Biological Effects of Radiofrequency Radiation
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5.7 Endocrine, Physiological and Biochemical Effects

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5.7.1 Endocrine Effects

The endocrine system in coordination with the nervous system is a major regulatory system in the body. Alterations in the function of the neuroendocrine system often reflect the efforts on the part of the animal to maintain homeostasis when subjected to stressful internal and external stimuli. Detection of changes in the endocrine system is a sensitive means of analyzing the animal’s responses either to direct stimulation of the endocrine organs themselves or to stimulation of the CNS. Animals exposed to a wide variety of stimuli generally respond with a rather specific pattern of physiologic changes, usually referred to as the general adaptation syndrome, and the stimuli that can provoke the syndrome are usually called stressors. An increase in the concentration of corticosteroids in the blood above that which would normally occur at that time of day in the absence of a stimulus is considered by many to be an indicator of an animal’s response to stress. Such an increase results when an internal or external stimulus, either chemical, physical, or emotional, excites neurons of the hypothalamus to release corticotropin-releasing hormone, which drives the pituitary to release adrenocorticotropic hormone (ACTH). This hormone then stimulates the adrenal cortex to secrete corticosteroids. Among the strongest stressful stimuli are surgery, anesthesia, cold, narcosis, burning, high environmental temperature, and rough handling or restraint.

The thyroid gland plays a principal role in regulating basal metabolism, as well as in generating metabolic heat in the tissues. Changes in thyroid activity can result from changes in thyroid-stimulating hormone from the hypothalamic-hypophyseal system and/or increased metabolic activity of the thyroid gland due to heating. Direct interaction with the CNS could also produce changes in thyroid activity. Moderate or gradual heating results in a reduction of thyroid activity. Moderate or marked elevation of body temperature results in an increase in thyroid activity. The effects of RF radiation on the endocrine system are discussed below and summarized in Table 5-19.

Thyroid function of rats following exposure to 2450-MHz (CW) microwaves at 10, 20, and 25 mW/cm² (SARs from 0.25 W/kg per mW/cm² for 4 or 16 h) was studied by Parker (1973). No effects on thyroid gland function were found at these exposures. However, at 15 mW/cm² (SAR estimated at 0.75 W/kg), exposure for a longer period (60 h) was reported to produce a significant decrease in serum-protein-bound iodine, thyroxine, and thyroid/serum iodine ratio. A significant rectal temperature increase (1.7°C) was reported at 25 mW/cm², but not at lower power densities. Magin et al. (1977a,b) irradiated the surgically exposed thyroid gland of anesthetized dogs with 2450-MHz (CW) microwaves using a waveguide applicator at power densities of 72, 162, and 236 mW/cm² (SARs from 58 to 190 W/kg) for 2 h. One thyroid was irradiated while the other was used as a control. Tissue temperatures of 39, 41, and 45°C were maintained in the thyroid at the three power densities. They reported an increased release of thyroxine (T₄) and triiodothyronine (T₃) at all power densities, which showed that the thyroid gland in the dog can be stimulated directly by microwave heating.

Miloš and Michaelson (1972) exposed rats to 2450-MHz microwaves at 1, 10, and 100 mW/cm² (SAR = 0.25 W/kg per mW/cm²) for single exposures of 10, 20, 30, and 60 min and at 1 and 10 mW/cm², 8 h/day, for 8 weeks, and reported no effect on T₃ levels, thyroxine levels, or on the uptake of radioactive iodine. No rectal temperature increase was observed at 10 mW/cm² or less. At 100 mW/cm² there was a constant rise in rectal temperature throughout exposure, up to 42°C at the end of the exposure period. Histopathological examination of the thyroid glands also showed no effect from the exposure.

