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Flight, Orientation, and Homing Abilities of Honeybees Following Exposure to 2.45-GHz CW Microwaves

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Foraging-experienced honeybees retained normal flight, orientation, and memory functions after 30 minutes' exposure to 2.45-GHz CW microwaves at power densities from 3 to 50 mW/cm^2. These experiments were conducted at power densities approximating and exceeding those that would be present above receiving antennas of the proposed solar power satellite (SPS) energy transmission system and for a duration exceeding that which honeybees living outside a rectenna might be expected to spend within the rectenna on individual foraging trips. There was no evidence that airborne invertebrates would be significantly affected during transient passage through microwaves associated with SPS ground-based microwave receiving stations.

Key words: honeybees, invertebrates, behavior, solar power satellite, 2.45-GHz microwaves, continuous wave

Large quantities of solar energy could be collected in space by geosynchronous solar power satellites (SPS). This energy could be transmitted by microwaves from the satellite, and converted at the earth's surface to electrical energy. Each SPS could produce approximately five Gigawatts, the equivalent of several nuclear plants. This concept, first conceived by Peter Glaser [1968] and reviewed recently by Kraft and Piland [1980], has potential for meeting global energy needs by using the sun's almost inexhaustible energy [Glaser, 1980]. Studies to assess the feasibility of the SPS project [Koomanoff and Sandahl, 1980] include an effort to anticipate potential environmental problems. One concern is the potential biological effects on airborne biota that cannot be excluded from earth-based microwave receiving stations where 2.45-GHz continuous wave microwaves (CWM) at maximal power density of 23 mW/cm^2 would be received near the rectenna center. The behavior of birds and flying insects in the rectenna areas could be a crucial element. Possibly in cold weather they may be attracted by a thermal advantage, owing to microwave absorption. Attractive nest sites may be created inadvertently by the rectenna design. Or airborne biota may be repelled by sensing the microwave fields. Orientation and navigation possibly could be affected, as well as other behavior that is essential for survival. Almost no information is available on the biological effects of CWM on airborne biota.

Our objective is to assess potential biological effects of CWM on the honeybee, Apis mellifera L., a species that is ideal for research purposes and also ecologically and economically important, especially as the primary pollinating agent for approximately one-third of

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the food produced in the United States. Honeybees are also vital for pollinating flora that provide food for wildlife and help to prevent soil erosion.

In honeybee colonies, thousands of bees make multiple daily foraging trips for nectar, pollen, and water at sources within approximately 5 km from their hives [Gary, 1979]. Successful return flights from these trips require the proper functioning of various mechanisms involved with metabolism, neuromuscular coordination, orientation, navigation, and memory. After returning to the apiary, entry into their own hive requires a high degree of visual discrimination, especially when hives similar in appearance are in proximity. In this study, these behaviors were used collectively as a bioassay in which experienced foraging bees were treated with CWM and then released near the apiary to determine the frequency of successful return to the apiary and to the correct hive within the apiary. These data permitted quantification of any performance decrements caused by CWM exposures. The basic premises are that the expression of these behavioral events is contingent upon normally functioning physiological mechanisms and that performance decrements would be induced by any adverse CWM effects.

We arranged five hives in a 1.5-m circle; hive entrances were oriented toward the center. From each hive we captured 120 foraging-experienced, pollen-laden bees as they were entering their respective hives during mid-morning. We identified each bee by gluing a numbered plastic tag (manufactured by Chr. Graze KG, 7056 Weinstadt-Endersbach, West Germany) on the thorax and placed it into a compartmentalized cage that held five bees (Fig. 1). Cages were assigned randomly to one of the following groups: 1) microwave-

