LOW POWER RADIO-FREQUENCY AND MICROWAVE EFFECTS ON HUMAN ELECTROENCEPHALOGRAM AND BEHAVIOR

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• *In a pilot study of ten human subjects, temporary changes in brain waves and behavior were seen on exposure to power densities lower than* 10^{-12} *W/cm*^{2}*, which is substantially below typical urban levels. Frequencies included .1 to 960 MHz continuous and 8.5 to 9.6 GHz pulse-modulated waves. Since the relaxation frequency of protein-bound water is considered to fall between 100 and 1,000 MHz, absorptions and quantum effects may be the mechanistic basis for the electroencephalogram changes observed in most of the subjects produced by* 10^{-15} *W/cm*^{2} *cw radio-frequency energy of between 130 and 960 MHz. Constructive and destructive interference patterns from standing waves within the skull possibly interact with the bioelectric generators in the brain, since electroencephalogram wave amplitudes and frequencies increased or decreased respectively at different radio wavelengths.*

INTRODUCTION

Radio-wave sickness is a term Eastern European and Soviet researchers have applied to a group of clinical syndromes observed in persons occupationally exposed to electromagnetic fields.[1,2] Those researchers believe that low-intensity electromagnetic waves produce adverse effects upon the autonomic and central nervous systems of animals and man. Reported symptoms in humans, regarded in the U.S.S.R. and Eastern Europe as typical microwave-induced functional disturbances of the central nervous system, include headache, increased fatigability, increased irritability, dizziness, loss of appetite, sleepiness, sweating, difficulties in concentration or memory, depression, emotional instability, dermographism, thyroid gland enlargement, and tremor of extended fingers. More serious but less frequently observed is the microwave-associated diencephalic syndrome that includes hallucinations, insomnia, syncope, and inhibition of visceral functions.[1]

Some American researchers believe that they also have detected the above effects, which can mimic symptoms of many diseases produced by other causes.[3] Zaret[4] has described cataracts whose development pattern is characteristic to microwave exposure and whose earliest stage consists of thickening of the posterior lens capsule. This could be expected, since in 1894 Sir Oliver Lodge[5] demonstrated that high-frequency (hf) radio waves could be focused and magnified by ordinary glass lenses and the ocular lens has that same capability. Frey[6] discovered that human auditory perception occurs when low power pulse-modulated radio-frequency (rf) illuminates the head. Frey et al.[7] showed that arrhythmias associated with rf illumination could be induced in isolated frog hearts. Avoidance behavior was observed in rats irradiated by low level pulsed and continuous-wave (cw) radio frequencies.[8] Bawin et al.[9] have shown that a sharp increase in calcium efflux occurs in chick brain tissues exposed to a low power, modulated rf field of 147 MHz. Such findings clearly indicate the sensitivity of nervous system function to low intensity rf irradiation.

It has been shown that the main link between nervous and endocrine systems is the hypothalamic-pituitary axis; and it is known that all combinations of variation of heart rate, arterial pressure, heart diameter, myocardial contractility, and blood flow can be elicited by stimulating various portions of the hypothalamus.[10] From the hypothalamic centers through the hypophysis to peripheral endocrine glands, a stepwise amplification of hormonal stimuli has been observed. Thus the whole endocrine system displays characteristics of a biological amplifier with the hypothalamus as the most sensitive and crucial region.[11] While the hypothalamus is not exclusively concerned with temperature-regulating function, interference with this region can drastically affect temperature reguation.[12] Low power radio waves have been seen to produce changes in the regulatory activities of the hypothalamus,[13] which is part of the midbrain and occupies a central position within the limbic system.[14] Kievit and Kuypers[15] demonstrated limbic basal forebrain and hypothalamic direct afferent fiber connections to the frontal and parietal cortex and noted that behavioral phenomena can be elicited within this system. The hypothalamus has been linked to emotional behavior, many states of which can be produced by electrical means.[14]

The present study is an attempt to identify effects on the human nervous system of low power rf energy.

