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Can EMF Exposure During Development Leave an Imprint Later in Life?

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People in industrialized nations live in an environment of ubiquitous electromagnetic field (EMF) exposure, both natural and anthropogenic. The intensity, variety, and geographic distribution of anthropogenic EMF exposures have grown dramatically since the mid 20th century, with many uses serving, and in close proximity to, human populations, such as electric power distribution, radio and television transmission, and more recently, personal cell phone communication units and transmitting towers. Thus, it is reasonable to ask if this EMF exposure could cause alterations in the physiology of developing organisms, since they are generally assumed to be the most sensitive to chemical stressors. In this report, we review work published beginning in the late 1980s. Initial reports indicated that exposure of chicken eggs during embryonic development to power-line electric fields of 50 and 60 Hz, at 10 V/m in air (which is frequently in locations inhabited by humans), could cause the brain tissues of the hatched chickens to respond differently in a particular test.

More recently, an anecdotal report of human sensitivity to EMF has appeared that shows a health-related influence of prior exposure history to particular power-line frequencies in chemically sensitized individuals. These reports open the question of whether the ambient electromagnetic environment can leave an imprint on developing organisms and if such imprint changes have the potential for health consequences.

Keywords Brain tissue; Electric fields; Imprinting; Sensitive subpopulations; 50 Hz; 60 Hz.

Introduction: Basis for Hypothesis Development

In the late 1960s and early to mid 1970s, Adey's group showed that low intensity electric and electromagnetic fields could affect human and monkey reactions times, as well as EEG pattern changes in monkeys and cats (for overview of this activity, see Liddle and Blackman, 1984). This research group also looked at neurotransmitter (GABA) release from cat brain under electric field exposure and observed calcium ion release at the same time, thereby setting calcium ion release (calcium efflux) as a surrogate measure of the neurotransmitter release.

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Subsequently, the research group selected a more manageable source of isolated brain tissue, newly hatched chickens, to allow them to perform more exacting biochemical experiments. When Adey's group described their results using chick brain tissue, scientists at the US Environmental Protection Agency (USEPA) started to independently test the findings reported in the chick brain experiments (for review of early results, see Liddle and Blackman, 1984).

Critical Exposure Conditions

The EPA research group was able to independently replicate the fundamental findings of the Adey group (Blackman et al., 1979). With the effect in hand, Blackman and his colleagues decided to start their exploration of this phenomenon by examining the features of the electromagnetic fields that were responsible for causing the changes that were seen. Their approach followed a classical radiation biology paradigm, that is, determine the detailed dose-response and frequency-response characteristics for the phenomenon in order to compare these features with what was known in the ionizing, ultraviolet, visible, and infrared regions of the spectrum.

Intensity

The Adey group showed a region of intensity and a region of frequency within which altered calcium efflux was observed. Blackman et al. (1979) performed a number of refined dose response studies, in which they revealed EMF-induced calcium release in two intensity regions, separated by intensity regions where no changes in calcium release occurred; these unexpected responses to intensity became known as intensity windows. Initially, this work used the same exposure conditions employed by Adey's group, that is, 147 MHz radiofrequency fields (RFR) that were amplitude-modulated by extremely low frequency fields (ELF) in the region of brain waves detected in mammals. This work was expanded to test a different carrier frequency, 50 MHz, and achieved similar results. In order to simplify mechanistic modeling efforts following a report by the Adey group that the ELF fields would cause similar effects, the Blackman group also tested ELF fields. Figure 1, taken from Blackman et al. (1982), is an example of intensity windows; please see that reference for details in materials and methods, and for the corresponding electric field intensities. There are now over 18 papers showing unusual changes in calcium ion release from a variety of biological samples, published by four different research groups, e.g., Bawin, Blackman. Dutta, and Schwartz.

Frequency

Another critical exposure variable that Blackman's group tested in detail was the influence of different frequencies. They observed multiple frequency regions that induce calcium release, separated by frequency regions where no altered release was observed. This type of unexpected response became known as frequency windows. Figure 2 is an example of frequency windows taken from Blackman et al. (1988a).

