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Effect of GSM 900-MHz Mobile Phone Radiation on the Reproductive Capacity of *Drosophila melanogaster*

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ABSTRACT

Pulsed radio frequency, (RF), electromagnetic radiation from common GSM mobile phones, (Global System for Mobile Telecommunications) with a carrier frequency at 900 MHz, ''modulated'' by human voice, (speaking emission) decreases the reproductive capacity of the insect *Drosophila melanogaster* by 50%–60%, whereas the corresponding ''nonmodulated'' field (nonspeaking emission) decreases the reproductive capacity by 15%–20%. The insects were exposed to the near field of the mobile phone antenna for 6 min per day during the first 2–5 days of their adult lives. The GSM field is found to affect both females and males. Our results suggest that this field-radiation decreases the rate of cellular processes during gonad development in insects.

Key Words: RF; GSM radiation; Electromagnetic fields; Biological effects; *Drosophila*; Reproductive capacity.

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INTRODUCTION

Radio frequency (RF) electromagnetic radiation has been reported to produce a number of biological effects on biomolecules, cells, and whole organisms, including changes in intracellular ionic concentrations, the synthesis rate of different biomolecules, cell proliferation rates, the reproductive capacity of animals, etc. (Bawin et al., 1975, 1978; Blackman et al., 1980, 1989; Dutta et al., 1984; Goodman et al., 1995; Kwee and Raskmark, 1998; Lin-Liu and Adey, 1982; Penafiel et al., 1997; Velizarov et al., 1999; Xenos and Margas, 2003).

During recent years, GSM mobile phones (Global System for Mobile Telecommunications), the most powerful RF transmitters in our everyday environment, have become widely and increasingly used by the public and to date there is no clear evidence about their possible biological effects.

Our experiments were designed to test the biological activity of RF electromagnetic radiation at 900 MHz, emitted by GSM mobile phones. This radiation is emitted in pulses with a carrier frequency within the range of 890–915 MHz and a pulse repetition frequency of 217 Hz (Hyland, 2000; Tisal, 1998).

The most stringent western exposure limits for RF radiation at 900 MHz, set by, International Radiation Protection Association (IRPA) and International Commission on Non-Ionizing Radiation Protection (ICNIRP), were established basically to protect biological tissue from temperature increases (thermal effects): these refer for occupational exposure to a power density value of 2.25 mW/cm^2 or whole-body mean specific absorption rate (SAR) value of 0.4 W/kg. In terms of electric field intensity (used in the near field of an antenna), the occupational exposure limit is 90 V/m. All the above values are to be averaged over any 6-min period during the working day. The corresponding general population limits are a power density value of 0.45 mW/cm^2, or whole-body mean SAR of 0.08 W/kg, or electric field intensity of 41.25 V/m, all averaged over any 6-min period during the 24-hr day, (ICNIRP, 1998; IRPA, 1988).

For the frequency of 217 Hz, the IRPA–ICNIRP limits for occupational exposure are 2.3 kV/m electric field intensity and 1.15 G (0.115 mT) magnetic field intensity for a few hours exposure during the day and for the general population 1.15 kV/m and 0.23 G for up to 24-hr exposure during the day (ICNIRP, 1998; IRPA, 1990).

We designed special experimental protocols, related to the reproductive capacity of the insect *Drosophila melanogaster*, a well-studied experimental animal with many advantages, including its short life cycle and process timing of its metamorphic stages and developmental processes (King, 1970). A series of experiments have been conducted on *Drosophila* which is a model organism, especially considering the process of oogenesis.

The basic cellular processes are identical in insect and mammalian cells. In addition, insects (particularly *Drosophila*) are much more resistant, at least to ionizing electromagnetic radiation, than mammals (Abrahamson et al., 1973; Koval and Kazmar, 1988; Koval et al., 1977, 1979). Therefore, a proper experimental protocol relating *Drosophila* could be very useful in assessing the bioactivity of electromagnetic radiation in general (including nonionizing radiation and electromagnetic fields).

In our experiments, the reproductive capacity was defined by the number of F_1 pupae. This number under the conditions of our experiments corresponds to the

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number of laid eggs (oviposition), since there is no statistically significant mortality of eggs or larvae that come from newly emerged paternal-maternal flies during their first 3 days of maximum daily oviposition.