An increased production of thyroid hormone in rabbits as measured by increased incorporation of ¹³¹I and increased radioactivity per gram of thyroid (verified by autoradiography) was reported by Baranski et al. (1972). The animals were exposed for 3 h/day for 4 months to 10-cm (3-GHz, PW) microwave at an average incident power density of 5 mW/cm² (SAR estimated at 0.25 to 0.75 W/kg). They reported no increase in body temperature or thyroid hormone levels. The pulse parameters were not given, so peak power density cannot be calculated.) Lu et al. (1977) reported serum thyroxine levels in rats exposed to 2450-MHz microwaves at 1, 5, 10, and 20 mW/cm² (0.25, 1.25, 2.5, and 5 W/kg) for 1, 2, 4, or 8 h. Decreased thyroxine levels were observed at 20 mW/cm² following 4- and 8-h exposures. The thyroxine values at shorter exposures and lower power densities were not significantly different from the sham values, except for an increase after 4 h at 1 mW/cm², which appears to be a chance variation, since at both higher and lower power densities and at longer and shorter periods of exposure no effect was detected. There were small but statistically significant rectal temperature increases at 1 mW/cm² after 4 h, at 5 mW/cm² after 1 and 2 h, and at 10 mW/cm² after 2 and 4 h of exposure. The increases were in the range of 0.2 to 0.56°C. The lack of correlation between power density, exposure time, and rectal temperature increase, along with the small recall...
Ps pulses of either 1.42 or 10 GHz, and the isolated chicken heart, were unable to detect changes in heart rate during exposure to 24,000-MHz (PW) radar fields. They did, however, detect effects on the electrocardiogram (ECG), including abnormal P and T waves from 3-min exposures at 74 mW/cm².

Frey and Seifert (1968) showed that 100-µs pulses at a carrier frequency of 1.425 GHz given at asynchronous periods with the ECG (220 ms after the P wave) resulted in tachycardia or heart arrhythmia in the isolated frog heart. The peak power density was 60 mW/cm² (average power density ~ 0.6 mW/cm²). Liu et al. (1976) reported no effect on heart rate with isolated frog hearts or in hearts irradiated in situ in a similar study. The in situ hearts were exposed to 100-µs pulses of either 1.42 or 10 GHz, and the isolated frog hearts were exposed to 100-µs pulses of 1.42 GHz. The pulse was delivered on the rising phase of the R-wave from the ECG, which is somewhat delayed following the P-wave used by Frey and Seifert. The R-wave follows the P-wave by about 200 ms.

Clapman and Cain (1975), however, tried to replicate the study of Frey and Seifert using similar pulse widths (10 µs), peak and average power densities (60 mW/cm² and 0.6 mW/cm²), carrier frequency (1.42 GHz), and method of isolating the frog heart; they reported no change in heart rate. No, no heart rate changes were found when they conducted studies with a different peak power (5.5 W/cm²), frequency (3 GHz), and pulse widths (2 and 150 µs). Clapman and Cain were able to produce an increased heart rate with 20-mA current pulses synchronized 200 ms after the P-wave peak.

The results of microwave exposure on the cardiovascular system (Table 5-22) indicate that whole-body exposure of sufficient intensity to produce heating which would be expected from heating alone. In the isolated heart there appears to be a stimulation of the autonomic nervous system from microwave exposure at levels where very little heating is expected (1 to 2 W/kg). Low levels of synchronized PW microwaves (10 to 32 mW/kg) apparently are ineffective in producing detectable alterations in heart rate.

5.7.5 Biological Effects of Low Frequency Modulation of RF Radiation

Interest in the biological effects of low frequency modulation of RF radiation stems from reports of changes caused by exposure to electric and magnetic fields in the sub-ELF range (0 to 30 Hz). It has been reported that exposure to low-frequency electric fields changes the reaction time in humans (Konig and Ankerimuller 1963, Hamer 1968 Konig 1971) and in monkeys (Gavalas et al. 1970; Gavalas-Medici and Day-Magdalene 1976), and alters circadian activity in certain organisms (Day-Magdaleno 1976). Friedman et al. (1967) observed that magnetic fields modulated at low frequencies also change reaction time in human beings.

Two other studies that provide important background information are reported by Kaczmarek and Adey (1973, 1974). In the first report, they described release of calcium ions and γ-aminobutyric acid (GABA) from the cerebral cortex of cats in response to small changes in the extracellular concentration of calcium. In 1974, they demonstrated release of calcium ions and GABA from the cat cortex in response to low intensity electric currents, pulsed at 200 Hz, applied directly to the cerebral cortex. Thus, extracellular calcium and electric current have similar effects on the release of GABA and calcium ions from brain tissue.