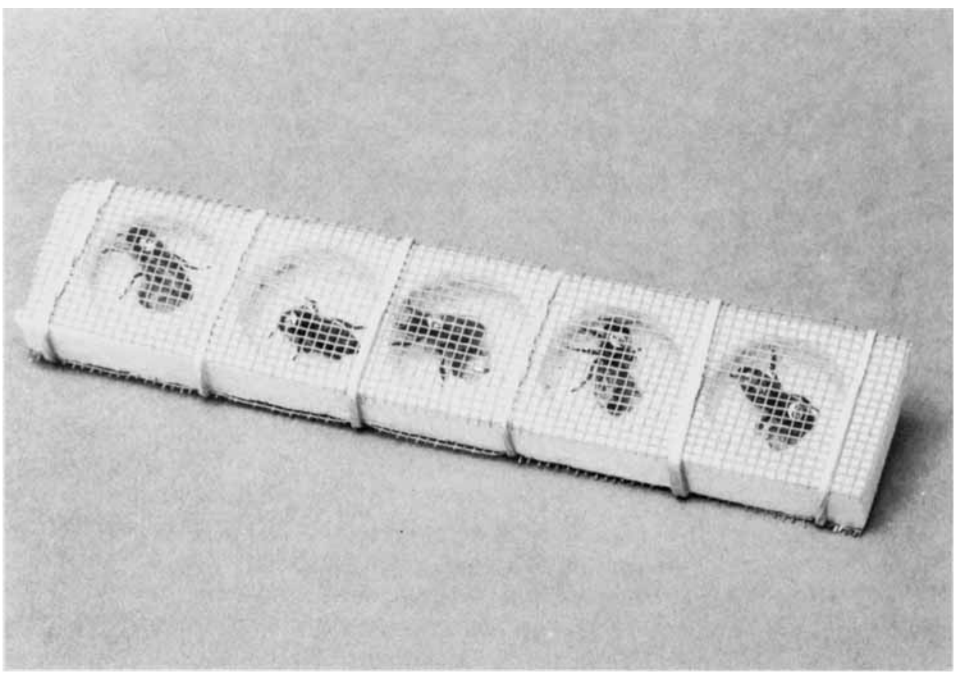

Fig. 1. Microwave-transparent styrofoam cage containing five compartments for confining bees individually. Fiberglass screen on top and bottom is secured with rubber bands. Invert sugar fondant is accessible through hole in the floor of each compartment, and held in place by Scotch tape. Water is provided by placing top screen in contact with a wet sponge that can be reached by the bees through the screen apertures.

treated (MT), in which two cages (10 bees) from each colony were exposed, respectively, in a treatment chamber at one of five levels of CWM, viz, 3, 6, 9, 25, or 50 mW/cm^2 for 30 minutes; 2) sham controls (SC), in which two cages (10 bees) from each colony were placed in a sham irradiation chamber concurrently with each MT group; 3) laboratory controls (LC), in which two cages (10 bees) from each colony for each group were held in a separate laboratory for the duration of all microwave treatments; and 4) hive controls (HC) that were treated identically to LC until posttreatment release (described later). All confined bees had continuous access to a 3-mm ball of invert sugar fondant as food. Water was available continuously, except during the 30-minute exposures to microwaves, by resting inverted cages on water-saturated sponges so that bees could insert their proboscis through the apertures of the plastic screen to reach the wet surface.

Microwave radiation utilized for treatments was generated by a 2.45-GHz continuous wave power supply capable of generating 300 watts with ripple not exceeding 2%. Radiation was transmitted by wave guides from the power supply to a Narda-644 horn antenna mounted in the top of a rectangular exposure chamber. Walls were lined with Eccosorb HT-99 (Emerson and Cuming). The treatment area (61 X 61 cm) was a styrofoam platform (4 cm thick) located 121 cm from the horn and resting on SPY-12 absorber (Emerson and Cuming). Microwave energy entering the chamber was continuously monitored with a Boonton 41-4A power detector. A crystal detector (Hewlett-Packard) was periodically substituted for the Boonton detector to check the waveform from the power supply. Exposures at 25 and 50 mW/cm^2 were conducted utilizing the wave-guide system and varying the power to the magnetron. Lower power levels were produced with the use of an attenuator.

The sham chamber was constructed identically to the treatment chamber and connected to the treatment chamber as a means of receiving a constant flow of effluent air and sharing any chamber odors or pheromones that may be released by treated bees. This arrangement also equalized ambient air humidity (38–66% RH) and temperature (24–30 °C) in both chamgers during the respective treatments.

During exposure, five compartmentalized cages (13 X 2.5 X 1 cm) (Fig. 1) were placed adjacent to each other on each of two styrofoam platforms (18 X 12 X 2.5 cm) with a separation of 1 cm between the long axis of the cages. The two platforms were placed in the chamber, 118 cm from the horn, one on either side 18 cm from the center in the H plane, with the long axis of the cage parallel to the H plane and the center of the platform located 30 cm from the front of the chamber. The average specific absorption rates for an isolated bee for E, K, and H polarizations are 0.50, 0.030, and 0.025 W/kg, respectively, for an incident power density of 1 mW/cm^2. These estimates (made by Carl Durney, University of Utah) are based on a spheroidal model of a lossy dielectric and a long wavelength approximation [Johnson et al, 1975].

