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Biological Effects of Continuous Exposure of Embryos and Young Chickens to Electromagnetic Fields Emitted by Video Display Units

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The effects of continuous exposure of embryos and young chickens to electromagnetic fields (EMFs) emitted by video display units (VDUs) were investigated. Embryos and brood were continuously exposed during embryonic and postembryonic phases to EMFs emitted by two types of VDU (TV or computer). Embryonic mortality was evaluated in three independent experiments. Young chickens were immunized three times by porcine thyroglobulin (Tg). Blood samples were assayed after each immunization for specific anti-Tg antibodies (IgG), plasma corticosterone (CORT), and plasma melatonin (MLT). In the sham-exposed samples, embryonic death (10-33%) was restricted to the perinatal period and the IgG, CORT, and MLT responses of young chickens crested after the second immunization. Constant EMF exposure was accompanied by significantly increased fetal loss (47–68%) and markedly depressed levels of circulating anti-Tg IgG, CORT, and MLT. Collectively, these findings indicate that continuous exposure to EMFs, issuing from VDUs, adversely affects embryos and young chickens. *Bioelectromagnetics 18:514-523, 1997.* © 1997 Wiley-Liss, Inc.

Key words: embryonic development; chicken; VDU; electromagnetic field; immuno-neuroendocrinology

INTRODUCTION

During the past half century, the proliferation of electric appliances, communication systems that now blanket the earth, and a vast and ever-increasing network of electric power distribution systems have generated an exponential growth of EMFs. Non-ionizing EMFs, especially the extremely low frequencies (ELF), are generally believed to be innocuous to human health, due to their low-level energy deposition, the magnitude of which is well below the metabolic rate of the human body [Adey, 1981]. Recently, reports suggesting a possible link between ELF exposure and increased health risks in areas such as cancer [Savitz et al., 1990; Feychting et al., 1995], miscarriage [Wertheimer and Leeper, 1989; Infante-Rivard, 1995], and suicide or emotional depression [Poole et al., 1993; Savitz et al., 1994] have served to focus scientific interest, as well as raise public concern. Despite inconsistencies in reports, different animal studies have indicated that ELF field exposure affects embryonic development [Delgado et al., 1982; Ubeda et al., 1983; 1994; Berman et al., 1990; Martin, 1992], the immune system [Cadossi et al., 1992; Walleczek, 1992], or neuroendocrine functions [Oroza et al., 1987; Reiter, 1993]. However, in most laboratory studies, the physical systems generate EMFs different from those of household appliances, which are, for the population in general, the most common sources of ELF fields. Furthermore, most reports about associations between the use of video display units (VDUs) and the occurrence of diseases result from epidemiological studies [Goldhaber et al., 1988; Kavet and Tell, 1991; Schnorr et al., 1991; Lindbohm et al., 1992]. In the following study, we tested the effect of EMFs produced by two devices in residential and occupational use (TV or computer) on embryonic mor-

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tality, as well as immune, adrenal, and pineal functions in chickens.

MATERIALS AND METHODS

Exposure System

The source of EMFs was either a TV set (Thompson, D 55 cm, 55M x P83, 75 Watts/50 Hertz) or desk computer (Goupil G5 286 10, 220 V, 50 Hz). Most TVs and computers are the cathode ray tube type; therefore, they give off the same assortment of electromagnetic radiation, which includes radio waves, infrared radiation (heat), visible light, ultraviolet light, microwaves, X-rays, and very low frequency (VLF) and extremely low frequency (ELF) radiation [Stuchly et al., 1983; Paulsson, 1987; Kavet and Tell, 1991; Tofani and D'Armore, 1991]. The radio wave emission is reduced in accordance with international manufacturing standards. The infrared radiation in the form of heat is not a health hazard and the visible light is also harmless. The levels of ultraviolet light are less than indoor fluorescent lights or outdoor sunlight, and the amount of microwaves is almost undetectable. Strict international guidelines have reduced the level of X-rays below what is naturally present in the environment.

It is the ELF and VLF fields and especially their magnetic component that now raise concern. The cathode ray tube is coated on the inside with phosphor, which when hit by an electron beam is excited and yields a full screen image. In TV and computers, ELF and VLF fields are pulsed EMFs produced by two sets of deflection coils that control the movement of the electron beam as it sweeps across the screen. The ELF radiation (50–80 Hz and their harmonics) comes from the vertical deflection coils, which push the electron beam from the bottom to the top line. The horizontal deflection coils generate VLF (15–80 kHz and their harmonics) and push the electron beam in the horizontal plane. Safe Professional VLF and ELF meters (Safe Technologies Corporation, North Miami Beach, Florida, USA) were used to measure the intensity of the VLF and ELF fields, respectively. The data are reported in Table 1.