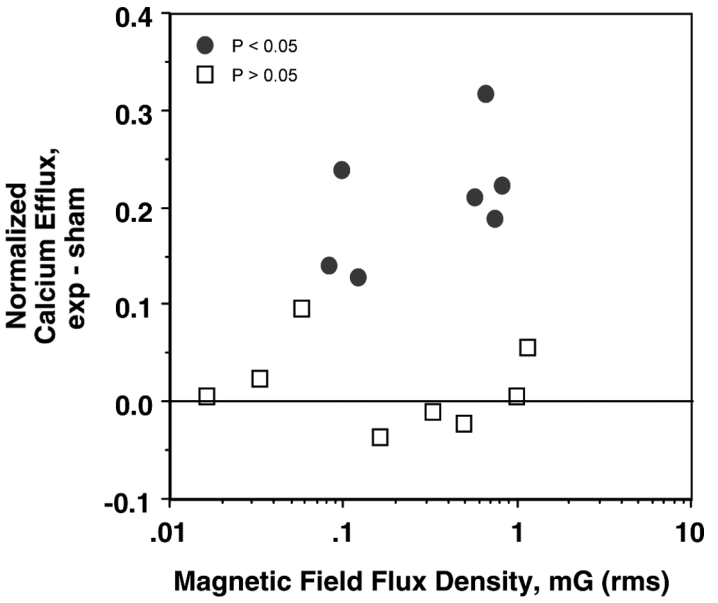

Figure 1. Calcium ion release from chick brain tissue as a function of ELF field intensity, given here as the magnetic component. The darkened circles show statistically significant effects under exposure to 16-Hz fields, whereas the open squares show non significant responses.

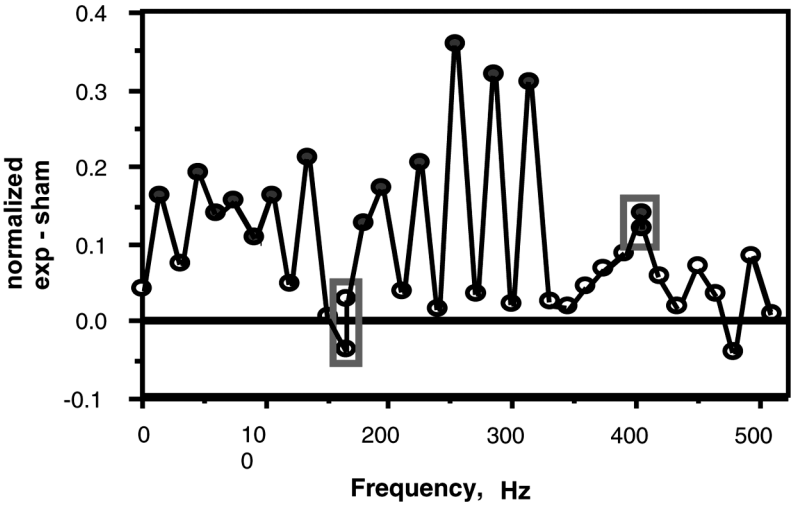

Figure 2. Calcium ion release from chick brain tissue as a function of the frequency of the ELF field. The intensity at each frequency is 0.69 mGrms (69 mT); eggs incubated in 60 Hz electric fields. The darkened circles show statistically significant effects under exposure to various frequency fields, whereas the open circles show non significant responses. Replicate experiments, see boxes, were conducted over 4 months later at 165 and 405 Hz, demonstrated the repeatability of the results.

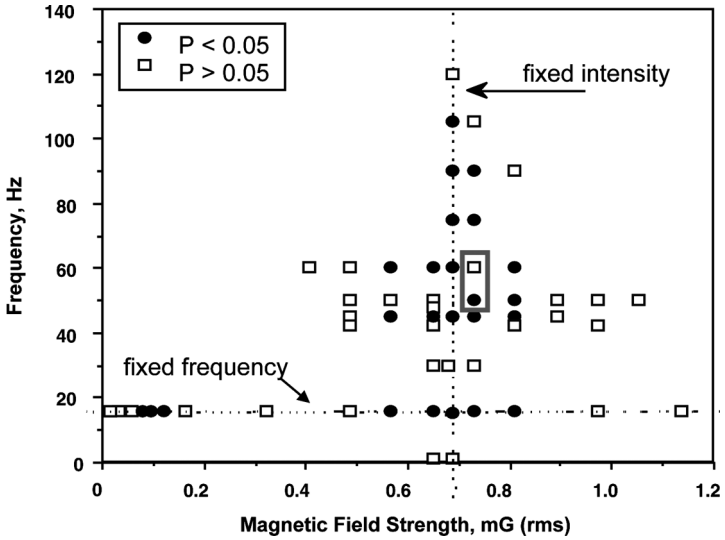

Figure 3. Summary of the frequency and intensity coordinates that had been tested for a change in calcium ion release from brain tissue under ELF fields. Closed circles show statistically significant changes; open boxes show non significant changes. Note, the tissues were from eggs unintentionally grown in a 60 Hz incubation environment. The box enclosed two frequencies at the same intensity that would be tested for influence of two different egg incubation environments.

