Food Foraging of Honey Bees in a Microwave Field (2.45 GHz CW)[1]

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ABSTRACT

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Honey bees were trained to fly 400 m from their colony to an indoor laboratory foraging arena exposed to 2.45 GHz continuous wave microwaves at 5 power densities (0, 5, 10, 20, and 40 mW/cm²). Foraging behavior did not differ from controls foraging within an unexposed sham arena in (1) number of round trips completed during a 3-h exposure session, (2) round trip time between the colony and the foraging arena, and (3) the length of time required to navigate the illuminated foraging arena. This study indicates that honey bees would not be adversely affected by foraging within a similar microwave field that would exist in future receiving antennae for the proposed solar power satellite energy transmission system in which power levels are expected to range from 23 mW/cm² at the antenna center to 1 mW/cm² at the edge.

Limited nonrenewable energy sources and the concern for harmful environmental effects resulting from the use of such fuels has stimulated research on technologies which would utilize the sun as an inexhaustible source of energy. One of the more promising solar energy proposals from economic (Herendeen et al. 1979), engineering (Kraft and Piland 1980), and pollution (Glaser 1980) standpoints is that of placing up to 60 satellites into geosynchronous orbit above the United States to collect solar energy and transport this energy via microwave beams (2.45 GHz continuous wave) to receiving antennae on earth for conversion into electricity. Each solar power satellite (SPS) would be capable of producing 5 GW of electricity, equivalent to the yield of several conventional coal or nuclear power plants. The Department of Energy and the National Aeronautics and Space Administration have conducted a feasibility study to determine if there may be any unacceptable environmental problems associated with this new technology (Koomanoff and Sandahl 1980). One major concern is the exposure of airborne biota within and near microwave-receiving antennae (rectennae) that will be ca. 10 km in diameter. Maximum power densities of 23 mW/cm² are expected at the center of rectennae and should diminish to 1 mW/cm² at the outer edge. Extremely low levels would be experienced at considerable distances outside the rectennae.

Engineering models predict that invertebrates would not be affected adversely by microwaves to be used in the SPS system. Terrestrial invertebrates are usually much smaller than the SPS wavelength (12.5 cm) and thereby should experience minimal energy absorption, rendering them essentially "invisible" to SPS microwaves. However, virtually nothing is known about the potential of invertebrates for perceiving this form of energy or, if perceived, the amount that would constitute a "meaningful" stimulus to which adaptive behavioral reactions may occur. Furthermore, there appears to be a great concern by the general public regarding any potential effects of SPS microwaves on animals, especially those species that appear vital to the preservation of the existing environment.

To answer some of the questions concerning possible effects of SPS microwaves on invertebrates, we proposed a comprehensive series of experiments that are described in detail in a previous report (Newsome 1978). The honey bee, *Apis mellifera* L., was chosen for initial studies for a number of reasons, including the following: (1) it is a flying invertebrate that cannot be excluded from rectennae, (2) it has a short life cycle and can be reared economically in large quantities so that many generations and large numbers of individuals can be studied rapidly, (3) it has a large number of highly stereotyped behavioral patterns that can be quantified accurately, (4) previous studies have shown that bees are sensitive to various forms of electromagnetic radiation (e.g., Greenberg et al. 1978, Paul and Warnke 1975), and (5) it is economically important by virtue of pollinating flora in undisturbed areas and crops that account for ca. one-third of the food produced in the United States (McGregor 1976).

The objective of this study is to determine if foraging behavior is altered by exposure of honey bees to SPS microwaves. Behavioral bioassays are an efficient means of detecting significant changes in physiology or biochemistry inasmuch as normal behavior is an expression of the normal physiological and biochemical mechanisms, collectively. Significant changes in behavior presumably could constitute a threat to survival. Specifically, this study was designed to provide a laboratory simulation of microwave exposure within or near the rectennal area where airborne invertebrates, especially honey bees, may enter while foraging or simply flying through the area. Will honey bees enter a microwave field of intensity equal to or higher than expected in the rectennal area, and would they continue to forage during exposure?

Materials and Methods

A population of bees was trained (Gary and Witherell 1970) to fly from an isolated colony located 400

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m northeast of the laboratory to identical treatment and sham microwave anechoic chambers with entrances located 4 m north and west, respectively, from the southeast corner of the laboratory. We used a genetically marked colony, homozygous (cd/cd × cd) for cordovan (Levin 1959), because the bees were easily identifiable visually by their cordovan-colored body, compared with common bee stock that is darker in color. Easy identification was essential to insure that bees from other noncordovan colonies in the area would not be included accidentally in the experiment. The trained cordovan bees were attracted to sugar syrup (25% sucrose without scent) feeder dishes (that simulated a rich nectar source) placed at the entrances of both the sham and treatment chambers (Fig. 1).