Antigen Preparation

Porcine thyroglobulin (Tg) (Sigma Chemical Co., St. Louis, MO, USA) was injected subcutaneously. The dose of porcine Tg to be inoculated was determined in a preliminary experiment and fixed to 125 μg/100 g body weight. Before immunization, porcine Tg was dissolved in saline (750 μg/ml) and mixed (v/v) with complete (first immunization) or incomplete (second and third immunizations) Freund adjuvant.

Experimental Design

Three independent experiments were carried out from 1993 to 1996. The TV or computer screen was covered with a black plastic bag to avoid exposure to visible spectrum. Figure 1 shows the scheme of the exposure design.

Experiment 1 This experiment was performed in spring of 1993 (May–June). The exposure device comprised two identical TV sets, one in the incubation room and the other one in the henhouse for the exposure of the eggs and chickens, respectively. In the incubation room (3 × 2 x 1.5 m), the eggs were placed 0.5–0.8 m in front of the TV set for the entire embryonic period (21 days). Two groups of 30 eggs each, from the Blache JA strain (Couvoir des Cévennes, Lédenon, France), were successively incubated in front of the same TV set: control or sham-exposed eggs (C) in front of the switched-off TV; exposed eggs (E) in front of the switched-on TV. The field strengths measured 0.5 and 0.8 m in front of the TV during embryonic phase are given in Table 1. Incubation was performed under 38 ± 1 °C, 45–50% humidity, and permanent darkness. The eggs were turned manually during the incubation period until embryonic day 19. From the 19th to the 21st day, the eggs were not moved; a peak of mortality occurs during this time period [Landauer, 1951; Baumann and Baumann, 1977].

Embryonic death was noticed by candling the eggs on day 3, 5, 7, 9, 11, and 13. After the 13th day, the eggs became so opaque that the embryos could no longer be seen through the shell. For this reason, embryonic death from 13 to 21 days of incubation was evaluated by opening the eggs from which the chicks did not hatch after the 21st day of incubation.

After hatching, the chicks from each group (C or E) were transferred to the henhouse and collectively housed in one cage (0.5 × 0.4 × 0.4 m) under controlled photoperiod [12 h light (0800–2000), 12 h dark]; the temperature in the cage was progressively reduced 1 °C per day from 38 °C to 22 °C. The cage containing newly hatched chicks was placed 0.5–0.8 m in front of the second TV set, either switched off (C group) or switched on (E group). The field intensities are measured at the level of the cages, 0.5 and 0.8 m in front of TV, and are given in Table 1. At the age of 2 weeks, the chicks from each group were distributed three per cage and the cages were placed 0.5-0.8 m in front of the TV.

Young chickens were repeatedly immunized by injecting porcine Tg subcutaneously at 21, 30, and

TABLE 1. Intensity of the VLF and ELF Fields Emitted by the TV and Computer*

Experiment	Exposure device	EMF	Position	Incubation room		Henhouse	
				0.5 m	0.8 m	0.5 m	0.8 m
1	TV	VLF (nT)	Off	2	2	2	2
			On	4	2	4	2
		ELF (nT)	Off	12	0	0	0
			On	270	135	260	140
2 and 3	Computer	VLF (nT)	Off	2	2	2	2
			On	13	3	10	2
		ELF (nT)	Off	27	0	27	0
			On	660	140	560	142

*The VLF and ELF fields emitted by the TV or computer, either switched off (Off) or switched on (On), were measured in the incubation room and henhouse. The field strength was determined 0.5 and 0.8 m, either in front of the TV (experiment 1) or from the side of the computer (experiments 2 and 3).

39 days of age. Blood samples were withdrawn from the brachial vein between 0900 and 1000, the day before immunization (D20) and at weekly intervals after the first (D29), the second (D38), and the third (D47) antigen challenge. Then the level of plasma CORT, as well as serum titers of specific anti-Tg antibodies (IgG) were measured. The animals had free access to food and water. The body weight was measured on day 47.