METHODS AND PROCEDURE

The study was conducted on five men and five women, all volunteers. These participants in a group of eight experiments completed from July 1975 through June 1976 were of necessity highly preselected. They ranged in age from 18 to 48 years. Three subjects had been occupationally exposed to very high frequency (vhf) and microwave radiation; the other seven had not. All were in apparent good health. Only one man and two women did not display prominent alpha waves with their eyes closed and no signal sources energized. Background and occupations of the volunteers varied. They included two professional health physicists, a radio chemist, a hospital intensive-care equipment expert, an electronics engineer, a computer programmer, a housewife, two secretaries, and a high-school graduate. In addition to the volunteers, four individuals were exposed to the rf test conditions. One electronics engineer calibrated the frequency and power scales of the test generators, another electronics engineer acted as experimenter, and two individuals in adjacent areas were performing work not related to the experiments although aware of their nature. These four are mentioned because, as discussed below, they manifested biological changes.

The rf ranges covered from .1 to 960 MHz and X-band. Power levels were varied from 10^{-16} to 10^{-13} W/cm^2. Women were tested within the 250 to 960 MHz range with cw only; one man was tested throughout the entire range used; two men were tested with pulse modulation in the X-band range (8.5-9.6 GHz; pulse mode 2 μsec on/6 μsec off). Subjects tested in the X-band were either standing or sitting with eyes closed 1 meter (m) from the open waveguide output oriented perpendicular to the sternum at the level of the 5th intercostal space. These tests were the only ones in which modulation was applied. All other tests were conducted with the signal sources used in cw mode only.

In the low-band tests, subjects were seated (usually with eyes closed) and oriented such that they could not see equipment or operator. During data gathering they did not know to what frequencies the sources were tuned nor did they know when the signal source was off or on. The antenna was a 1 m wire rod monopole supported by a wooden yardstick. It was placed parallel to and 1 m from the upper torso and head.

Each signal source was slowly tuned through its range during each experiment. Changes in the electroencephalogram (EEG) traces of a test subject that occurred at a given signal source dial setting were photographed from the cathode ray tube; and/or note was taken of the frequency that produced the changes. Previous to irradiation, the normal EEG tracings of the subjects had been noted or photographed. Experimental time for each volunteer was typically 50 min. Tests were done at different times of day at various locations in and out of a Faraday (shielded) room in Building 58 of Tektronix Industrial Park, Beaverton, Oregon. The room was approximately 6 m square with a floor-to-ceiling height of 2.5 m. Shielding consisted of two welded-seam sheet iron walls 10.2 cm apart. All power and door entry were through the center of the west wall. Radio frequencies between 1 and 300 MHz were attenuated to 80 decibels (db) below external ambient levels. The 60 Hz power line frequency was attenuated at least to 30 db. Spectrum analyzer measurements in the room showed that frequencies from .1 to 960 MHz were attenuated to —110 decibels per milliwatt (dbm).

The following antenna presentations were tried in the cw experiments: left side, right side, left rear, right rear. Because EEG effects were negligible with the latter three presentations, all data presented here were gathered with the left side presentation. Lead configurations used were: (A) plus input—left frontal parietal, minus input—left occipital, reference—left mastoid; (B) plus input—right occipital, minus input—right frontal parietal, reference—right mastoid; (C) plus input—right occipital, minus input—right frontal parietal, reference—left mastoid.

Signal sources included Hewlett-Packard 8640, General Radio 1209-B unit oscillator, and TS-35/AP, U. S. Navy surplus. Accuracy and power output levels, at a distance of one m from the generators, were measured with two Tektronix spectrum analyzers. The antenna power output levels from the two low-range generators were measured with a 7L-13 analyzer at no greater than —90 dbm (10^{-16} W/cm^2). The open waveguide power output level of the pulse-modulated X-band source was measured with a 491 analyzer at no greater than —60 dbm (10^{-13} W/cm^2). Allowing for unknowns such as reflections, whole body absorption, and possible point source concentrations, and disregarding near field effects at low-band frequencies, the average power density at the surface of a given volunteer's body during cw experiments was estimated to be on the order of 10^{-15} W/cm^2 (.000067 V per m). During the X-band experiments the estimated power level was about 10^{-12} W/cm^2 (.00195 V per m).