The studies of (1) behavioral changes in animals and human beings induced by low frequency signals and (2) biochemical changes in the brain caused by electric currents led to a study of the influence of electric fields on EEG patterns associated with a conditioned behavioral response in cats (Bawin et al. 1973). To increase the penetration of the signals into the tissue, they chose an RF carrier wave of 147 MHz, which was amplitude modulated at sub-ELF frequencies (e.g., 3 to 14 Hz). Alterations were observed in the rate of performance, accuracy of reinforced patterns, and resistance to extinction in learned behavior of the exposed animals compared to controls, indicating that the fields were acting as reinforcers. In order to determine whether these effects were mediated via peripheral receptors or occurred as a result of changes induced directly on the CNS, experiments were designed to examine the effects of modulated RF carrier waves on brain tissue in vitro.

5.7.5.1 Calcium Ion Efflux In Vitro: A Fundamental Finding

The association of calcium ions with brain tissue was selected as the biochemical marker to examine the influence of modulated RF fields because calcium ion efflux has been shown to be sensitive to electric currents applied directly to brain tissue in vitro, and because calcium ions have a prominent role in many biochemical and biophysical processes (e.g., cellular membrane integrity and function, enzyme cofactor, putative second messenger for the conduction of extracellular signals to the nucleus of the cell, neural tissue excitation and secretion of transmitter
substances at synapses). The first report of tissue was Bawin specific response, which occurred while the 147-MHz field at 1 to 2 mW/cm² (SAR estimated at 0.002 W/kg) caused enhanced efflux of calcium ions, but calcium ions was not due to heating of the samples.

In another report, Bawin et al. (1978) exposed chick brain tissue for 20 min to 450-MHz fields, amplitude modulated at 16 Hz, at 0.75 mW/cm² (SAR estimated at 0.0035 W/kg) under a variety of chemical conditions. The results demonstrated that (a) the enhanced efflux of calcium ions is not highly sensitive to the external calcium concentration, (b) bicarbonate appears to be important for enhanced efflux, (c) lowering the pH from 7.6 to 6.8 in the presence of bicarbonate may enhance the magnitude of efflux, and (d) lanthanum abolishes a reversal to field-induced retardation of calcium ion efflux.

Corroboration of the frequency-specific response described by Bawin and co-workers was provided by Blackman et al. (1979), who showed that 16-Hz amplitude modulation of 147-MHz carrier waves caused enhanced efflux in chick brain tissue in vivo, whereas modulation frequencies of 3, 9, and 30 Hz did not. Although the data had large variances, an unusual intensity response was described, i.e., only 0.83 mW/cm² (SAR estimated at 0.0014 W/kg) produced a statistically significant efflux enhancement (intensity values are corrected based on discussion in Blackman et al. 1980a); power densities (0.11, 0.55, 1.11 and 1.38 mW/cm²) below and above the effective value did not cause efflux. In a later report, Blackman et al. (1980a) used a revised statistical model and experimental procedure to reduce the influence of the large sample variance. An intensity response identical to their earlier result was found. However, when the distance between samples was halved, the range of intensities that produced enhanced efflux increased to include 0.55, 0.83, 1.11 and 1.38 mW/cm², whereas lower and higher values of 0.11 and 1.66 mW/cm² were ineffective. In addition, an intensity region from 0.55 to 1.11 mW/cm² caused enhanced efflux when 9 Hz was used as the modulation frequency. These data, obtained with more rigorous experimental protocol, provided additional support for the results of Bawin et al. (1979) and Blackman et al. (1979); however, the explanation for the dependence on sample spacing awaited further developments.