Experiment 2 This experiment took place in the summer of 1995 (July–August). The source of EMF consisted of two desk computers: one in the incubation room and the other one in the henhouse. Two groups of 30 eggs (C, E) from the Blache JA strain (Couvoir des Cévennes) were successively incubated according to the incubation conditions defined in experiment 1. However, in comparison with experiment 1, the eggs were placed 0.5–0.8 m from the side of the computer, either switched off (C group) or switched on (E group). The evaluation of embryonic mortality as well as the handling conditions of the chicks and chickens were exactly the same as in experiment 1, except that the cages containing the animals were exposed 0.5–0.8 m from the side of the computer. The EMF data measured in the incubation room and henhouse are reported in Table 1. Young chickens (C, E) were submitted to a slightly modified version of the immunization program used in experiment 1. They were immunized at 21, 30, and 36 days of age by subcutaneous inoculation of porcine Tg. Blood samples were collected between 0900 and 1000 on days 20 (D20), 29 (D29), 35 (D35), and 38 (D38), and assayed for plasma CORT and MLT, as well as serum titers of specific anti-Tg antibodies (IgG). The timetable changes employed in the immunization protocol were designed to refine the hormonal profiles between D29 and D38. Feed and water were available ad libitum. The body weight was measured on day 38.

Experiment 3 This experiment was conducted in autumn of 1995 (November–December). We replicated experiment 2 to check the previously recorded data on embryonic loss. Two samples (C, E) of 60 eggs each, from the Blache JA strain (Couvoir des Cévennes), were placed 0.50–0.80 m from the side of the computer and were successively incubated for 21 days. The incubation parameters, field characteristics and assessment of embryonic death were those reported in experiment 2. Control and exposed eggs (C and E) were not incubated simultaneously. Therefore, it is possible that during consecutive incubation sessions, uncontrolled parameters affected embryonic mortality. To check this possibility, for each group of eggs (C or E) incubated in the incubation room, a concurrent set of 60 eggs was incubated, without the computer, in a Maino incubator (0.5 × 0.4 x 0.4 m), (L.A.D.I. France, Paris, France). In the latter, the incubation conditions were the same as in the incubation room (38 °C, 45–50% humidity, permanent darkness). The rates of embryonic death recorded in the Maino incubator were compared. The distribution of the VLF and ELF fields in the Maino incubator will be presented in the Results section.

Determination of Hormones

Plasma CORT (ng/ml) was measured by competitive protein-binding assay as previously described [Youbicier-Simo et al., 1993]. Intra-assay and interassay coefficients of variation were 3.1 and 5.6%, respectively. The sensitivity of the assay was 0.05 ng/ml. Plasma MLT was determined by radioimmunoassay according to the method used by Cogburn et al. [1987]. Intra-assay and

interassay coefficients of variation were 14 and 12%, respectively. The sensitivity of the assay was 5 pg/ml.

Antibody Titration

The titers of IgG antibodies against porcine Tg were determined in sera by indirect enzyme-linked immunoabsorbent assay (ELISA) technique as previously reported [Youbicier-Simo et al., 1993]. The titers of anti-Tg antibodies were defined as the reciprocal of the plasma dilution yielding an absorbance equal to 1.0. The results were expressed as the decimal logarithm of serum titers.

Statistical Analysis

The data (mean ± S.E.M.) were processed by Mann-Whitney *U* test.

RESULTS

VLF and ELF Distribution

The magnitude of the VLF and ELF fields measured in the incubation room and henhouse are presented in Table 1.

Experiment 1 When the TV was switched off, the intensity of the VLF field was 2 nT, in both the incubation room and henhouse, regardless of the distance. This value corresponds to the sensitivity threshold of the VLF meter used. With the TV switched on, the VLF field strength measured at both sites was 4 and 2 nT at 0.5 and 0.8 m, respectively. The magnitude of the ELF field ranged between 0 and 12 nT with the switched-off TV; when the latter was switched on, the intensity of ELF decreased by half from 0.5 to 0.8 m, in both the incubation room (270 vs. 135 nT) or henhouse (260 vs. 140 nT).

Experiments 2 and 3 For the switched-off computer, the VLF field intensity corresponded to the detection limit of the VLF meter (2 nT). With the switched-on device, the VLF emission was about five times higher at 0.5 m than at 0.8 m in both the incubation room (13 vs. 3 nT) and henhouse (10 vs. 2 nT). For the turned-off computer, the ELF values were 27 and 0 nT at 0.5 and 0.8 m, respectively. When the computer was turned on, the ELF field strength was four times higher at 0.5 m than at 0.8 m: 660 vs. 140 nT in the incubation room; 560 vs. 142 nT in the henhouse.

In the turned-off Maino incubator, no ELF field could be detected and VLF was 2 nT. When the incubator was turned on, the VLF intensity did not vary (2 nT); meanwhile, 0.3 and 0.4 m from the ceiling of the incubator, the ELF values reached 650 and 150 nT, respectively.