The dial accuracy of the two lower frequency-band generators was within 5%. The X-band generator showed some erraticism; frequency-range accuracy and pulse-wave shapes were inconsistent. The observed biological results using this generator are included in this report although the frequencies that produced them were only close approximations.

Standard multichannel EEG equipment was not used because the rf signal sources in the test environment would have produced excessive instrument noise, artifact, and interaction. The EEG instrumentation actually used allowed sequential recording of a single trace from an electrode pair instead of the usual simultaneous tracings from cranial areas. In tests 1 and 2 a Tektronix 412 physiological monitor with floating power supply and isolated input circuitry was coupled to a Tektronix 7000 series mainframe with two vertical amplifiers and time base. For the other tests a Tektronix 412 input amplifier module was modified to match a Tektronix 5103-N mainframe and time base. A dual programmable operational amplifier was fabricated for the input stage; a stairstep generator was also built and installed, as was a double shielding cable configuration to further reduce rf and ac interference. Trace speeds from 1 sec to 1 μsec per division were available. Selectable bandwidths of .3 to 100 Hz, .4 to 100 Hz, and .4 to 2 kHz were incorporated into the unit. Calibrated sensitivities of 50 μV to 5 V per division were available. The common mode rejection ratio at 60 Hz was improved to greater than —126 db. The differential input resistance was increased from 10 to 115 MΩ. One, four, or eight traces could be displayed on the 10 × 12.5 cm cathode ray tube. During stepped multiple-trace recording, the trace began at the upper left and proceeded to the right, stepping down to the next division on the left sequentially until it arrived at the bottom right and started over again. Re-set selection allowed bottom right end of trace to go off screen while photographing data. Final standardized sensitivity setting was 100 μV per each 12.5 mm (1 division vertical) and trace speed was 25 mm/sec (2 divisions horizontal). Figure 1 is a baseline noise calibration trace at the above-noted sensitivity and speed showing typical performance in a varying rf field of 5 V/m with electrode leads resistively coupled. A Tektronix Polaroid instrument camera was used to record results when possible during tests.

A unipolar electrode configuration with one reference and two active leads, each 35 cm in length from cable shield, was used to minimize interference and artifacts. Pushbutton switchable selectivity with respect to the reference electrode allowed sampling from three different cranial areas without changing electrode placement. Plastic-covered skin surface type electrodes 18 mm in diameter, with 8 mm diameter silver-silver chloride contact areas, were applied with standard electrode paste and secured to the subject's head with Dermicel cloth tape and wide elastic headband.

Typical resistivity between any two of the three electrodes of about 20 kΩ was measured with a laboratory vacuum tube voltmeter. Resistivity between the reference electrode and the two active electrodes paralleled was about 13 kΩ. Typical operable dc offset potential between any two of the three electrodes was about 35 mV. There was no degradation of signals with up to 100 mV dc offset. Artifacts such as electrode and instrument interactions were identified by running noise calibrations on the EEG baseline. At the same spatial distance used in testing, three 1 kΩ resistors were connected in series with the leads. Each generator was then turned on and its frequency range tuned through. Some radio frequencies produced a one-division momentary downward shift on the baseline, but none of these frequencies produced any brain wave alterations in the volunteer subjects.

RESULTS

Certain of the volunteers' EEG traces displayed desynchronized alpha waves of 15 to 25% higher than normal amplitude and slow waves appeared when a radio signal source was on. Conversely, diminution and desynchronization of alpha wave amplitude, on the order of 20 to 50%, occurred at other rf irradiations and slow waves of increased amplitude also appeared. These two anomalous patterns were found in both men and women volunteers. Mental attitudes changed noticeably during the tests. Four of the male volunteers, the test engineer, and another technician experienced short term memory impairment[16] followed by concentration inhibition and by irritability. Three females expressed apprehension and mild irritation during the course of experimentation. Behavior of subjects, observers, test engineer, and experimenters appeared to change during the experiments.