Jones et al. (1981) examined the dependence on sample spacing by calculation of the electrical coupling between the samples; for simplicity the samples were modeled as spheres. They found that increased electrical coupling between the more closely packed spheres produced a broader range of internal field strengths within each sphere. Thus, if a given internal field strength were necessary to cause enhanced efflux, the chance would be greater for that internal field strength to occur in closely coupled samples exposed to a specific range of incident intensities. Jones et al. (1981) found this result to be consistent with the experimental findings of Blackman et al. (1980a). Thus a potential artifact was shown to be a logical result of the experimental procedures.

The intensity response observed by Blackman et al. (1979) with modulated 147-MHz carrier waves was confirmed by Sheppard et al. (1979) with 450-MHz carrier waves, modulated at 16 Hz, calcium-ion efflux was enhanced at 0.1 and 1.0 mW/cm², but not at 0.05, 2.0, or 5.0 mW/cm². The estimated SAR at 0.1 mW/cm² is 0.0047 W/kg. The results of these two reports show that the intensities producing calcium-ion efflux from chick brain tissue in vitro are within the range of 0.1 to 1.38 mW/cm² for modulated 147-MHz and 450-MHz carrier waves.

The apparent carrier-frequency independence of effective intensities was tested with a 50-MHz carrier wave, amplitude modulated at 16 Hz. Enhanced efflux of calcium ions occurred within two intensity regions (between 1.44 and 1.67, and at 3.64 mW/cm²; SARs were 0.0013 and 0.0035 W/kg, respectively) separated by intensities of no effect, including 0.72 mW/cm² (Blackman et al. 1980b). These effective intensity values were different from the corresponding values at 147-MHz radiation; thereby indicating a dependence on carrier frequency. In addition this result revealed the existence of more than one range of effective intensities.

The apparent discrepancy in effective power densities at the three different carrier frequencies (50, 147, and 450 MHz) has been resolved by the finding that efflux is dependent on the electric field strength within the tissue and not on incident intensity (Jones and Blackman 1980). The calculation to transform the incident intensity to internal field strength was based on an empirical model described by Jones et al. (1981). With the data available at 50 and 147 MHz, the model was used to predict intensities that would produce both alterations and no alterations in calcium-ion efflux; some predictions were tested and found to be valid (Blackman et al. 1981). These reports described two intensity ranges that appear effective for enhanced efflux at both 50 and 147 MHz, identified the internal electric field strength rather than incident intensity as the important exposure parameter, and showed the...
The effect of modulated RF fields on the EEG was investigated by Takashima et al. (1978). Rabbits were exposed 2 h daily for 6 weeks to 1.2 MHz, amplitude modulated at 15 Hz, or 5 MHz, amplitude modulated at 14 Hz. Following exposure, the EEG was recorded with scalp electrodes and, when compared to the pretreatment EEG pattern, was found to be altered with enhanced low-frequency components and decreased high-frequency components. The EEG pattern returned to the pretreatment pattern after
several weeks postexposure. Although the electric field intensity was given as 500 V/m, with an RF factor as large as 2, the important aspect of the results was that unmodulated fields of similar intensity had no effect on the EEG pattern. The absence of metallic electrodes in the animal during exposure avoids the major criticism of earlier studies that reported field-induced changes in EEG patterns (Gavalias et al. 1970; Bawin et al. 1973).

Sagan and Medici (1979) studied the influence of 450-MHz fields, sinusoidally amplitude modulated at either 3 or 16 Hz, on locomotor activity in young chickens. The experiments were performed in a plastic, modified Skinner box with light beams to monitor activity; the complete apparatus was placed in an anechoic chamber and exposed in the far field. The authors found no statistically significant change in performance during or immediately after a 23-min exposure at 1 or 5 mW/cm² (SAR estimated at 0.2 and 1.0 W/kg). They concluded that the lack of a field-induced response could be due to the use of modulation frequencies not present in the chicken's EEG during performance on the particular (fixed-time schedule) task. An alternative possibility, based on the multiple-intensity ranges observed for field-induced calcium-ion efflux, is that the two intensities used in this study may have been outside the effective ranges.