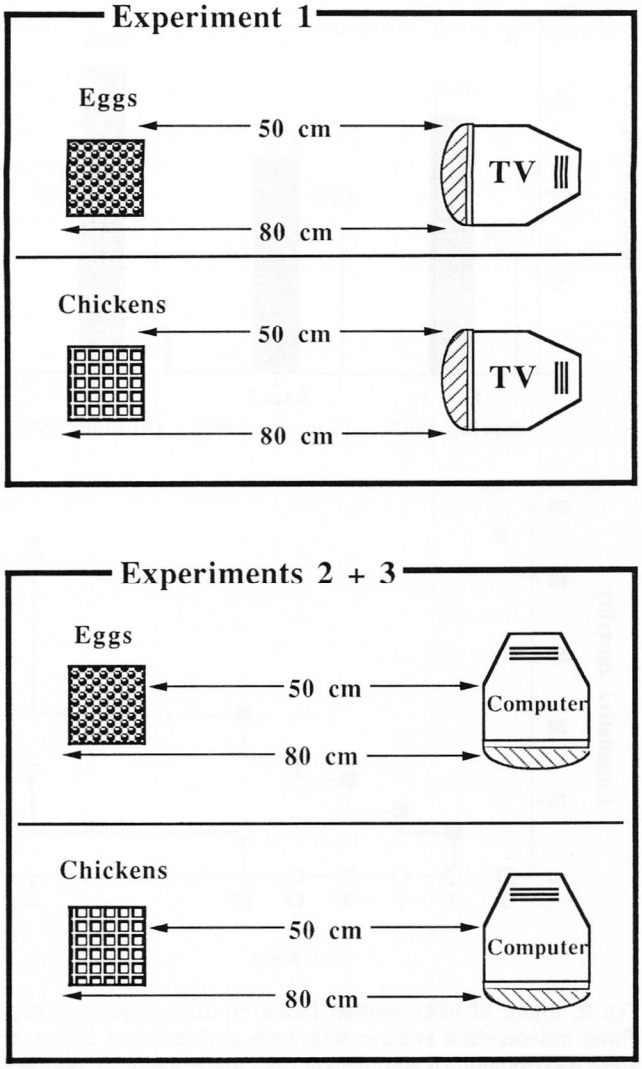

Fig. 1. Scheme of the EMF exposure design. In experiment 1, the eggs and chickens were exposed 0.5–0.8 m in front of the TV set. In experiments 2 and 3, they were placed 0.5–0.8 m from the side of the computer.

Embryonic Mortality

Embryonic mortality was evaluated by two methods. In the first method (Figure 2 (a)), embryonic death (%) was expressed as the ratio of the total number of dead embryos observed from the 3rd to the 21st day of incubation over the total number of fertilized eggs determined on the 3rd day of incubation. In the second method (Figure 2 (b)), embryonic mortality was measured at 2 day intervals from day 3 to day 13 and on day 21 by adding up current and previous counts