Near midnight, local time, during an X-band pulse-modulated test with a power level of 10^{-12} W/cm^2 at the subject's sternum, the three males present (subject, technician, and author) noticed severe frontal headache. The (C) EEG lead configuration was used. The author checked his electrocardiogram (ECG) after the test and noted that it had deviated from normal and displayed a previously absent ventricular pre-excitation pattern.[17] The three males felt mentally and physically sluggish the following day to the extent that they could do no work. Forty-eight hours after the X-band test the author's ventricular conduction pattern reverted to

FIGURE 1. Baseline noise figure in 5 V varying rf field.

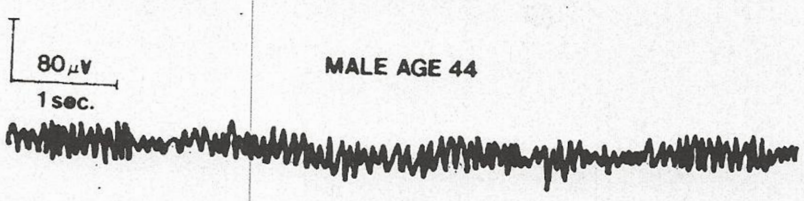

FIGURE 2. Male subject (age 44), eyes open in Faraday room at 11:30 P.M. local time and no irradiation. Trace shows 70 μV, 12 Hz alpha waves.

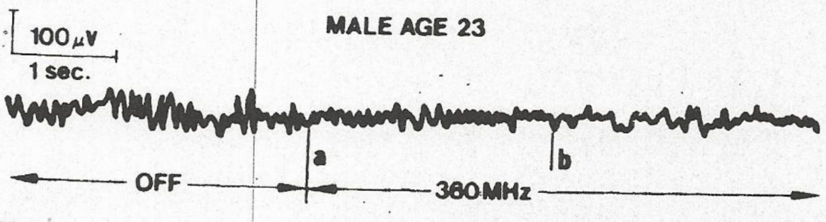

FIGURE 3. Male subject (age 23), eyes closed in unshielded room at noon local time. Trace from left to point (a) shows 10 Hz alpha waves of 65 μV amplitude with no irradiation. 380 MHz irradiation of 10^{-15} W/cm^2 power density at point (a) shows the alpha waves desynchronized to 14 Hz beta-like waves and the amplitude lowered to 35 μV. At point (b) slow waves of 2 to 6 Hz appeared.

normal limits. A follow-up X-band test in early afternoon did not show the same effects. The EEG displayed only slight changes in component amplitudes and no frontal headache or ECG pattern deviation occurred.

The two and only tests done in the shielded room were conducted near midnight, local time, with a male volunteer. The cw frequency ranges covered .1 to 525 MHz and signal source power level at 1 m distance from the left side of the 44-year-old subject was 10^{-15} W/cm^2 when on. The (A) EEG lead configuration was used in the first test, the (C) EEG lead configuration in the second. Two trace speeds of 125 mm/sec and 250 mm/sec were used with sensitivity settings of 80, 100, and 160 μV per vertical division. The subject was tested with and without radiation and with eyes open and closed. Three significant observations were made. The subject's brain waves showed a 12-Hz alpha component of 70 μV amplitude with eyes open and no signal source on (Fig. 2). When the Faraday room door was opened, allowing stray environmental rf radiation to enter, no such component was observable. (Neither did subject's brain waves show this component outside a Faraday enclosure at other locations.) 130 and 260 MHz produced small EEG variations when sampled from the left hemisphere; 200 MHz produced a larger effect on this hemisphere; and 380 MHz produced large variations when sampled from the right hemisphere. 380 MHz was found to produce similar EEG alterations on two other males' right hemispheres outside the Faraday enclosure. Figure 3 is representative. This 23-year-old volunteer's normal alpha frequency of 10 Hz (eyes closed) and 65 μV amplitude was decreased to 35 μV. The alpha component was increased to 14 Hz beta-like waves, and slow waves of 2 to 6 Hz appeared. The experiment was done around noon with 10^{-15} W/cm^2 cw stimulation. Trace speed was 25 mm/sec with sensitivity of 100 μV per 12.5 mm division and bandwidth of .4 to 100 Hz.