In summary, four groups (Adey et al.; Blackman et al.; Dutta et al.; Takashima et al.) have shown that RF fields, sinusoidally modulated at sub-ELF frequencies, especially 16 Hz, cause CNS changes in different in vitro preparations and in the live animal. Many of these studies have been analyzed in reviews (Adey 1981; Blackman et al. 1981; Greengard et al. 1982; Myers and Ross 1981). It is generally agreed that both the mechanism of interaction and the physiological consequences of these changes are yet to be established.

5.7.5.3 Non-CNS Studies

The effects of exposure of pancreatic tissue and T-lymphocytes to RF fields, sinusoidally amplitude modulated at low frequencies, have been examined. An increase of calcium-ion efflux from rat pancreatic tissue exposed at 2 mW/cm² for 1 to 2.5 h at 147 MHz, modulated at 16 Hz (estimated SAR < 0.075 W/kg), has been reported by Albert et al. (1980). However, the efflux was not accompanied by a change in protein secretion, which is normally associated with calcium mobilization in the pancreas. The authors attributed the lack of protein secretion to a limitation imposed by the exposure conditions, i.e., a relatively small volume of medium was available to the tissue for normal metabolic activity. In another in vitro assay, the cytotoxic activity of mouse T-lymphocytes was suppressed by a 2-h exposure (1.5 mW/cm²) to 450-MHz fields, modulated at frequencies between 16 and 100 Hz (Lyle et al. 1983). Peak suppression occurred at 60-Hz modulation, with smaller effects at 16, 40, 80, and 100 Hz. The exposed cells recovered full cytotoxic activity 12.5 h after the termination of exposure. This result demonstrated an inhibitory but reversible effect on a cell-mediated immune response by modulation frequencies.

5.7.5.4 Sinusoidal ELF and Sub-ELF Signals

Most of the studies reviewed above demonstrate an absolute requirement for low-frequency sinusoidal modulation of the RF carrier wave in order for the signal to be effective biologically. For completeness, several reports are mentioned that describe biological effects of exposure to low frequencies in the absence of an RF carrier wave. Bawin and Adey (1979, 1977) exposed chicks and cat cerebral tissue for 20 min to 1, 6, 16, 32 or 75 Hz at electric field gradients of 5, 10, 56, and 100 V/m in air. Only two frequencies, 6 and 16 Hz, caused a reduction in calcium-ion efflux at 10 and 56 V/m for the chick tissue, and at 56 V/m for the cat tissue. Because all other combinations produced no field-induced responses, the authors described "amplitude and frequency windows" for calcium-ion efflux. Electric field gradients within the tissue were estimated to be 10¹⁷ V/m. The field-induced reduction in efflux is in contrast to the enhancement caused by modulated RF carrier waves. Nevertheless, the frequency-dependence observed in the two studies was similar, which suggests an interaction with a common substrate at the site of interaction.

Blackman et al. (1982) used chick brain to study the influence of 16-Hz signals at 15 intensities between 1 and 70 V/m in the efflux of calcium ions. Two intensity regions that included 5, 6, and 7.5 V/m and 35, 40, 45, and 50 V/m caused enhanced efflux. No field-induced effects were seen below 1, 2, and 2.5 V/m, between 10, 20, and 30 V/m, or above 60 and 70 V/m) the two effective intensity regions. Moreover, 1- and 30-Hz signals at 40 V/m caused no change in efflux. This finding is consonant with the reports of multiple-intensity regions of enhanced efflux caused by modulated RF radiation (Blackman 1980b, 1981). In addition to the intensity response, the frequency dependence corroborated reports by Bawin and Adey (1976) for low-frequency signals, and by Bawin et al. (1975) and Blackman et al. (1979) for modulated RF fields.

In these two low-frequency studies, the cause of the slight difference in effective intensities is unknown. The major disagreement in the results of Bawin and Adey (1976) and Blackman et al. (1982) is the direction of the change in efflux; the latter authors state that the "cause may be found in the slightly different preparations and procedures used in the two laboratories."
Several research groups have reported biological changes induced by low-frequency, sinusoidally oscillating magnetic fields. The myxomycete Physarum polycephalum has a longer mitotic cycle and reduced respiration rate after chronic exposure to 2.0-gauss magnetic fields at 75 Hz (Goodman et al. 1979). Human fibroblasts in culture exposed to sinusoidally varying magnetic fields similar exposure during development of the egg produced less viable eggs and pupae in the exposed samples than in controls (Ramirez et al. 1983). These results suggest that low-frequency, sinusoidally varying fields may alter fundamental biological processes.