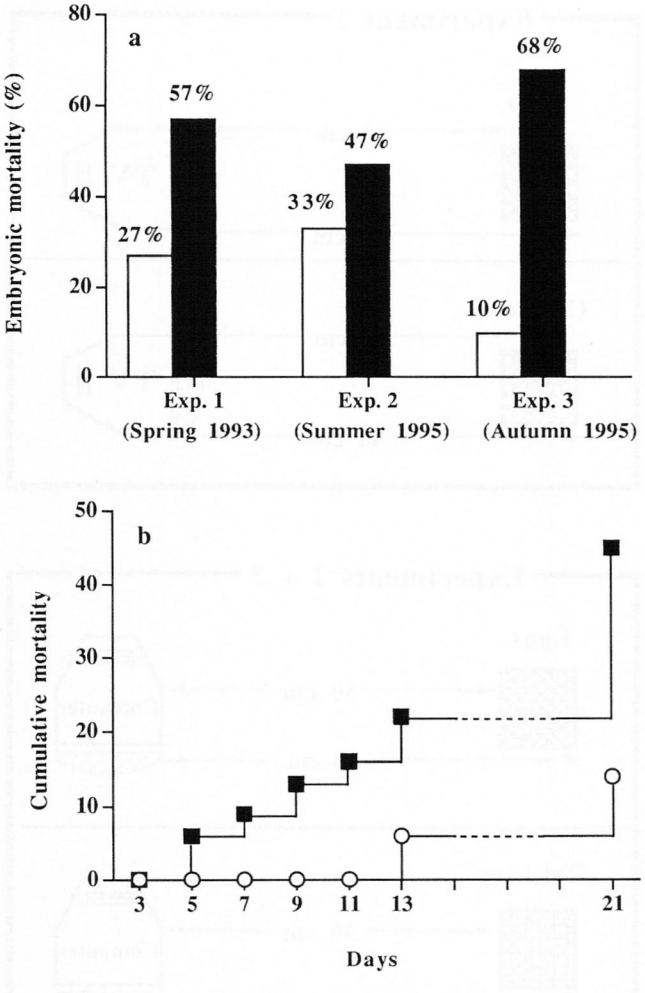

Fig. 2. Effect of VDU-emitted EMFs on embryonic mortality. Three independent experiments were performed in spring of 1993 (experiment 1), summer of 1995 (experiment 2), and autumn of 1995 (experiment 3). Embryonic mortality was expressed as (a) the total count of dead embryos during the whole embryonic phase or (b) estimated by candling the eggs at 2-day intervals (day 3, 5, 7, 9, 11, 13) and at hatching day (day 21), and adding current and previous counts (cumulative mortality). **(a)** The sham-exposed (C) and exposed (E) groups are represented by white and dark columns, respectively. **(b)** Sham (C) and EMF (E) exposures are represented by circles and squares, respectively.

(cumulative mortality). For cumulative mortality, only the data from experiment 3 are shown, because identical profiles of cumulative mortality were obtained for experiments 1 and 2.

Experiment 1 Total embryonic death was twice that in the exposed group (57%) than in controls (27%). Twenty-two and 13 chicks hatched from 30 control and 30 exposed eggs, respectively. One chick from each group died during the first week after hatching.

Experiment 2 Continuous EMF exposure was also associated with increased embryonic loss, though to a lesser extent than in experiment 1: 33 and 47% for the sham and EMF exposures, respectively. It is worth noting that in the control group, 3 eggs of 30 initially incubated were not fertilized. Eighteen chicks hatched from the sham-exposed eggs and sixteen from the exposed ones. During the first week after hatching, one control and six exposed chicks died.

Experiment 3 The same trend was observed, with the worsening of embryonic mortality in the exposed group (68%) compared with their sham-exposed counterparts (10%). In the Maino incubator, embryonic mortality was the same during the two incubation sessions (15%).

For the three experiments, embryonic death in the control groups was greater in the second half of embryonic phase; in this case, 60% of total dead embryos occurred near the end of the incubation period, as suggested by their size. In the exposed groups, embryonic loss covered the entire embryonic phase.

Hormonal and Antibody Responses to Immunization by Porcine Thyroglobulin

The CORT and antibody (IgG) responses to immunization by porcine Tg are presented in Table 2.

Experiment 1 Ten chickens from each group (C, E) were randomly bled. Regardless of experimental groups, CORT levels remained at baseline values before immunization (D20). After porcine Tg inoculation, the sham-exposed chickens (C) exhibited increasing CORT levels that crested at D38 and finally dropped to baseline values at D47. Assessed in parallel with CORT, the specific antibody response (IgG) varied increasingly from the first to the third immunization. On the other hand, the CORT levels remained steadily low in the exposed chickens (E), who also failed to mount an IgG response despite a slight increase at D38 and D47.

Experiment 2 Blood samples were collected from all the living subjects (17 control and 10 exposed chickens). Irrespective of experimental groups, CORT did not vary significantly before immunization (D20). After antigen challenge, the CORT levels of the control chickens increased progressively until D38, paralleled by the specific IgG response. Conversely, in the exposed chickens, the CORT levels hardly shifted from D20 to D38, and the pattern of the antibody response matched that observed in experiment 1. The melatonin response profile of the sham-exposed chickens (Figure 3) was similar to that of CORT. Continuous exposure to EMFs depressed melatonin below the baseline level.

TABLE 2. Effects of VDU-Emitted EMFs on Corticosterone and Immunoglobulin G (IgG) Responses of Young Chickens Immunized by Porcine Thyroglobulin*