The 200 MHz irradiation in the shielded room tests produced two opposite conditions in left hemisphere brain-wave variations. The 70μV amplitude of the 12 Hz alpha component of the male volunteer, with eyes open, diminished with irradiation to 30 μV, then 60 μV, 3 to 4 Hz waves appeared. But with eyes closed, an 80 μV amplitude of the 12 Hz alpha component increased with irradiation to 100 μV and the frequency slowed to 10 Hz. The 130 and 260 MHz irradiations decreased

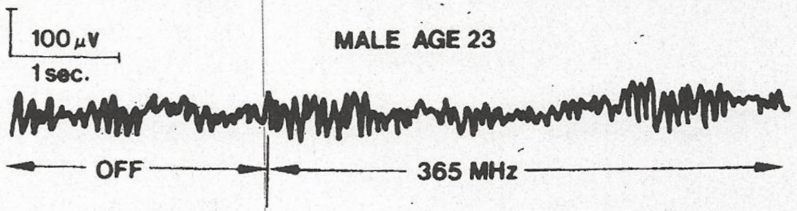

FIGURE 4. Same subject, time of day, and experimental conditions as Fig. 3. 365 MHz irradiation increased the 10 Hz alpha wave frequency to 11.5 Hz; the amplitude was increased from 65 μV to 80 μV.

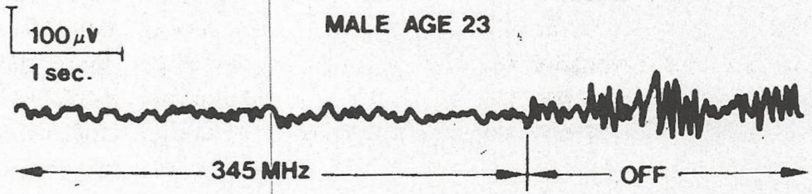

FIGURE 5. Same subject, time of day and experimental conditions as Fig. 3. 345 MHz irradiation waves produced desynchronized alpha waves of 12 Hz and slow waves of 30 μV amplitude. When irradiation was turned off, alpha amplitude increased to 100 μV, then recovered to normal amplitude of 65 μV and 10 Hz frequency. Slow waves disappeared.

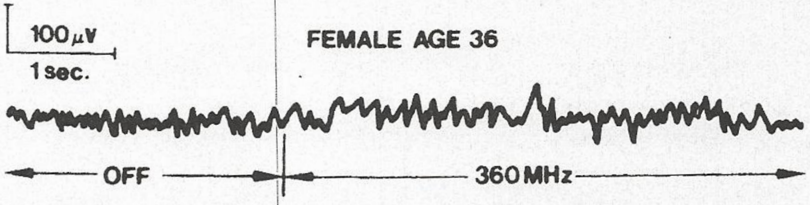

FIGURE 6. Female volunteer (age 36), same time of day and experimental conditions as Fig. 3. Normal alpha waves of 50 μV amplitude and 10 Hz frequency are shown at left of trace. 360 MHz irradiation desynchronized the waves and increased the amplitude to about 80 μV, and 2 to 6 Hz slow waves appeared.

the amplitude of the left hemisphere 12 Hz alpha component from 70 μV, with eyes open, to 60 μV, and the component frequency increased to 16 Hz.