During late afternoon after all treatments were completed, the MT, SC, and LC bees were transferred outdoors to a release site 100 m from their hives. Releases were made into a plastic tray with lubricated (Petrolatum) side walls that prevented escape by walking in the event released bees were unable to fly. We released the bees of the HC group directly into their respective hives through a hole in the hive cover to circumvent the necessity of flight from the release site to the apiary. The HC group served as an additional control on the acceptance of tagged bees by the colonies and provided a means to assess our method of recovering tagged bees from the hives. On the next 3 days after each release, we carefully examined all combs of bees in all hives at dawn (before foraging commenced) and recovered the tags from all groups.

Our sampling, treatment, release, and census-taking procedures were conducted on each of 10 days, yielding a total of 6,000 bees in the experiment.

Weather conditions were ideal for bee flight during release times. Released bees either flew quickly from the cages and departed from the site or remained in the collection tray if they could not fly. We observed no behavioral differences in any groups. Of the 6,000 tagged bees, 64 (1.1%) died prior to treatment, 207 (3.5%) died after treatment and prior to release or were moribund at release time, 5,729 (95.5%) flew when released, and 5,166 (86.1%) returned successfully to the apiary, of which 4,908 (95.0%) returned successfully to the correct hive.

Data were submitted to analysis of variance, and orthogonal comparisons were made (Table 1). We found no significant differences in the frequency of successful return to the apiary for any of the treated, sham, or control groups. Slightly fewer MT bees returned to the apiary than sham bees, regardless of the power density levels, which could suggest the possibility of mild electromagnetic effects on the more sensitive individuals. However, MT and SC groups did not vary significantly from LC or HC groups.

A low frequency of bees returned to the wrong hives in the apiary (Table 1). We observed no significant differences between any groups. This evidence indicates no problem of orientation or visual discrimination within the apiary. When hives similar in appearance are in proximity, the shifting of some bees between hives, referred to as "drifting," is normal behavior.

Mortality of bees after treatment and before release (Table 1) did not differ significantly among any of the groups and approximated normal daily mortality of bees that are old enough to forage. Bees of foraging age live only approximately 2–3 weeks during summer months.

Bees that flew from the release site but that were not recovered at the apiary were presumably lost in the area. Significantly more HC bees were accounted for after release, owing to release directly into the hives. A small percentage of bees from MT, SC, and LC

TABLE 1. The Responses of Honeybees Exposed to 2.45-GHz Continuous Wave Microwave Radiation and Released 100 m From Their Hives*

	Mean number of bees per 10 bee groups			
Treatment	Returned to apiary	Returned to wrong hive in apiary[a]	Died after treatment	Not accounted for after release
3 mW/cm^2	8.4 ± 1.6	0.4 ± 0.7	0.4 ± 0.7	1.1 ± 1.3
Sham	8.5 ± 1.3	0.5 ± 0.7	0.3 ± 0.6	1.0 ± 1.1
6 mW/cm^2	8.6 ± 1.3	0.5 ± 0.8	0.6 ± 0.8	0.8 ± 0.8
Sham	8.7 ± 1.3	0.4 ± 0.5	0.2 ± 0.5	1.0 ± 1.1
9 mW/cm^2	8.5 ± 1.4	0.5 ± 0.7	0.3 ± 0.7	1.0 ± 1.0
Sham	8.9 ± 1.1	0.4 ± 0.7	0.2 ± 0.4	0.8 ± 1.0
25 mW/cm^2	8.5 ± 1.4	0.4 ± 0.5	0.3 ± 0.7	1.0 ± 1.1
Sham	8.7 ± 1.3	0.4 ± 0.6	0.3 ± 0.6	1.0 ± 1.1
50 mW/cm^2	8.3 ± 1.2	0.5 ± 0.7	0.5 ± 0.8	0.9 ± 0.8
Sham	8.6 ± 1.1	0.6 ± 0.9	0.3 ± 0.5	0.9 ± 1.0
Laboratory controls	8.5 ± 1.5	0.4 ± 0.9	0.5 ± 0.8	1.0 ± 1.1
Hive controls	8.9 ± 1.1	0.2 ± 0.7	0.3 ± 0.6	0.6 ± 0.8

*Each value is the mean ± 1 standard deviation. All means are based on 50 groups (daily sample from five hives during 10 days) of 10 bees each. A total of 6,000 bees were studied.
[a]Bees flew to other hive after release in the correct hive.

groups may have returned to the apiary but left the hives prior to the census. Rejection of some bees by colonies is not uncommon when they have been held out of the colony for hours and submitted to procedures that may alter their odor and/or behavior.

Our data indicate the absence of statistically or biologically significant effects, either beneficial or detrimental, of CWM on confined honeybees that are exposed individually for 30 minutes at power densities proposed for use in the SPS system at rectenna sites where CWM would be received. This study suggests that airborne invertebrates approximating the size of honeybees would not be affected significantly when flying or passively drifting through CWM within rectenna areas.

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