	Experiments	Group (n)	D20	D29	D35	D38	D47
Corticosterone (ng/ml)	1	C (10)	3.0 ± 0.1	3.4 ± 0.1	—	6.0 ± 0.2[a,b]	2.6 ± 0.1
		E (10)	2.3 ± 0.2	2.0 ± 0.2	—	2.5 ± 0.1	2.4 ± 0.2
	2	C (17)	2.4 ± 0.1	3.5 ± 0.1	4.5 ± 0.1	8.6 ± 0.4[a,b]	—
		E (10)	2.5 ± 0.1	3.0 ± 0.1	3.4 ± 0.1	4.0 ± 0.1	—
IgG (titer log)	1	C (10)	1.6 ± 0.1	3.4 ± 0.2[a,b]	—	4.0 ± 0.1[a,b]	3.7 ± 0.7[a,b]
		E (10)	1.5 ± 0.1	2.0 ± 0.2	—	2.7 ± 0.3[a]	2.7 ± 0.4[a]
	2	C (17)	1.3 ± 0.0	3.8 ± 0.2[a,b]	4.8 ± 0.5[a,b]	5 ± 0.3[a,b]	—
		E (10)	1.5 ± 0.9	2.2 ± 0.4	3.8 ± 0.2[a]	2.8 ± 0.2[a]	—

*Corticosterone and antibody (IgG) responses of the sham (C) and EMF exposed (E) chickens immunized by porcine thyroglobulin. In experiment 1, the chickens were immunized at the age of 21, 30, and 39 days; blood samples were collected on days 20 (D20), 29 (D29), 38 (D38), and 47 (D47) and assayed for corticosterone and IgG. In experiment 2, antigen challenge was performed at the age of 21, 30 and 36 days, and blood was collected on days 20 (D20), 29 (D29), 35 (D35), and 38 (D38).
[a]$P < .01$ vs. D20.
[b]$P < .01$ vs E.

Evaluation of the Body Weight

Permanent EMF exposure was accompanied by significantly ($P < .05$) reduced body weight (Figure 4), either at D38 (experiment 2) or D47 (experiment 1). In experiment 1, the mean body weight was 650 ± 9 g and 605 ± 5 g for the control and exposed chickens, respectively. In experiment 2, the mean body weight was 842 ± 20 g and 714 ± 24 for the control and exposed chickens, respectively.

DISCUSSION

Television sets and computers give off an assortment of electromagnetic waves ranging from X-rays to ELF EMFs. Most studies assessing health risks of VDU-released EMFs consider VLF and ELF fields quantitatively the most important and potentially bioactive [Kavet and Tell, 1991; Shnorr et al., 1991; Walsh et al., 1991]. In the present discussion, only these two categories of fields will be considered.

Embryonic death was essentially restricted to the end of the incubation period for the sham-exposed organisms (60% of total dead control embryos). A possible explanation to this time-limited mortality is that the end of incubation corresponds to the preparation for hatching and represents a critical period [Landauer, 1951; Baumann and Baumann, 1977]. Chicken embryos exposed to TV or computer-generated EMFs exhibited a higher death rate than their sham-exposed counterparts. This detrimental effect arose early and lasted during the entire embryonic period, and it worsened by the end of incubation. The two successive incubation sessions performed in the Maino incubator, in the absence of the exposure device (computer) and concurrently with sham and EMF exposures (experiment 3), yielded similar low death rates (15%), which were close to that observed in the sham-exposed group (10%). It is worth noting that both the Maino incubator and the incubation room were held under identical incubation conditions. Furthermore, the eggs incubated at both sites were submitted to comparable field strengths. Together, these arguments preclude the involvement of uncontrolled parameters that might have affected embryonic mortality in the sham-exposed and exposed groups during consecutive incubations. Consequently VDU-generated EMFs appear as the main causative factor of increased embryonic defect in the exposed group. In line with our findings, other investigators reported that the exposure of fertile chicken eggs to a pulsed ELF magnetic field for the first 48 h of incubation was accompanied by increased embryonic death [Delgado et al., 1982; Ubeda et al., 1983, 1994; Martin, 1988, 1990, 1992].

In the Maino incubator, the embryonic death was only 15%, despite an ELF field strength of 650 nT measured at the level of the eggs. Such an observation seemingly conflicts with the high death rate (47–68%) associated with our exposure system, the computer, which emits in the same ELF range (660 nT at 0.50 m). The intensity of the incident field is not apparently the unique causative factor of the ELF-induced bioeffects. EMFs generate currents when going through body tissue by induction, and the latter is proportional to the field frequency. The combination of the field