Other cw frequencies at a power density of 10^{-15} W/cm² that produced prominent EEG changes in males' right hemispheres were found at 335, 340, 345, and 780 MHz. Female volunteers' right hemispheres showed EEG alterations at 350, 360, 420, 820, and 960 MHz. X-band pulse-modulation tests on two male volunteers, at a power density of 10^{-12} W/cm², showed EEG changes around 9.1 and 9.15 GHz. Brain-wave alterations occurred almost immediately upon tuning a generator to a frequency that produced them and then almost immediately reverted to their

TABLE I. Radio Frequencies (rf) and Correlative EEG Changes. [Continuous wave (cw) data: 10^{-16} W/cm² 1 m antenna presented 1 m from left side of subject. Pulse-modulation data: 10^{-12} W/cm² open waveguide output 1 m from subject and directed at sternum.]

rf (MHz)	Number of subjects affected	Sex, age	Test conditions [a]	Local time	Effect correlation [b]
Radio frequencies that produced increased amplitude of EEG alpha component, increased slow wave index, and desynchronizations:					
200 cw	1	M 44	LH,FR,EC(A)	midnight	.8
350 cw	1	F 35	RH,UR,EC(B)	evening	.3
360 cw	1	F 36	RH,UR,EC(C)	midday	1.0
365 cw	1	M 23	RH,UR,EC(C)	midday	.8
9,100 pulse	1	M 34	RH,UR,EC(C)	midnight	.25
9,150 pulse	1	M 34	RH,UR,EC(C)	midnight	1.0
Radio frequencies that produced decreased amplitude of EEG alpha component, increased slow wave index, and desynchronizations:					
130 cw	1	M 44	LH,FR,EO(A)	midnight	.25
200 cw	1	M 44	LH,FR,EO(A)	midnight	1.0
260 cw	1	M 44	LH,FR,EO(A)	midnight	.25
335 cw	1	M 44	RH,UR,EC(C)	midmorning	.25
340 cw	1	M 48	RH,UR,EC(B)	evening	.4
345 cw	1	M 23	RH,UR,EC(C)	midday	1.0
380 cw	3	M 44	RH,FR,EC(C)	midnight	1.0
		M 36	RH,UR,EC(B)	evening	.6
		M 23	RH,UR,EC(C)	midday	1.0
420 cw	1	F 18	RH,UR,EC(B)	evening	.4
780 cw	1	M 48	RH,UR,EC(B)	evening	.4
820 cw	1	F 32	RH,UR,EC(B)	evening	.25
960 cw	2	F 35	RH,UR,EC(B)	evening	.3
		F 36	RH,UR,EC(B)	evening	.3
9,150 pulse	1	M 44	RH,UR,EC(C)	midnight	1.0
				midafternoon	.25

[a] LH—left hemisphere; RH—right hemisphere; FR—Faraday room; UR—unshielded room; EO—eyes open; EC—eyes closed. (A) = plus input—left frontal parietal; minus input—left occipital; reference—left mastoid. (B) = plus input—right occipital; minus input—right frontal parietal; reference—right mastoid. (C) = plus input—right occipital; minus input—right frontal parietal; reference—left mastoid. [b] Based on relative magnitude of effects, with maximum effect = 1.0.

normal patterns when the generator frequency was changed or turned off. Table I lists the radio frequencies and the corresponding EEG changes.

Figures 4 and 5 show other rf-induced EEG changes. Time of day, subject, and experimental conditions are the same as for Fig. 3. At the point indicated in Fig. 4, the 365 MHz irradiation increased the normal alpha amplitude from 65 to 80 μV; the alpha frequency was increased to 11.5 Hz. In Fig. 5, the 345 MHz irradiation produced desynchronized alpha waves of low amplitude and prominent slow waves. Alpha amplitude decreased to 30 μV and frequency increased to 12 Hz. The last portion of the trace, when irradiation was turned off, shows alpha amplitude increased to 100 μV then recovered to normal amplitude of 65 μV and normal frequency of 10 Hz as the slow waves disappeared.