In earlier experiments, performed to study the effects of magnetic fields (Ma and Chu, 1993; Ramirez et al., 1983) or RF fields (Pay et al., 1978), on the reproduction of the same insect, the procedures comprised counting of laid eggs, as a basic part, an operation that encounters significant error. In addition in one of those works (Ma and Chu, 1993), use was not made of newly emerged paternal-maternal flies as we did, but instead flies were taken from the general stock population. Eggs from older flies have a considerable percentage of mortality. In another of those works (Ramirez et al., 1983), only the female flies were exposed, which were 4 days old and already mated when placed in the field. Therefore, any effect on spermatogenesis or on mating was excluded, and any effect on oogenesis was diminished. In the last of the above experiments (Pay et al., 1978), they studied the oviposition of individual pairs of adult flies that were developed from pupae that were exposed for only 10 min in a very intense microwave field (able to produce large temperature increases) 100 hr posthatching. Therefore, the exposure took place many hours before the beginning of oogenesis, which in *Drosophila* starts during the last stages of pupation (King, 1970). Besides, oviposition from individual pairs may have a large variability because some male flies do not accomplish copulation while others accomplish copulation with more than one female. In all the above experiments, a large number of nondeveloped eggs laid both in exposed and control groups were reported.

As we shall see, our experiments differ significantly from the above earlier ones.

MATERIALS AND METHODS

We carried out experiments with *Drosophila melanogaster* flies, Oregon R, wild-type, held in glass bottles and kept in incubator at 25°C, with 12-hr periods of light and darkness and 70% relative humidity.

In each experiment, we collected newly emerged adult flies from the stock; we anesthetized them very lightly with diethyl ether and separated males from females. We put the collected flies in groups of 10 in standard laboratory 50-mL cylindrical glass vials (tubes), with 2.5-cm diameter and 10-cm height, with standard food, which forms a smooth plane surface, 1-cm thick at the bottom of the vials. The glass vials were closed with cotton plugs.

The food consisted of 450 mL water, 4 g agar, 13 g yeast, 32 g rice flour, 16 g sugar, 25 g tomato pulp. The mixture was boiled for over 10 min to ensure sterility, which was preserved by the addition of 2 mL propionic acid and 2 mL ethanol. This food quantity was enough for 25–30 glass vials, which were sterilized before the food was added.

We exposed the flies within the glass vials by placing the antenna of the mobile phone outside of the vials, in contact with the glass wall and parallel to the vial's axis. The total duration of exposure was 6 min per day in one dose, and we started the exposures on the first day of each experiment (day of eclosion). The exposures took place for a total of 5 days in each experiment in the first two (A, B) sets of experiments and for a total of 2 days in the third (C) set of experiments, as described below.

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The daily exposure duration of 6 min was chosen to have exposure conditions that can be compared with the established exposure criteria. Besides, earlier experiments had shown that only a few minutes of daily exposure were enough to produce a significant effect on the insect's reproductive capacity (Panagopoulos et al., 2000a).

The experimenter could speak on the mobile phone during connection (this we called "modulated" or "speaking" emission) or could just make no sound, ("nonmodulated" or "nonspeaking" emission). We had already noticed that the intensity of the emitted radiation increases considerably when the user speaks during connection than when there is no speaking (Panagopoulos et al., 2000a). In both cases, during the exposures, the experimenter's position in relation to the mobile phone and the glass vials was the same. The mobile phone was held close to the experimenter's head with its antenna facing downward, being at the same time parallel and in contact with the glass vials. The exposures and the field measurements took place in a quiet but not sound-isolated room to simulate the actual conditions to which a user is subjected while speaking and while listening, correspondingly. The room conditions and the positions of all items around the experimental bench were always the same.

Each time before exposure, the cotton plugs were pushed down in the glass vials to confine the flies to a small area of 1-cm height between the cotton and the food to provide roughly even exposure to all flies. After the exposure, the cotton plugs were pulled back to the top of the vials, and the vials were put back in the culture room.

We carried out three sets of experiments. In the first set (A), we exposed the insects to the mobile phone's GSM field while the mobile phone was operating in nonspeaking mode (nonmodulated emission). In the second set of experiments (B), the mobile phone was operating in "speaking" mode ("modulated emission") during the exposures. The third set of experiments (C) was designed to record the effect of the GSM field on the reproductive capacity of each sex separately.