Low-frequency, pulsed magnetic fields have also been reported to produce alterations in diverse biological systems. These systems include the developing chick embryo (Dewing et al. 1982; Ledoga et al. 1983), Drosophila egg laying and mortality (Ramirez et al. 1983), the de-differentiating amphibian red blood cell (Chiabrera et al. 1979), transcription in the Dictyostelium organism (Goodman et al. 1983), nerve cells in culture (Dixey and Rein 1982), and mouse bone cells in culture (Luben et al. 1982). Many of these studies used an intricate pulsed waveform, which has been used in therapeutic devices for bone nonunions. All the studies used pulse repetition rates below 500 Hz, with most below 100 Hz. Recently, Liboff et al. (1984) questioned the need for the particular wave shapes because it appears that the essential element is the low-frequency field.

5.7.5.5 Summary

Many reports of effects of RF fields that are amplitude modulated at very low frequencies have not been independently corroborated. The major exception is calcium-ion efflux from chick brain tissue in vitro at intensity levels far below those that cause heating. This exception, combined with the results of studies of brain biochemistry and EEGs in animals and with synaptosomes the human neurtalplastoma cells in culture, provides evidence that CNS tissue from several species, including human beings, is affected by low-intensity RF fields sinusoidally amplitude modulated at specific low frequencies (Table 5-23). The physiological significance of these field-induced effects is not established.

5.7.6 Unresolved Issues

In addition to the CNS-related changes, amplitude-modulated RF fields have been reported to alter an immune response and a pancreatic tissue function. These reports with diverse biological systems are without apparent connection to each other except for the physical agent causing the change. The biological effects of frequency-modulated RF radiation, e.g., FM radio signals, are not known. The reports cited above of Merritt and co-workers indicate that pulsed square-wave modulation may not cause calcium-ion efflux, whereas data from the Bawin et al. and Blackman et al. studies show that sine wave modulation is effective.

No report has yet described a mechanism of action in sufficient detail to identify the conditions necessary and sufficient to explain unequivocally calcium-ion efflux in the brain or the other biochemical changes caused by modulated RF fields. The response to specific frequencies and intensities is unusual and at present unexplained. This response to amplitude-modulated RF radiation or to sub-ELF signals alone may be a true field effect at a very low SAR and at biologically relevant frequencies, i.e., in the range of frequencies normally present in the EEG. The frequency-specific nature of the responses provides evidence against heat as the underlying cause. The unusual, multiphase-range response challenges standard dose-response analyses, and by its very nature, may prevent the invocation of threshold levels.

Other areas of unresolved issues include comparisons of CW vs. PW microwaves under identical exposure conditions. Such studies would help determine if the differences seen by Wangemann and Cleary (1976) were due to different exposure conditions or to the irradiation parameters (CW or PW). There is also a paucity of information on the effects of RF radiation at different frequencies, particularly at frequencies of environmental importance. Studies at different frequencies would help to determine the reasons for differences in effects at similar SARs. Such studies might help explain why Wangemann and Cleary (1976) reported no change in serum chemistry values in rats at 0.8 W/kg (2450 MHz), and why Lovely et al. (1977) reported no change in serum chemistry values in rats at 1 W/kg (914 MHz).

There are also data such as those reported by Boggs et al. (1972) where the results from microwave heating to a predesigned temperature are different from those resulting from the same temperature produced by other means of heating. Perhaps there are differences in the uniformity of heating or in the rate of heating which would account for these differences. In addition, a study by Defics et al. (1979) reported elevated serum triglyceride and p-lipoprotein levels in mice exposed to 2450 MHz at 1.5, 3.3, or 4 mW/cm², but not at 1 mW/cm². Because the exposures were conducted in a multimodal cavity, SAR values were not reported and cannot be predicted. If this study is repeated, particular attention should be given to dosimetry. An alternative is to
make or report dosimetric measurements in the exposure system used.