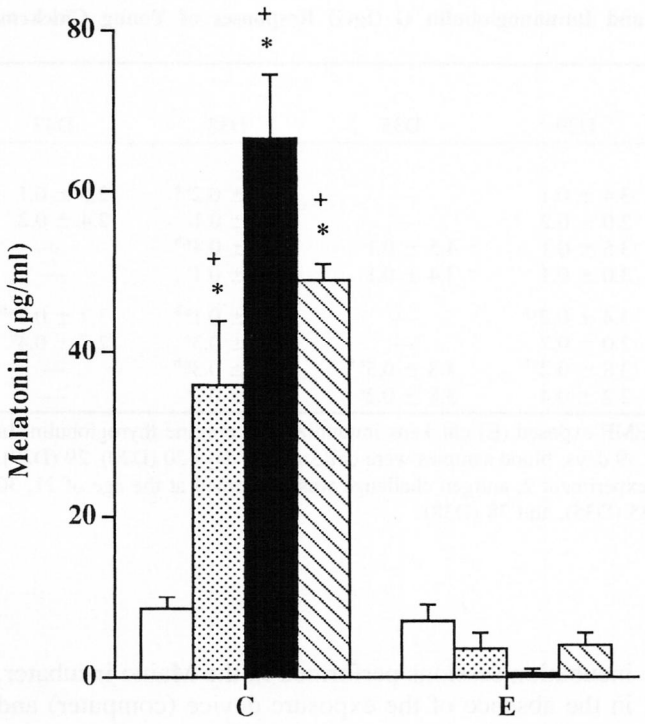

Fig. 3. Effect of VDU-releazed EMFs on the melatonin response of young chickens immunized by porcine Tg. The sham-exposed (C) and exposed chickens (E) were immunized at 21, 30, and 36 days of age and melatonin levels were measured in 20 (white columns), 29 (dotted columns), 35 (black columns), and 38 (hatched columns) day old chickens. The data represent mean ± S.E.M. *$P < .01$ vs. D20; + $P < .01$ vs. E.

strength with the other field characteristics (frequency, waveform, duration of exposure), in a certain range termed ''window'' of sensitivity, is required to yield the observed bioeffects of EMFs [Bawin and Adey, 1976; Delgado et al., 1982; Juutilainen et al., 1986; Martin, 1988; Cadossi et al., 1992]. For example, using a low-level pulsed magnetic field (10-1000 Hz, 0.12, 1.2, 12 μT), Delgado and co-workers [1982] observed 100% structural abnormalities only for specific combinations (100 Hz, 0.12, 1.2, 12 μT, or 1000 Hz, 1.2 μT). Another illustration of the window effect comes from the work of Ubeda and colleagues [1994], who demonstrated that a pulsed ELF magnetic field (100 Hz, 1 μT) was effective in increasing embryonic mortality only when the time of rise and fall of pulses was 2.1 μs, not 85 μs. The electric device of the Maino incubator gives off sine waves, whereas the TV or computer releases saw-tooth shaped pulses, the latter being generally considered as the most harmful [Ubeda et al., 1983; Juutilainen et al., 1986; Lerchl et al., 1990; Martin, 1992; Reiter and Richardson, 1992; Koch et al., 1993]. Because both systems work in the same range of ELF frequency (50 Hz) and field strength (650–660 nT) and were used for the same length (21 days), we can reasonably postulate that the discrepancy noticed in death rate between exposed and sham-exposed organisms likely results from the differences in the shape of waves.

Some experts mention ELF as the primary concern. In our study, the magnitude of the VLF field was by far below ELF intensity (see Table 1). Magnetic induction effects are proportional to the field frequency; small VLF and larger ELF fields have comparable magnetic inductions, because the frequency of the VLF field is higher (15–85 kHz is higher than 15–80 Hz). For this reason, VLF fields can hardly be considered harmless.

However, even though VDU-emitted EMFs appear causally linked to aggravated embryonic death, this cause-and-effect relationship must be viewed cautiously, because the EMF-exposed organisms also seemed sensitive to seasonal fluctuations of climate: the autumn embryonic mortality (68%) was greater than spring (57%) and summer (47%) ones. In the sham-exposed group embryonic mortality was also influenced by seasonal variations: 33% mortality in sum-

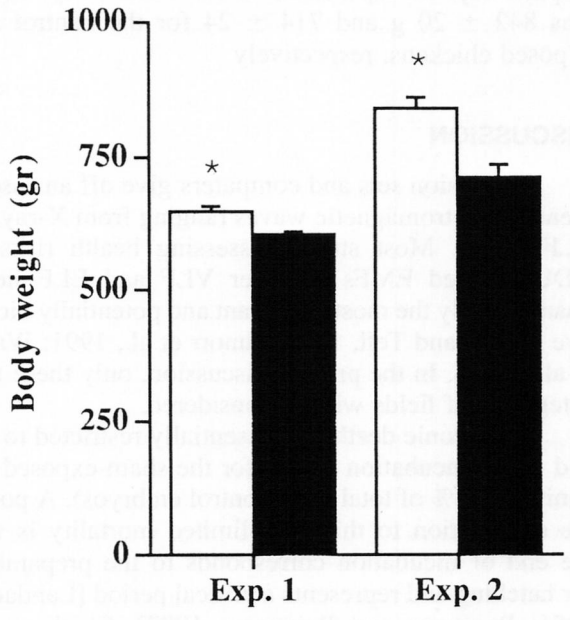

Fig. 4. Effect of VDU electromagnetic emissions on the body weight of young chickens. After blood sampling, the young chickens were weighed at 38 (experiment 2) and 47 (experiment 1) days of age. The sham-exposed (C) and exposed (E) groups are represented by white and dark columns, respectively. The data represent mean ± SEM. *$P < .05$ vs. E.