In the first two sets of experiments, we separated the insects into two groups: (1) the exposed group (E) and (2) the sham exposed (control) group (SE). (Each one of the two groups consisted of 10 female and 10 male, newly emerged flies). The sham exposed groups had identical treatment as the exposed ones, except that the mobile phone during the 6-min exposures was turned off. The 6-min daily exposures took place for the first 5 days of each experiment.

In each group we kept the 10 males and the 10 females for the first 48 hr of the experiment in separate glass tubes. As we have described before (Panagopoulos et al., 2000a), at eclosion, adult female flies already have in their ovaries eggs at the first preyolk stages and oogenesis has already started. The eggs develop through 14 distinct stages, until they are ready to be fertilized and laid, and the whole process of oogenesis lasts about 48 hr. By the end of the 2nd day of their adult life, the female flies have in their ovipositor the first egg of stage 14, ready to be fertilized and laid (King, 1970). At the same time, the first mature spermatozoa (about 6 hr after eclosion) and the necessary paragonial substances (about 12 hr after eclosion) in male flies have already been developed (Connolly and Tully, 1998; King, 1970; Stromnaes and Kvelland, 1962). Keeping males separately from females for the first 48 hr of the experiment ensures that the flies are in complete sexual maturity and ready for immediate mating and laying of fertilized eggs.

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After the first 48 hr of each experiment, the flies were anesthetized very lightly again and males and females of each group were put together (10 pairs) in another glass tube with fresh food and allowed to mate and lay eggs for 72 hr. During these 3 days, the daily egg production of *Drosophila* is at its maximum (from the 3rd to 5th day of its adult life), stays at a plateau or declines slightly for the next 5 days, and diminishes considerably after the 10th day of adult life (Bos and Boerema, 1981; Ramirez et al., 1983; Shorrocks, 1972).

In the third set of experiments (C), the mobile phone was operating again in speaking mode during the exposures, but in this set of experiments we separated the insects into four groups (each one consisting again 10 male and 10 female insects). In the first group (E1), both male and female insects were exposed. In the second group (E2), only the females were exposed. In the third group (E3), we exposed only the males and the fourth group (SE) was sham exposed (control). Therefore in this third set of experiments, the 6-min daily exposures took place only during the first 2 days of each experiment while the males and females of each group were separated and the total number of exposures in each experiment was two instead of five. This set of experiments was carried out to record the effect of the GSM field on the reproductive capacity of each sex separately.

After 5 days from the beginning of each experiment in all three sets of experiments, the flies were removed from the glass vials and the vials were maintained in the culture room for 6 additional days, without further exposure.

After the last 6 days, most F_1 embryos (deriving from the laid eggs) are in the stage of pupation, where they can be clearly seen with bare eyes and easily counted on the walls of the glass tubes. (At the last stages before pupation, larvae leave the food, climbing on the walls of the glass vials). There may be a few embryos still in the last stages as larvae, which are big enough and ready for pupation (on the surface or already away from the food), so that they can be easily counted. (If the remaining larvae are still many and the counting is imprecise, the experimenter can wait an additional day and recount the pupae). There may be also already a few newly emerged F_1 adult flies, which can also be counted easily.

During the last 6 days, we inspected the surface of the food within the glass vials under the stereomicroscope for any nondeveloped laid eggs or dead larvae, something that we did not see in our experiments (empty egg shells can be seen after hatching). The number of observed exceptions (nondeveloped eggs or dead larvae), both in exposed and control groups (less than 5%), was within the standard deviation of progeny number. (The insignificant percentage of F_1 egg and larvae mortality is due to the fact that the paternal-maternal flies were newly emerged during the first 2–5 days of their adult lives). Therefore the number of pupae in our experiments corresponded to the number of laid eggs (oviposition). Furthermore, the counting of pupae can be done with minimal error, whereas the counting of laid eggs under a stereomicroscope is subject to considerable error.

The oviposition of *Drosophila* is influenced by many factors: temperature, humidity, prior anesthesia, crowding, and food (King, 1970). Special care was taken to keep all these factors constant. Experience in handling the flies is necessary to prevent accidental deaths.