The dishes were moved gradually farther inside the runways, enclosed by removable glass plates, until the bees learned to enter area B inside the laboratory. Any noncordovan bees that appeared were immediately captured and sacrificed, a practice that was continued throughout the experiment. Populations increased rapidly, owing to the efficient communication system of honey bees (Frisch 1967). When ca. 50 bees were actively foraging at each of the respective runways, the runway feeding dishes were removed. Intensive searching behavior ensued; within minutes a few bees learned to enter the chambers via the Plexiglas tube (1.9 cm I.D., 2.5 cm O.D., 33 cm long) which reduced to a smaller tube (0.95 I.D., 1.3 cm O.D., 15 cm long) to the chamber runway (F) where they discovered the feeder (G), a polystyrene petri dish (5.5 cm diameter, 1.3 cm deep) recessed in the floor with the upper rim flush with the floor. Inside the dish was ca. 15 ml of 25% sucrose syrup on top of which floated a thin (0.2 cm) styrofoam disc (4.9 cm diameter) on which bees stood while feeding around the periphery. The

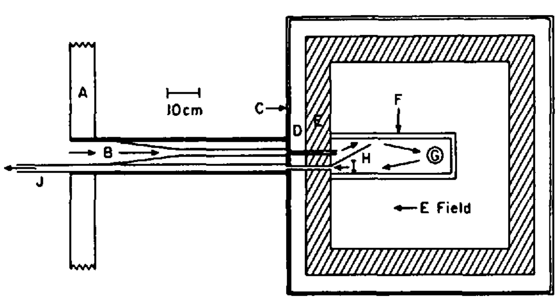

FIG. 1.—Cross-section (horizontal) of anechoic chamber showing the foraging arena with entrance and exit tubes that allow bees to enter and leave the chamber during microwave exposure. (A) Laboratory wall, (B) runway entrance with constricting walls that guide bees to the entrance tube, (C) exterior wall (plywood and aluminum) of chamber, (D) 5-cm vented air space, (E) internal chamber wall constructed of microwave absorbing material, (F) styrofoam foraging arena covered with fiber glass screen, (G) artificial flower (feeder) containing sucrose syrup, (H) area constricted by angular cardboard partition to guide exiting bees to exit tubes, (I) exit tube, and (J) extension of exit tube beyond laboratory wall to inhibit the entry of bees.

feeder was designed to expose the minimum amount of syrup, consistent with easy access, needed to prevent bees from falling into the syrup where they would become fouled and unable to fly. After feeding, exiting bees tended to accumulate in area H where they were guided to the exit tube opening (I) by a cardboard partition (15 cm long). The small exit tube (13.5 cm long) connected to a larger exit tube (J) that extended 16 cm beyond the outer laboratory wall as a means of preventing arriving bees from entering the exit tube. Bees quickly learned to move through the system during the initial foraging trips. They were free at all times to exit from any area of the system by either the entrance or exit tubes. All movements of bees outside the chambers could be observed in the transparent runway system.

Two days before onset of the microwave treatments, 25 trained foragers were sampled randomly from each chamber by being permitted to enter a small, cylindrical 8-mesh wire cage that telescoped momentarily over the end of the exit tunnel (J). Captured bees were individually narcotized by a 10-sec exposure to carbon dioxide to facilitate gluing a numbered identification tag (manufactured for bees by Chr. Graze KG, 7056 Weinstadt-Endersbach, West Germany) to the thorax. Tagged bees were released immediately at the point of initial capture for resumption of foraging. Thereafter the populations of foraging bees at each chamber were stabilized by capturing and sacrificing all untagged bees, including additional unwanted bees recruited to the chambers by the tagged bees. Tagged bees, with few exceptions, foraged exclusively at the chamber to which they were trained initially. Fidelity to small foraging areas is a typical behavior (Singh 1950) that was enhanced in this study by affixing a large (38 by 28 cm) blue or yellow card on each outside entrance, respectively, to provide orientation cues that simulated flower color. Tagged bees that "crossed over" to the wrong chamber were sacrificed.

The following procedures were repeated on each of 5 consecutive days. Early each morning the existing tagged bees recruited new populations to each anechoic chamber, of which ca. 75 were permitted to learn, primarily by following tagged bees, to forage in the chambers. After ca. 1 h of foraging experience the tagged bees from the previous day were sacrificed and 25 newly recruited bees were tagged for each chamber, respectively, as described previously. Tagging operations required ca. 2 h. The newly tagged bees were allowed to forage for ca. 2 more h to insure complete recovery from the tagging operation and to permit bees adequate time to attain stabilized foraging activities. Then a 3-h microwave treatment was initiated each afternoon in which the power density levels in the treatment chamber were set randomly at 0, 10, 40, 20 and 5 mW/cm^2 on each of the 5 days, respectively.

