection* (pp. 97-174). Copenhagen: World Health Organization.

Norback, D., & Edling, C. (1991). Environmental, occupational, and personal factors related to the prevalence of sick building syndrome in the general population. *British Journal of Industrial Medicine, 48,* 451-462.

Oftedal, G., Vistnes, A.I., & Rygge, J. (1995). Skin symptoms after the reduction of electrical fields from visual display units. Scandinavian *Journal of Work and Environmental Health, 21,* 335-344.

Perry, F.S., & Pearl, L. (1988). Power frequency magnetic field and illness in multi-storey blocks. *Public Health, 102,* 11-18.
Perry, F.S., Reichmanis, M., Marino, A.A., & Becker R.O. (1981). Environmental power-frequency magnetic fields and suicide. *Health Physics, 41,* 267-277.
Plog, B.A. (1996). Overview of industrial hygiene. In: B.A. Plog, J. Niland, & P.J. Quintan (Eds.). *Fundamentals of industrial hygiene, 4th ed.* Itasca, IL: National Safety Council.
Poole, C., Kavet, R., Funch, D.P., Donelan, K., Chary, J.M., & Dreyer, N.A. (1993). Depressive symptoms and headaches in relation to proximity of residence to an alternating-current transmission line right-of-way. *American Journal of Epidemiology, 137,* 318-330.
Prato, F.S., Ossenkopp, K.P., Kavaliers, M., Uksik, P., Nicholson, R.L., Drost, D., & Sestini, E.A. (1988-1989). Effects of exposure to magnetic resonance imaging on nocturnal serum melatonin and other hormone levels in adult males: Preliminary findings. *Journal of Bioelectricity, 7,* 169-180.
Reiter, R.J. (1990). Effects of light and stress on pineal function. In: B.W. Wilson, R.G. Stevens, & L.E. Anderson (Ed.). Extremely low frequency electromagnetic fields: *The question of cancer* (pp. 87-107). Columbus, Ohio: Batelle Press.
Savitz, D.A. (1993). Overview of epidemiologic research on electric and magnetic fields and cancer. *American Industrial Hygiene Association Journal, 54,* 197-204.
Schaffer, Ch.B., Dandley, G.N., Noll, K.M., Killian, G.A., & Davis, M.J. (1981). Introduction and theories of affective disorders. In: G.C. Palmer. (Ed.). *Neuropathy of central nervous system and behavioral disorders.* New York: Academic Press.
Seegal, R.F., Wolpaw, J.R., & Dowman, R. (1989). Chronic exposure of primates to 60-Hz electric and magnetic fields: II. Neurochemical effects. *Bioelectromagnetics, 10,* 289-301.
Shivers, R.R., Kavaliers, M., Teskey, G.C., Prato, F.S., & Pelletier, R.M. (1987). Magnetic resonance imaging temporarily alters blood-brain barrier permeability in the rat. *Neuroscience Letters, 76,* 25-31.
Smith, M.J., Cohen, B.G.F., & Stammerjohn, L.W. (1981). An investigation of health complaints and job stress in video display operations. *Human Factors, 23,* 387-400.
Stollery, B.T. (1986). Effects of 50 Hz electric currents on mood and verbal reasoning skills. *British Journal of Industrial Medicine, 43,* 339-349.
Stollery, B.T. (1987). Effects of 50 Hz electric currents on vigilance and concentration. *British Journal of Industrial Medicine, 44,* 111-118.
Stoops, G.J., & Janisschewsky, W. (1979). *Epidemiological study of workers maintaining HV equipment and transmission lines in Ontario (research report).* Montreal, Quebec, Canada: Canadian Electrical Association.
Sweetland, J., Kertesz, A., Prato, F.S., & Nantau, K. (1987). The effect of magnetic resonance imaging on human cognition. *Magnetic Resonance Imaging, 5,* 129-135.
Thompson, C. (1984). Circadian rhythms and psychiatry. *British Journal of Psychiatry, 145,* 204-206.
Weaver, J.C., & Astumian, R.D. (1992). Estimates for ELF effects: Noise-based thresholds and the number of experimental conditions required for empirical searches. *Bioelectromechanics, 119*(Suppl.), 119-138.
Wehr, T.A., Wertz, J.A., Goodwin, F.K., Duncan, W., & Gillin, G.C. (1979). Phase advance of circadian sleep-wake cycle as an antidepressant. *Science, 206,* 710-713.
Welker, H.A., Semm, P., Willig, R.P., Commentz, J.C., Wiltschko, W., & Vollrath, L. (1983). Effects of an artificial magnetic field on serotonin N-acetyl transferase activity and melatonin content of the rat pineal gland. *Experimental Brain Research, 50,* 426-432.
Wever, R. (1973). Human circadian rhythms under the influence of weak electric fields and the different aspects of these studies. *International Journal of Biometeorology, 17,* 227-232.
Wilson, B.W. (1988). Chronic exposure to ELF fields may induce depression. *Bioelectromagnetics, 9,* 195-205.
Wilson, B.W., Chess, E.K., & Anderson, L.E. (1986). 60-Hz electric-field effects on pineal melatonin rhythms: Time course for onset and recovery. *Bioelectromagnetics, 7,* 239-242.
Wilson, B.W., & Saffer, J.D. (1993). Electromagnetic field health effects: An issue for developing countries? *Journal of Scientific and Industrial Research, 52,* 331-337.
World Health Organization (WHO). (1984). *Extremely low frequency (ELF) fields. Environmental health criteria 35.* Geneva: World Health Organization.

IN SUMMARY

Potential Emotional and Cognitive Disorders Associated With Exposure to EMFs

A Review.

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AAOHN Journal 1997; 45(2):69-75.

1. Published studies have found neither a consistent association nor a simple dose-response relationship between exposure to EMFs and emotional and cognitive responses.

2. The inconsistency in results and lack of a simple dose-response relationship suggest that the potential association between EMFs and cognitive and emotional responses is complex, possibly restricted to specific exposure frequencies and intensities and confounded by exposure to other stressors.

3. Further work to examine the association between EMFs and cognitive and emotional responses by specific electromagnetic frequencies and intensities in the context of known sources of stress is indicated.