We used a very common model of GSM mobile phone device in our experiments. We measured the mean power density of the radiation emitted by the

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mobile phone device plus the mean electric field intensity at 900 MHz, with the field-meter, RF Radiation Survey Meter, NARDA 8718, with its probe inside a glass vial similar to the ones we used for the insects in our experiments. The measured mean power density for 6 min of modulated emission, with the antenna of the mobile phone outside of the glass vial in contact with the glass wall and parallel to the vial's axis was $0.436 \pm 0.060\,\mathrm{mW/cm^2}$, and the corresponding mean electric field intensity was $37.21 \pm 7.10\,\mathrm{V/m}$. The nonmodulated (NM) corresponding measured values were $0.041 \pm 0.006\,\mathrm{mW/cm^2}$ power density and $16.68 \pm 3.68\,\mathrm{V/m}$ electric field intensity. In addition, we measured in the same way the mean electric and magnetic field intensities at the extremely low frequency (ELF) range, with the field-meter, Holaday HI-3604, ELF Survey Meter. The measured values for modulated field, excluding the ambient electric and magnetic fields of 50 Hz, were $6.05 \pm 1.62\,\mathrm{V/m}$ electric field intensity and $0.10 \pm 0.06\,\mathrm{mG}$ magnetic field intensity. The corresponding nonmodulated values were $3.18 \pm 1.10\,\mathrm{V/m}$ and $0.030 \pm 0.003\,\mathrm{mG}$. These ELF components of the GSM field are basically due to the pulse repetition frequency of 217 Hz (Hyland, 2000; Tisal, 1998). All the above values are average values from eight separate measurements of each kind ± standard deviation (SD). These values are typical for all commonly used GSM mobile phone devices emitting at 900 MHz with 2 W peak power output (we tested several different devices of this kind).

The experimenter's position in relation to the mobile phone during the measurements was the same as during the exposures.

Therefore, the measured exposure values are in general within the established exposure limits.

RESULTS

Experiments with Nonmodulated GSM Field

We carried out four experiments (A1–A4) with nonmodulated field (non-speaking emission). The exposure parameters in this case simulate the situation when the user listens through the mobile phone during connection. Results from each experiment, are listed in Table 1.

Table 1 shows the mean number of F_1 pupae (corresponding to the number of laid eggs) per maternal fly in the groups E(NM) exposed to nonmodulated (NM), GSM mobile phone field and in the corresponding sham exposed (control) groups SE(NM) during the first 3 days of the insect's maximum oviposition.

Statistical analysis (single-factor ANOVA test) shows that the probability that mean oviposition differs between the exposed and the sham exposed groups, owing to random variations, is $P < 5 \times 10^{-4}$.

Experiments with Modulated GSM Field

We carried out four experiments (B1–B4), with modulated emission (the experimenter was speaking close to the mobile phone's microphone, during

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Table 1. Effect of nonmodulated GSM field on the reproductive capacity of *Drosophila melanogaster*.

Experiment no.	Groups	Mean no. of F_1 pupae per maternal fly	Deviation from control
A1	E(NM)	9.7	−16.38%
	SE(NM) (control)	11.6	
A2	E(NM)	10	−15.96%
	SE(NM) (control)	11.9	
A3	E(NM)	9.8	−20.16%
	SE(NM) (control)	12.4	
A4	E(NM)	10.4	−19.38%
	SE(NM) (control)	12.9	
Average ± SD	E(NM)	9.975 ± 0.31	−18.24%
	SE(NM) (control)	12.2 ± 0.57	

Table 2. Effect of modulated GSM field on the reproductive capacity of *Drosophila melanogaster*.

Experiment no.	Groups	Mean no. of F_1 pupae per maternal fly	Deviation from control
B1	E	6.7	−48.85%
	SE (control)	13.1	
B2	E	5.1	−56.78%
	SE (control)	11.8	
B3	E	5.6	−53.72%
	SE (control)	12.1	
B4	E	6	−53.125%
	SE (control)	12.8	
Average ± SD	E	5.85 ± 0.67	−53.01%
	SE (control)	12.45 ± 0.6	

the exposures). The exposure parameters in this case simulate the situation when the user speaks on the mobile phone during connection. Results are listed in Table 2.