Data recorded during the 3-h treatment period were used to determine (a) the total number of round trips, (b) the mean round trip time, and (c) the mean time each bee was inside the anechoic chamber. Data were based on bees that made at least 12 trips during the 3 h. Data at each chamber were recorded continuously by two observers, one inside the laboratory to record the tag number and entrance time as the bees passed a given point in the large entrance tube, and the other outside to record the tag number and exit time from exit tube (J). An audible alarm signaled at 1-min intervals to coordinate data recording by the four observers. Microwave exposure was continuous in the treatment chamber throughout each 3-h session, except for a 2-min period each half hour when the power was turned off while refilling the feeders.

The microwave anechoic chamber closely simulated conditions anticipated within and surrounding the SPS rectennae. Power was conveyed from a 2.45 GHz continuous wave power supply (ripple < 2%) through waveguides into a Narda standard gain horn (model 644) that was oriented vertically within the anechoic chamber. A Boonton power detector (model 41–4A) connected to a 50 dB cross guide coupler (Arra model 284–602–50–n) and to a Data Precision digital multimeter (model 1350) provided a continuous readout of power levels within the microwave exposure chamber. The power detector was calibrated with a Narda microwave meter (model 8611) and probe (model 8623) that had been calibrated against a custom-built, three element orthogonal dipole probe (courtesy of Environmental Protection Agency, Research Triangle Park, N.C.), which was in turn calibrated against a reference probe at the U.S. National Bureau of Standards.

A cross-section diagram of one of the two anechoic chambers used in this study is shown in Fig. 1. These rectangular chambers (88 by 88 by 196 cm) were constructed of plywood with an interior lining of sheet aluminum (C). A vented air space (D) separated the outer chamber from an inner chamber wall constructed of microwave-absorbing material (Emerson and Cuming HT–99 ceramic absorber for the walls and ceiling and SPY–12 pyramidal rubberized absorber for the floor). The exposure area (61 by 61 cm) was located 121 cm from the horn and corresponded to the floor of the chamber foraging runway (F). The chamber was passively cooled by air vents located at the top of the air space and actively cooled by a fan (Pamotor model 7606) blowing air into the bottom of the chamber. All materials used in constructing the runway (F) within the chamber were microwave transparent; e.g., the runway arena (38 by 12 by 2 cm) was made of styrofoam covered with fiber glass screen on top.

Temperatures were monitored continuously during exposure within the foraging arena and within the feeder solution with a gallium-arsenide fiber optic temperature monitoring unit (designed and custom-built by D. Christensen, University of Utah, Salt Lake City) and recorded on an Omniscribe chart recorder (model B5237–5). Temperatures within the sham foraging arena and feeder were monitored continuously with copper-constantan thermocouples (Omega models SCPSS–062E–6 and SCPSS–020E–6, respectively) connected to electronic ice-point references (Omega model MCJ-T) and recorded on an Omniscribe chart recorder (model B5237–5).

Results and Discussion

During the 5-day study, 181 (93 and 88 for the treatment and sham chambers, respectively) of the 250 tagged bees returned to forage after tagging, a high rate of return considering the brief training period and the probability that some bees were tagged before establishing a fixed behavior pattern at the food source. Relatively naïve, newly recruited bees have a low tolerance for disturbance; i.e., they frequently cease visitation to the area if disturbed significantly. Of the returning foragers, 13 (4 and 9 trained to the treatment and sham chambers, respectively) were excluded from data analysis because of inconsistent foraging activity, based on the criteria mentioned earlier.

The mean daily foraging populations did not differ significantly for the microwave (18 ± 4) and sham (16 ± 3) chambers (Fig. 2). During the 3-h observation periods, bees made ca. 20 to 30 round trips (Fig. 2). There was no evidence that the microwave field deterred entry into the chamber.