Figure 6 is the EEG trace of a woman volunteer, age 36, with eyes closed. Time of day and experimental conditions are the same as for Fig. 3. The normal alpha amplitude of 50 μV and 10 Hz in the first part of this recording became desynchronized, increasing in amplitude to about 80 μV; 2 to 6 Hz slow waves of 80 to 100 μV amplitude appeared during 360 MHz cw irradiation.

To date none of the volunteers, or others involved with the tests, have shown any after effects.

DISCUSSION

The various lead configurations and antenna orientations tried during the cw tests demonstrated that only the following combination produced easily repeatable results: plus input—right occipital; minus input—right frontal parietal; reference—left mastoid; with antenna presented 1 m from left hemisphere. Experiments were performed at midmorning, midday (approximately noon), midafternoon, early evening, and midnight. The midday and midnight tests showed the most marked and similar EEG changes with antenna presentation from the left side. If radio ionospheric propagation characteristics were involved, it would be expected that outside a Faraday enclosure day-side results would have differed significantly from night-side results.

It is possible that certain body circadian rhythm chemical processes are involved. Hemisphere dominance could be another factor, since all volunteers were right-handed. It is known that two structures within the brain have opposite phases in the production of norepinephrine—the pineal and the hypothalamus.[18,19] Peaks and ebbs in the production of this catecholamine occur near noon and midnight. Since rf energy is known to affect the hypothalamus[13] it is reasonable to suspect that the pineal, as well as other brain structures, might also be affected by this energy. Around noon and midnight, norepinephrine interaction with rf would be more likely to occur, thus might contribute to more pronounced EEG alterations.

However, many other substances (particularly serotonin[19,20]) in the brain may also interact with rf energy. Altered EEG patterns resulting from electrical stimuli should be expected to reflect corresponding behavior changes. It has been shown that both the thalamus and hypothalamus are especially sensitive in this respect.[20] The 6 Hz waves that appeared in some EEG patterns were similar to those waves associated with annoyance seen in earlier EEG research.[21] A dephasing of the normally opposite alpha brain-wave amplitudes in each hemisphere during certain information processing may result from rf-induced interference patterns.[22] One researcher has concluded that the EEG is useful for evaluating radio-wave effects in humans, noting that it "offers an important objective method of examination at a time when clinical evidence of disordered function—in particular neurotic signs—is only slight."[23]

A complete theoretical explanation of these results presents a problem, but almost certainly quantum effects and absorption are involved. Non-resonant absorption leads to an energy conversion in which phonon or vibrational motion is produced. The rf may be capable of exciting near-surface bone such as the skull into vibrational oscillation primarily because of its piezoelectric properties.[24] It is known that a spherical body is so electrically loaded that its bandwidth is extraordinarily large,[25] and it is possible to consider the head as a biologically complicated spherical antenna that may interact in several ways with rf impinging upon it. It is noted that rf between .3 and 3 GHz at a relatively low power density can penetrate the skull,[6,26] and standing waves will sometimes occur.[27] Guy[28] described typical rf power absorption patterns for a sphere representing the human head for different frequencies and the relations involved. Grant[29] has pointed out that if resonance absorption can occur in biologic tissue as a result of microwaves, then significant repercussions concerning hazard from this radiation might exist. With a resonance absorption, a sharp peak over a small frequency range would occur in tissue that could not be observed outside of this range. Grant also mentioned that the overall dielectric behavior of biologic material at microwave frequencies is primarily determined by its aqueous content, and that most researchers agree that the relaxation frequency of protein-bound water must fall between 100 MHz and 1 GHz. Significantly, the EEG changes seen in the majority of the participants in this study were produced by cw rf between 100 and 960 MHz. Therefore it is likely that resonance absorptions occurred.

CONCLUSION

The current United States general population exposure standard (for radio frequencies of 10 MHz and above) is 10×10^{-3} W/cm^2. A typical urban environmental power density averaged over several radio bands for about 5% of the population has been given as slightly in excess of 10^{-6} W/cm^2.[30] This corresponds to 1.95 V/m, and compared to the 67 μV/m cw rf power seen to produce biological changes in these experiments, a meaningful risk factor for the general population appears to exist. Since rf in the environment rapidly continues to increase, there is a need for research further clarifying rf effects on biological systems.