Table 2 shows the mean number of F_1 pupae (corresponding to the number of laid eggs) per maternal fly in the groups E, exposed to modulated GSM field and in the corresponding sham exposed groups, SE, during the first 3 days of the insect's maximum oviposition.

The statistical analysis shows that the probability that mean oviposition differs between the exposed and the sham exposed groups, owing to random variations, is $P < 10^{-5}$.

The above results from the first two sets of experiments (A and B) are represented graphically in Fig. 1.

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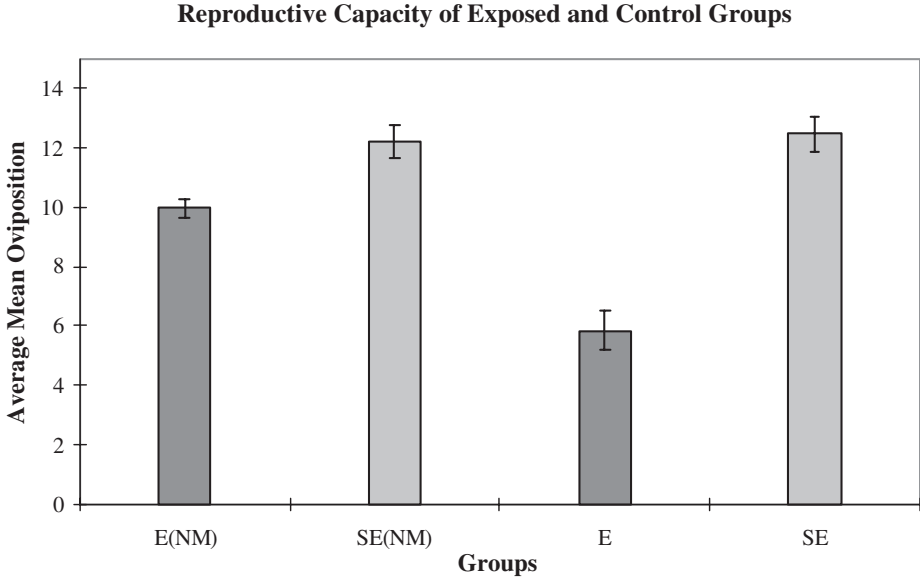

Figure 1. Average value from four experiments of mean number of F_1 pupae, per maternal fly, during the first 3 days of maximum daily oviposition, of the groups exposed to nonmodulated and modulated GSM field [E(NM), E] and the corresponding sham exposed, [SE(NM), SE], groups. (The error bars correspond to standard deviation.)

Comparing the Effect of Modulated GSM Field on the Reproductive Capacity Between Male and Female Insects

We carried out a third set of four experiments (C1–C4) with the modulated GSM field, in which we separated the insects into four groups as described above. In this set of experiments, we exposed the insects to the GSM field only during the first 2 days of each experiment (again for 6 min per day), while male and female insects of each group were separated. During the next 3 days of mating and egg-laying, the insects of each group were transferred everyday into a new vial with fresh food without any further anesthesia. This small alteration in the procedure allowed us to see if there were any differences in the effect of the prior exposures from day to day. The results from this set of experiments are listed in Table 3.

These results are represented graphically in Fig. 2.

Statistical analysis (single-factor ANOVA test) shows that the probability that mean oviposition differs between the four groups because of random variations is $P < 10^{-7}$.

The results of the third set of experiments show that the GSM field affects the reproductive capacity of both sexes. The female insects (E2) seem to be more affected than males (E3).

In this set of experiments, the difference in oviposition between the four groups was larger during the first 2 of the 3 days of mating and egg-laying.

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Table 3. Effect of modulated GSM field on the reproductive capacity of each sex.