mer versus 27 and 10% in spring and autumn, respectively.

The interference of ELF fields with developing embryos is often linked to structural anomalies, as well as biochemical alterations [Delgado et al., 1982; Ubeda et al., 1983; Juutilainen et al., 1986; Berman et al., 1990; Li et al., 1995; Martin and Moses, 1995], and both changes are likely to affect some physiological processes, particularly in adulthood [Reiter et al., 1988]. In this respect, our young adult chickens constantly exposed to ELF fields emitted by the TV or computer failed to produce raised CORT, MLT, and IgG responses to immunization by porcine Tg. Other reports relating to possible endocrine and immune bioeffects of ELF fields match our own results: ACTH, CORT, testosterone, MLT, and prolactin levels [Huxtable and Lafranconi, 1983; Oroza et al., 1987; Reiter, 1993], as well as lymphocyte proliferation [Cadossi et al., 1992; Walleczek, 1992] are damaged by the ELF field treatment. It is interesting to note that we found that the CORT, MLT, and antibody responses of the sham-exposed chickens crested simultaneously after the second antigen challenge. This concomitant rise is highly relevant physiologically: the elevation of CORT prevents an excessive expansion of immunocompetent cells, thereby decreasing the probability of autoimmune and lymphoproliferative diseases [Besedovsky and Sorkin, 1977; Maestroni et al., 1989]. On the other hand, the increase of MLT balances the action of CORT to avoid immunodepression [Maestroni et al., 1989; Youbicier-Simo et al., 1996a, b]. Furthermore, the pineal and adrenal glands, which produce MLT and CORT, respectively, as well as the immune system, are the key systems of adaptation to environmental insults [Reiter, 1988; Maestroni et al., 1989; Szafarczyk et al., 1993]. Our findings take on meaningful importance in terms of concern about the potential hazard VDU-emitted EMFs may represent for human health, even though the present evidence is from nonhuman species. Further support to this assumption comes from the observation that continuous exposure of developing organisms to VDU electromagnetic emissions was associated with significantly reduced body weight. Consistently, the body mass and length of CBA/S mice are significantly reduced after exposure of the fetuses to a sawtooth pulse magnetic field [Frölen et al., 1993; Svedenstal and Johanson, 1995].

Little is known about how ELF fields are linked to the organism and/or tissues. At the embryonic level, the developing nervous system is the most vulnerable to EMF exposure [Delgado et al., 1982; Berman et al., 1990; Ubeda et al., 1983; 1994]. Magnetoreception seems to be located at different levels of the visual pathway, namely the retina and pineal gland [Reuss et al., 1983; Welker et al., 1983; Semm, 1988], and also in the brain [Semm, 1983; Kirschvink et al., 1992]. Moreover, in vitro studies indicate a direct sensitivity of lymphocytes to EMFs [Cadossi et al., 1992; Walleczek, 1992]. As suggested by our results, the ELF field can affect the immune system either directly or through neuroendocrine-immune communications. To date, no satisfactory physical mechanism has been put forward to explain the observed biological effects of nonionizing EMFs. However, strong experimental evidence has established that changes in calcium ion transport mechanisms in tissues or calcium ion-mediated responses to neurotransmitters and hormones are involved in bioactive ELF field coupling in living systems [Bawin and Adey, 1976; Walleczek, 1992]. A possible mechanism, shaped by experimental studies, states that at the cellular level appropriate membrane magnetoreceptors must be simultaneously and coherently activated (biological cooperativity) to produce effects on the biochemical functioning of the cell. The reports of Farell et al. [1993], Mullins et al. [1993], Litovitz et al. [1994], and Martin and Moses [1995] lend support to this hypothesis.

Most reports on potential health hazards from VDU electromagnetic emissions result from epidemiological studies. Not only does this study present evidence of physiological correlates of exposure to such radiations, it also reveals the sensitivity of endogenous systems vital to adaptation and homeostasis.

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