The mean round trip times and time spent in the foraging arena are summarized in Fig. 3 and 4, respectively. No significant differences were found at any of the power levels. Our data indicate that microwave-treated bees experienced no detectable alterations in orientation and navigation behavior,

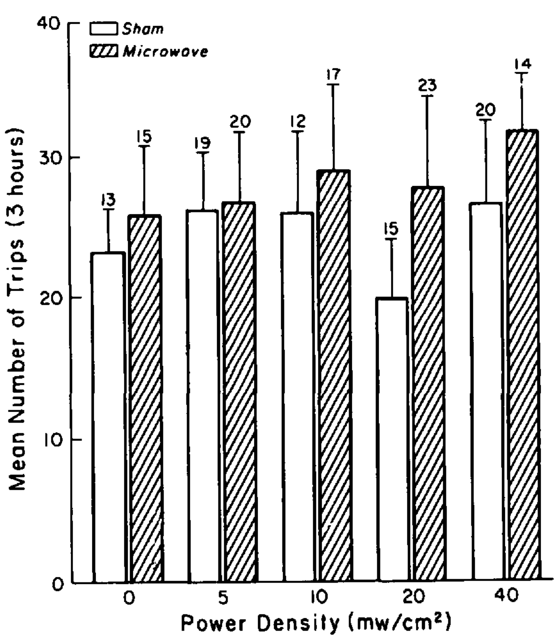

FIG. 2.—Mean number of round trips per bee from hive to the chambers, plus one standard deviation. Figure above standard deviation mark is the number of bees for each treatment that completed at least 12 round trips during the 3-h period.

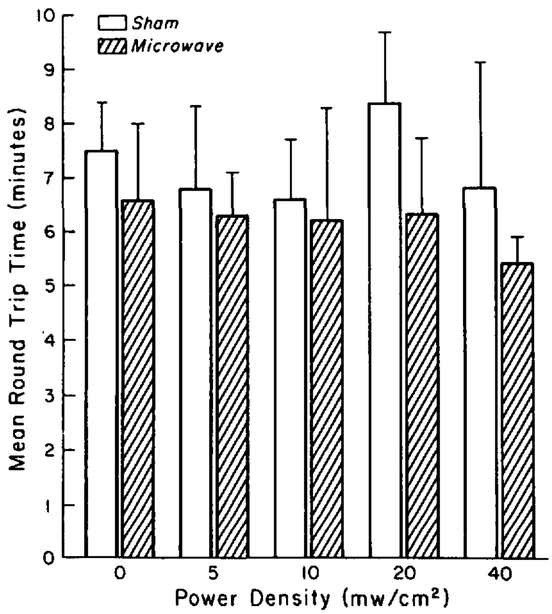

FIG. 3.—Mean round trip time per bee from the hive to the chambers at the various power densities tested, plus one standard deviation.

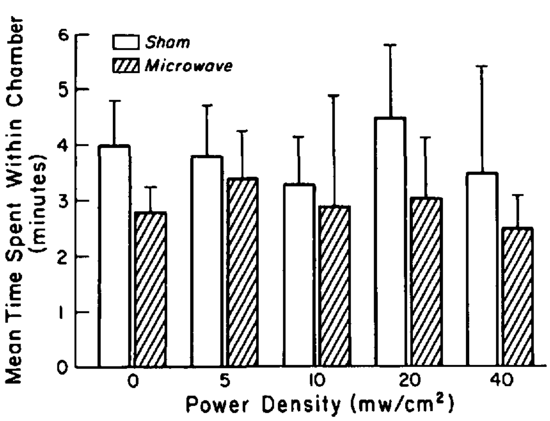

FIG. 4.—Mean time during each trip that was spent within the foraging arena at the various power densities, plus one standard deviation.

either while flying between the field colony and laboratory or while navigating within the chamber system. Approximately 5.5 to 8.5 min were required by most bees to complete a round trip, including 2.5 to 4.0 min within the chambers, indicating that bees in the treated chamber were exposed to microwaves during ca. half of the 3-h treatment periods.

This study provided evidence that honey bees readily enter microwave fields at power densities similar to and exceeding those expected to be present in rectennae of the proposed SPS system. It also establishes that the honey bees perform normally during and after microwave exposure, unlike the effects of 2.45 GHz microwaves on Y-maze learning in white rats at 50 mW/cm², in which the learning curve was significantly better for the exposed than for the unexposed rats (Nealeigh et al. 1971).

Although previous studies with indoor foraging arenas (Bermant and Gary 1966, Nunez 1970) have been used, this is the first study in which such arenas have been utilized to survey possible performance decrement effects from environmental pollutants. This system has great potential for studying the effects of a great variety of treatments ranging from various frequencies of electromagnetic radiation to toxic materials in the environment.

Surprisingly few noncordovan bees from other colonies discovered the food sources during this study, probably because there was a gentle inward flow of air at the entrances caused by a slight negative pressure of the building. The attractive odors from the bees and the food source, normally used as orientation cues by naïve bees in finding a feeding station, were thus removed and exhausted at other locations which attracted newly recruited bees away from the functional entrances. This system permits large populations of bees to be monitored and fresh populations to be generated for each treatment as a means of preventing interactions between treatments when the same individuals are used for various treatments.

Acknowledgments

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