Experiment no.	Groups	Mean no. of F_1 pupae per maternal fly	Deviation from control
C1	SE (control)	13.2	
	E1	8.5	−35.61%
	E2	9.4	−28.79%
	E3	11.7	−11.36%
C2	SE (control)	13.8	
	E1	7.6	−44.93%
	E2	8.9	−35.51%
	E3	12.1	−12.32%
C3	SE (control)	12.9	
	E1	7.8	−39.53%
	E2	9.3	−27.91%
	E3	11	−14.73%
C4	SE (control)	13.5	
	E1	6.9	−48.89%
	E2	7.8	−42.22%
	E3	12.2	−9.63%
Average ± SD	SE (control)	13.35 ± 0.39	
	E1	7.7 ± 0.66	−42.32%
	E2	8.85 ± 0.73	−33.71%
	E3	11.75 ± 0.54	−11.985%

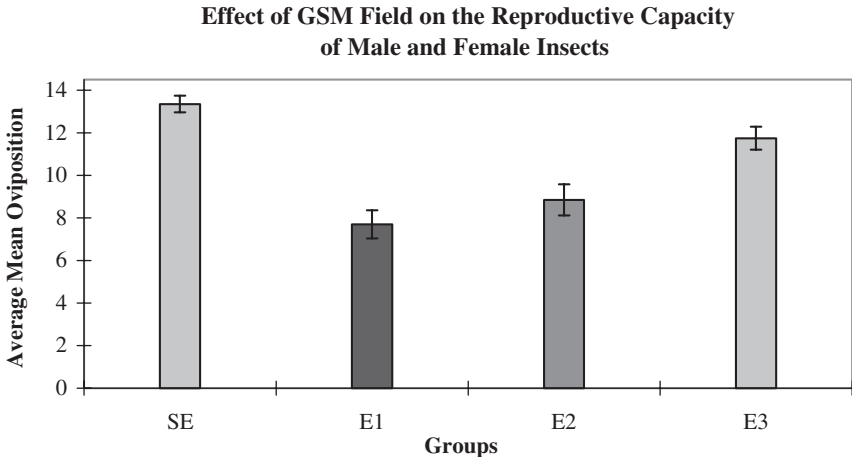

Figure 2. Effect of modulated GSM field on the reproductive capacity of each sex of *Drosophila melanogaster*. Average mean number of F_1 pupae ± SD per maternal insect. SE-sham exposed groups; E1-groups that both sexes were exposed; E2-groups in which only the females were exposed; E3-groups in which only the males were exposed.

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DISCUSSION

The statistical analysis clearly shows that the exposed *Drosophila* groups differ in offspring production (up to 60% decrease), compared to the control groups, due to the effect of the GSM field.

Our experiments clearly show that GSM radiation affects the reproductive capacity of both female and male insects. The reason why female insects seem to be more affected than males is possibly due to the fact that the exposures started a few hours after eclosion, thus a few hours after oogenesis starts in female flies, while at the same time the first mature spermatozoa are about to be completely developed in male flies of the same age (spermatogenesis starts earlier than oogenesis).

The reproductive capacity is much more decreased with modulated emission (50%–60%), than with nonmodulated emission (15%–20%). In addition, the power density of modulated emission is increased by about one order of magnitude in relation to nonmodulated emission. Thus, the effect is not linearly correlated with the emitted power density, but it is better correlated with the electric field intensity.

We have chosen to refer to the radiation in terms of power density, which can be readily measured objectively, rather than in terms of SAR, which can never be accurately estimated, especially for small insects.

We did not detect any temperature increases, caused by the GSM field, within the glass vials (in the food). (We used an Hg thermometer with 0.05°C accuracy). Even if there were some temperature increase, certainly smaller than 0.1°C, this would not have any observable effect on the insect's oviposition (Srivastava and Singh, 1998). Therefore, the recorded effect cannot be attributed to any possible temperature increases caused by the radiation; in other words, it is considered as a nonthermal one.

Actual GSM signals are never constant. There are always changes in the intensity and frequency of these signals. Electromagnetic fields with changing parameters usually are more bioactive than fields with constant parameters, (Goodman et al., 1995), possibly because it is more difficult for living organisms to get adapted to them. Experiments with constant GSM signals can be performed, but they do not simulate actual conditions. To simulate actual conditions, we used in our experiments a common GSM mobile phone itself.

Usually in biological experiments with RF fields, special constructions are used to ensure constant exposure conditions of different samples simultaneously [e.g., transverse electromagnetic field (TEM) cells, radial transmission lines, etc.] In our experiments, it was not important to have all the flies within a vial under a constant power density or SAR, because this would not simulate actual conditions and because the recorded effect is purely statistical. Certainly, because the characteristics of the exposure system were not constant, a proper statistical analysis was necessary. If the variance within the groups between different experiments were too large, the statistical analysis would give an improperly large probability for the null hypothesis. In all three sets of our experiments, the statistical analysis gave a negligible probability for the null hypothesis.