The reported effects on thyroid function at 3.75 W/kg for 60 h contrasted with no effect at 6.25 W/kg for 16 h (Parker 1973) suggests that the total amount of energy absorbed may also be an important consideration. Additional studies could define further the relative importance of dose rate compared with total dose.

Table 5-23. Summary of Studies Concerning Biological Effects of Low Frequency Modulation of RF-Radiation

<table>
<thead>
<tr>
<th>Effects</th>
<th>RF Modulation</th>
<th>Species (MHz)</th>
<th>Intensity (mW/cm²)</th>
<th>Time (min)</th>
<th>SAR (W/kg)</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Altered calcium-ion efflux in brain tissue in vitro</td>
<td></td>
<td>Chicken 147</td>
<td>6-20</td>
<td>1.2</td>
<td>20</td>
<td>0.002</td>
</tr>
<tr>
<td>Influence of pH and lanthanum</td>
<td></td>
<td>Chicken 450</td>
<td>6-16</td>
<td>0.75</td>
<td>20</td>
<td>0.003</td>
</tr>
<tr>
<td>Modulation intensity</td>
<td></td>
<td>Chicken 147</td>
<td>16</td>
<td>0.87</td>
<td>20</td>
<td>0.004</td>
</tr>
<tr>
<td>Intensity specificity and sample spacing</td>
<td></td>
<td>Chicken 147</td>
<td>9-16</td>
<td>0.83</td>
<td>20</td>
<td>0.004</td>
</tr>
<tr>
<td>Theoretical analysis of sample spacing</td>
<td></td>
<td>Chicken 147</td>
<td>16</td>
<td>0.83</td>
<td>20</td>
<td>0.004</td>
</tr>
<tr>
<td>Sensitivity</td>
<td></td>
<td>Chicken 450</td>
<td>15</td>
<td>0.1</td>
<td>20</td>
<td>0.005</td>
</tr>
<tr>
<td>Two intensity ranges</td>
<td></td>
<td>Chicken 50</td>
<td>16</td>
<td>1.5</td>
<td>20</td>
<td>0.003</td>
</tr>
<tr>
<td>Theoretical analysis of RF dependence</td>
<td></td>
<td>Chicken 50</td>
<td>16</td>
<td>—</td>
<td>20</td>
<td>0.001</td>
</tr>
<tr>
<td>Test of predictions of theoretical analyses</td>
<td></td>
<td>Chicken 147</td>
<td>16</td>
<td>0.37</td>
<td>20</td>
<td>0.006</td>
</tr>
<tr>
<td>No effect for pulse modulation</td>
<td></td>
<td>Rat 1000</td>
<td>16, 32</td>
<td>0.5-15</td>
<td>20</td>
<td>0.15-4.35</td>
</tr>
<tr>
<td>No effect for pulse modulation</td>
<td></td>
<td>Rat 1000</td>
<td>16</td>
<td>1.10</td>
<td>20</td>
<td>0.29-2.9</td>
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<tr>
<td>Change in calcium efflux kinetics in synaptosomes</td>
<td></td>
<td>Chicken 450</td>
<td>16</td>
<td>0.83</td>
<td>20</td>
<td>0.003</td>
</tr>
<tr>
<td>Frequency and intensity specificity in cultured neuroblastoma cells</td>
<td></td>
<td>Chicken 450</td>
<td>3</td>
<td>16, 10</td>
<td>23</td>
<td>0.2</td>
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<tr>
<td>Frequency and intensity specificity in cultured neuroblastoma cells</td>
<td></td>
<td>Mouse 450</td>
<td>16-100</td>
<td>1.5</td>
<td>20</td>
<td>0.12</td>
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<td>Altered calcium-ion efflux in parotidic tissue in vitro</td>
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<td>Rat 147</td>
<td>16</td>
<td>2</td>
<td>60-150</td>
<td>&lt;0.075</td>
</tr>
</tbody>
</table>

*Est SAR
**Square wave
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APPENDIX A
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