Combined Intensity and Frequency Responses

The extended frequency series shown in Figure 2, following on the extended intensity responses, was of substantial interest to us. We became interested in the potential influence of the electrical environment during the 21-day period that the eggs were incubated before the chickens were hatched. The concern was that the frequency and intensity patterns were influenced by the EMF frequency conditions, i.e., 60 Hz, present during embryogenesis and development. From this concern, an experiment was hatched.

The unusual intensity and frequency response regions were eventually plotted in a pseudo-three dimensional map in Figure 3 (see also Blackman et al., 1985). Two chick-brain treatment conditions were selected (see box in Figure 3) to test brain tissue for altered calcium ion release when the eggs were incubated under 60 Hz or under 50 Hz environments. The hypothesis was that the egg incubation conditions would not affect this outcome.

Experimental Design

The experiment was fairly simple. We acquired fertilized eggs that had been collected and stored at physiological zero and incubated them under conditions where we could control the frequency of a electric field and set the voltage at 10 Vrms/m, which is an intensity that is frequently present in American households. The incubating eggs would be exposed to electric fields at either 50 Hz or 60 Hz. The eggs we had been using up until this time had all been incubated in commercial incubators with electrical heating coils energized by 60 Hz current.

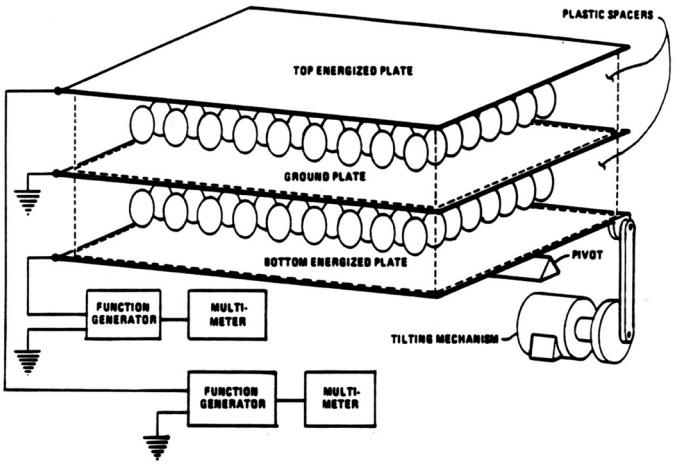

Figure 4. Diagram of the exposure system for the eggs during incubation. The top volume was energized with one frequency and the bottom volume was energized with the other frequency. This system was housed in a humidified walk-in incubator room maintained at 36°C.

Our experimental design required chickens to be hatched from eggs exposed to 50 Hz or to 60 Hz, and their brain tissues to be tested for response under 50 or 60 Hz fields in our standard calcium efflux assay. In our model, we expected to see the same calcium efflux results for eggs exposed to 50 and to 60 Hz. Figure 4 pictures the exposure system we used, which was housed in a humidified walk-in incubator room maintained at 37°C. The eggs in the top layer were exposed to one frequency and those in the bottom to the other frequency.

Because of the design, there was no leakage of frequencies from one layer to the other (Blackman et al., 1988a; Joines et al., 1986). In our first experiment, the top layer was exposed to 50 Hz, and the bottom, to 60 Hz.

Results

The research outcome was surprising. It appeared that the eggs exposed to 60 Hz gave the same results obtained when the eggs were incubated at the supplier, whereas those eggs incubated at 50 Hz showed different results. These differences were statistically significant in spite of the need to use a very rigorous statistical test (Bonferroni-adjusted *t*-test) due to the complex experimental design. See Table 1, experiment #1.

We repeated this exact experiment to determine if we could replicate the results, and the results were essentially the same (see Table 1, experiment #2). From these results, it was apparent that either the field conditions during incubation were influencing the response of the brain tissue for the hatched chickens, or the position within the exposure device was causing a decided bias that influenced the results. We tested for the latter possibility by energizing the lower level of the exposure device with 50 Hz, and the upper level with 60 Hz.

The results of the reversed exposure conditions in the exposure system are shown in Table 2, experiment #3, with the results from experiment #2 offered for

Table 1
Results of experiment #1 and #2. These experiments were exact repeats of each other

	Electric field effects in developing embryos* Repeat experiments-50 Hz in top tier or egg exposure system				
Expt. #	Egg exposure, Hz	Brain exposure, Hz	Mean Ca efflux ratio**	SE	N
1	50	50	1.025	0.032	36
		60	0.958	0.035	36
	60	50	**1.395**<	0.067	36
		60	1.059	0.037	36
2	50	50	1.005	0.047	40
		60	1.038	0.029	40
	60	50	**1.448**<	0.052	40
		60	1.032	0.032	40

*eggs exposed to 10 V/m (in air) electric fields during incubation.
**brain tissue from hatched chicks assayed for EMF-induced change in Ca efflux.
<indicates $P < 0.01$, using Bonferroni-adjusted t-tests.
For details see Blackman et al. (1988b).