Although there isn't any established biochemical explanation for the biological effects of electromagnetic fields in general, we think that an explanation of our results can be sought in correlation with other laboratory studies that have showed

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that electromagnetic fields alter the proliferation rate of cells, as well as the rate of DNA, RNA, and protein synthesis (Fitzsimmons et al., 1989, 1992; Goodman and Henderson, 1988, Goodman et al., 1983; Kwee and Raskmark, 1993, 1995, 1998; Luben, 1991; Luben et al., 1982; Rodan et al., 1978; Schimmelpfeng and Dertinger, 1993).

These biochemical processes are strongly affected by changes in cytosolic ion concentrations (especially calcium), and such changes can be induced by RF-microwave fields (Bawin et al., 1975, 1978; Blackman et al., 1980, 1989; Dutta et al., 1984; Lin-Liu and Adey, 1982). It has been shown that RF fields modulated by extremely low frequencies (ELF) decrease cytosolic calcium ion concentration. In some experiments, this effect was at a maximum for power densities between 0.6 and 1 mW/cm^2 (Bawin et al., 1975, 1978). The GSM signals are RF carrier signals, pulsed at ELF and the power density level in our experiments was close to these values ($0.436 \pm 0.060\ mW/cm^2$).

It is known that cell proliferation, DNA, RNA, and protein synthesis are connected with increased cytosolic ion concentrations (especially calcium) (Berridge, 1975a, 1975b; Lijnen and Petrov, 1999; Ozawa et al., 1989; Petrov and Lijnen, 2000; Tran et al., 1998) and with depolarization of the plasma membrane, (Jaffe and Robinson, 1978, Bedlack et al., 1992).

Thus, we can reasonably assume that because RF fields can decrease cytosolic calcium ion concentration, they can also decrease the rate of DNA, RNA, and protein synthesis, and the cell proliferation rate. In the early stages of *Drosophila* oogenesis and spermatogenesis there are repeated cell divisions, accompanied by DNA, RNA, and protein synthesis. In addition, DNA, RNA, and protein synthesis, is continued during the whole processes. Any decreases in cell proliferation rate and in the synthesis rate of the above biomolecules would result in retardation of the whole processes of oogenesis, spermatogenesis, and the synthesis of proteins, necessary for the oviposition (like ''sex peptide''), which in turn will cause a decrease in the insect's reproductive capacity.

The effect of external electromagnetic fields on the cytosolic ion concentrations seems to be connected with interaction between the external field and the cation channels of the plasma membrane, which results in irregular gating of these channels (Liburdy, 1992; Ozawa et al., 1989; Rodan et al., 1978). A biophysical mechanism for this interaction has been proposed by us (Panagopoulos et al., 2000b, 2002). According to this mechanism, ELF fields of the order of a few V/m are able to irregularly gate electrosensitive channels on a cell's plasma membrane and therefore disrupt cell function. In addition, pulsed fields are shown to be more bioactive than continuous ones. Therefore, according to our proposed mechanism, the ELF components of a GSM signal, due to the pulse repetition frequency of 217 Hz, with a mean electric field intensity of the order of 6 V/m, can possibly disrupt cell function and consequently affect the reproductive capacity of a living organism.

In our experiments, we used a well-defined biological system to analyze the effects of GSM mobile phone radiation on insect reproduction. The results of our experiments show that pulsed RF radiation with a carrier frequency of 900 MHz, emitted by GSM mobile phones, with exposure conditions similar to those a mobile phone user is subjected to, is highly bioactive, causing significant alterations in the reproductive capacity of insects. The results are clear, and although the exact

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underlying mechanism is yet unknown, we have nevertheless proposed a realistic explanation, which is in good agreement with other reported experimental data.

Although we cannot simply draw a parallel from our results to possible corresponding effects on humans, we think that our results imply the need for prudent avoidance of exposure to GSM radiation and the cautious use of mobile phones. Because the exposure levels in our experiments are within the current IRPA–ICNIRP exposure limits, these results possibly suggest a reconsideration of the existing exposure criteria toward a direction to include also nonthermal biological effects.

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