The data from this study suggest that very low power-density rf can interfere with the normal brain-wave pattern of humans; and if these patterns are meaningful in terms of mood and behavior, then rf affects these parameters as well.

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LOW POWER MICROWAVE EFFECTS ON THE HUMAN ELECTROENCEPHALOGRAM: SUPPORTING RESULTS OF BISE

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Bise[1] reports significant effects upon the alert human EEG during irradiation by low intensity cw microwave electromagnetic energy. His observations include: (1) Significant repeatable EEG effects for any one subject during irradiation occur only at specific microwave frequencies within the band 0.1-1 GHz. (2) The major EEG effect is initial desynchronization of the predominant brain wave followed by transition of the frequency of the predominant brain wave from the alpha wave region (10 to 12 Hz) to the "slow" or delta wave region (2 to 4 Hz) after seconds of irradiation at specific microwave frequencies with intensities on the order of 10^{-15} W/cm.^{2} (3) Significant EEG effects are reported as occurring only with irradiation of the left side of the subject.

These results are supported by the independent theoretical analysis of Stocklin and Stocklin[2] based on the physics of the brain/skull cavity together with potential energy considerations of proteins integral to the neural membrane, including Stark-effect rotational energy transitions of these integral proteins. The major pertinent conclusion of ref. 2, which follows from prolate spheroidal analysis of the adult human brain/skull cavity combined with the electromagnetic propagation characteristics of brain tissue and the microwave fields generated by proteins integral to activated neurons, is that an energetically stable state of the brain is an oscillatory state observable by EEG instrumentation as brain waves. Reference 2 shows that the brain/skull cavity is capable of supporting a number of characteristic modes, each mode identified by a specific three-dimensional standing wave pattern of electric and magnetic field amplitudes together with a specific mode frequency. Frequencies lie in the protein rotational frequency band. While the lowest mode ($m = 0$) does not appear capable of supporting the stable oscillatory state, the next three lower odd modes ($m = 1, 3, 5$) are major contributors to that state. The energy of these lower modes predominates in the limbic cortex. For the parameters of ref. 2, the base frequency of the lowest mode is 267 MHz, and base frequencies of the next three lower odd modes lie between 400 MHz and 1 GHz.

The mechanism of the stable oscillatory state can be described as follows. Phase-locking among lower mode microwave fields generated by integral proteins induces and maintains simultaneous firing by large numbers of neurons mainly in the limbic cortex on both sides of the longitudinal fissure. Action potentials, of course, are produced at the same time, forming an action potential "sheath" concentrated in the limbic cortex. Local neuron deactivation following action potential generation "switches off" the microwave field and the action potential sheath travels inward, via the corpus callosum if that neural tract is available, through the thalamic region and out to the limbic cortex where the process is repeated.

Physically, this mechanism may be thought of as a pulsed microwave oscillator in which the presence of neural pathlengths other than the mean pathlength between hemispheres and the varying number of acjunction with those of ref. 2. In addition to propagation characteristics of the brain tissue and the cavity wall, mode characteristics are determined by two geometric properties of the brain: the cephalic index of the brain (its shape) and the semi-focal distance of the brain (its size). Differences in these two geometric parameters among subjects lead not to different sets of modes but only to different mode frequencies with quantitatively different spatial mode properties. Consequently, estimation of brain cephalic index and semifocal distance using external skull measurements on subjects permits estimation of each subject's characteristic mode frequencies, which in turn would permit a mode-by-mode treatment of the data and analysis for change in mode frequency with changes in geometric properties. Furthermore, using the estimate of 5×10^{-14} W to "activate" one integral protein with microwave energy, data of ref. 1 would indicate that a maximum of about 5000 neurons are involved in the initial stage of any induced mode.

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