Table 2
Results of experiment #2 contrasted with results of experiment #3. The energizing frequencies were inverted in experiment #3 compared to experiments #1 and #2

	Electric field effects in developing embryos* Expt. #2: 50 Hz in top tier or egg exposure system Expt. #3: 60 Hz in top tier or egg exposure system				
Expt. #	Egg exposure, Hz	Brain exposure, Hz	Mean Ca efflux ratio**	SE	N
2	50	50	1.005	0.047	40
		60	1.038	0.029	40
	60	50	**1.448**<	0.052	40
		60	1.032	0.032	40
3	50	50	0.986	0.042	32
		60	1.059	0.047	32
	60	50	**1.385**<	0.049	32
		60	1.035	0.039	32

*eggs exposed to 10 V/m (in air) electric fields during incubation.
**brain tissue from hatched chicks assayed for EMF-induced change in Ca efflux.
<indicates $P < 0.01$, using Bonferroni-adjusted t-tests.
For details see Blackman et al. (1988b).

comparison. *Note: The data are displayed in all three cases with the 50 Hz results at the top of each table for convenience only; this does not represent the field conditions in the top and bottom locations.*

The hypothesis that position in the exposure device caused bias in the results was not proven. Hence, we inferred that the significant difference in the response of brain tissue was dependent on the frequency of the electric field during incubation. For a 10 Vrms/m field, the internally generated current density is estimated to be 0.126 microA/m2 in each egg which translates to roughly 0.67 microA/m2 for a seated person (Blackman et al., 1988b). These current values are very low, so low that the results seem impossible from a crude signal level to noise perspective. It is apparent from this study that more sophisticated modeling is needed of the interaction of the fields with the process of embryogenesis, and with sensitive sites of action.

Discussion

There is a laboratory report by Jenrow et al. (1998) indicating that there is a decay in rat hippocampal rhythm by magnetic fields that persists in postexposure intervals. The authors speculate (via personal communication) that this response may be due to encoding by the initial exposure.

Additionally, there is an intriguing recent report about chemically sensitive people. Smith (2005) has reported in a conference paper that about 10% of chemically sensitive people can be further sensitized by power-line frequency electric fields. This phenomenon was observed when Smith was called in to consult at an institution in the UK about patients who were being desensitized to chemicals, but who were reacting in a manner similar to chemicals when electrical storms passed through the area. With institute clinicians, Smith performed spectral scans of these sensitive patients using very low voltage electric fields. Essentially, all patients showed a reaction to the power-line frequency in the UK, 50 Hz, but their response to different higher frequencies was individual-specific. Returning several weeks later, the patients responded similarly, including the sensitivity in some to the different, higher frequencies. There were several patients who did not respond to 50 Hz fields, but who did respond to 60 Hz fields. When the clinicians subsequently examined the patients' medical files to determine the location of birth, those responding to 50 Hz were found to be born and raised in the UK, whereas those responding to 60 Hz were found to be born and raised in the U.S., where 60 Hz is the standard power-line frequency. Although this study should be considered anecdotal or pilot in nature, when viewed with perspective of the laboratory data presented by Blackman et al. (1988b) there is reason to seriously consider the possibility of electric and magnetic imprinting from exposures experienced during development on subsequent sensitivities later in life to anthropogenic agents.

Summary and Conclusions

This report reopens the question of whether the ambient EMF environment can leave an imprint on developing organisms, including humans. One subgroup of people who may be particularly sensitive are those who are already manifesting sensitivities to chemicals. The question then arises, are these chemically sensitized individuals the most vulnerable subgroup in the population?

More broadly, epigenetics (Bjornsson et al., 2004; Esteller, 2005) is an emerging research discipline in the fields of development, cancer, and toxicology, involving changes in the control of genes being turned on and off. One component of the gene control process is the cytosine methylation at CpG sites in promoter regions of genes (Feinberg, 2001). This process occurs both in the animal and plant kingdoms and study is being pursued in laboratory animals (Dolinoy et al., 2006) and humans, particularly identical twins, comparing those brought up in different environments with those in the same environment (Fraga et al., 2005). Questions researchers in bioelectromagnetics can pursue are: (1) Do we all carry an EMF imprint due to exposure at some life stage; and (2) Are there any health consequences?

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In memory of W. Ross Adey

Supplied by Cindy Sage

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