AN ACOUSTIC EVALUATION OF ELECTRONIC MOSQUITO REPELLERS

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ABSTRACT. An analysis of the acoustic output of 4 commercial devices claimed to repel mosquitoes showed fundamental frequencies between 1.95 and 5 kHz and many harmonics extending into the ultrasonic range. None of them had significant repellent effects on laboratory bred *Aedes aegypti* or *Culex pipiens* or on field populations, mostly of *Ae. hexodontus*.

INTRODUCTION

The development and marketing of several small sound generators intended to repel female mosquitoes followed the publication in an electronic hobbyist's journal of an article entitled "Build the Bug-Shoo" (Greenlee 1970). This pocket-sized device was claimed to be effective because "The female mosquito is thought to be repelled by the same sound that attracts the male." The sound that attracts the male, in species that mate in swarms, is generated by the wing movement of the female (Roth 1948, Belton and Costello 1979) and although this sound is complex, only the fundamental frequency of the wingbeat—a sine wave—is essential to attract males (Wishart and Riordan 1959).

Another statement in the article is that "the male mosquito is attracted by a humming noise at a frequency of 2000 Hz" (cycles per second). This is incorrect—the males of most pest species in North America are attracted by frequencies of 200–350 Hz, the wingbeat frequencies of the corresponding females (Belton 1967, Belton and Costello 1979). Set at the frequency he suggests, Greenlee's device produces a sound 6–10 times too high to duplicate the buzz of a female.

The Bug-Shoo, a unijunction-transistor oscillator driving a miniature earphone, was built in 1972. Its output waveform consisted of a train of pulses that could be varied over a wide range of frequencies. Its sound is, therefore, complex and contains harmonics whose frequencies depend on the pulse rate. Because it could be tuned over a wide range of frequencies a comprehensive analysis of this device was not practical.

The 4 commercial sound generators tested all had fixed frequency outputs. Advertising for one of them claimed that its output contained ultrasonic frequencies that simulated an echolocating bat and that this would repel biting insects (Costello and Brust 1976). Another generator was claimed by its manufacturers to simulate the buzz of a male mosquito which they suggested would repel mated females. Three of the generators appear to be based on the unijunction oscillator of Greenlee and therefore should have pulsed outputs but the only descriptions in the literature of the acoustic output of commercial mosquito "repellers" stated that they were sine waves (Kutz 1974, Singleton 1977). The following analysis of the output of 4 of them was therefore carried out.

Because the American Mosquito Control Association is still receiving enquiries about such devices (T. D. Mulhern, Executive Director, personal communication) tests of their effectiveness were made and their potential is discussed in relation to claims for their mode of action.

MATERIALS AND METHODS

Three devices were tested both in the laboratory and in the field. They are identified as follows: A, "electronic gadget electronic mosquito repeller," supplied by Murray Distributors Ltd., North Vancouver B.C.; B, "Electronic Mosquito Repeller" obtained from Peak Distributions Ltd., Surrey B. C. and C, "Moziquit" supplied by Electronic Pest Controls Ltd., Montreal P.Q. All are roughly rectangular 6×5×2 cm deep plastic boxes with a transistor-radio earphone at the bottom right of the front face. The device claimed to sound like a male, D, is currently being marketed in Canada (June 1981) by Canaco Marketing, Toronto, Ont. with the name "Antibite." It was apparently also available in Europe under the name "Antipic." It is cylindrical, about 7×2.5 cm in diameter with the earphone facing upward at the top of the cylinder. The sound level from each was measured using a Bruel and Kjaer type 2204 impulse precision sound level meter with a 4145 condenser microphone, at a distance of 1 cm. The amplified output of the meter was fed into a Tektronix type 3L5 spectrum analyzer to determine the frequency content of the sound in the range between 100 Hz and 50 kHz. An oscillogram of the sound and its spectrum were photographed simultaneously from a Tektronix type 556 dual beam oscilloscope.

The effectiveness of the 4 devices was investigated using screen cages, 30×30×60 cm high, with a sleeve of 15 cm dia in the Plexiglas front. Eight 1-min tests were carried out each with 100 previously untested female *Aedes aegypti* (Linnaeus) and five 5-min tests each with 50 untested female *Culex pipiens* Linnaeus.

The tests on *Ae. aegypti* were run with one of the devices on the floor of a cage. Its sound was transmitted upwards when it was switched on and it was off in alternate tests. All the mosquitoes landing on and probing a human hand were counted during each test. The tests on *Cx. pipiens* used a restrained white rat and counts were made during the 5-min tests of each device. The counts of *Cx. pipiens* were compared with a single control test with no device in the cage.

Field tests of the devices available in 1977 (A, B and C) were carried out at 6 different sites in mountain woodland using 5-min counts of landings on 2 seated subjects, each with an exposed forearm. Alternate counts were made with the devices switched on and off. Two counts (first on then off) were made with device A and 2 with device B. Because these tests had little effect on biting rates a final two counts were made with devices A, B and C switched on together and then off. The results were analyzed with the χ^2 test and the significance determined at the 1% level ($P<0.01$). Because of the low numbers landing, Yates' correction was applied to the results obtained from *Cx. pipiens*.

RESULTS

The output of the 4 commercial devices is shown in Fig. 1, A to D. The left-hand traces are accurate representations of 2 msec of the sound from each device in the audible frequency range. The right-hand traces are spectral analyses showing a linear representation of sound pressure (vertical scale) at frequencies between 0 and 50 kHz (horizontal scale). The sensitivity of the microphone is greatly decreased above 20 kHz so that the vertical calibration does not hold good for the right half of the spectra. The spectra show a series of peaks. The peak at zero frequency is an artifact generated by the analyzer. To its right is the low-amplitude fundamental frequency of the device (arrowed) and succeeding peaks are those of the second (asterisked) and higher harmonics, each of which is linearly related to the sound pressure at that frequency. Each sound had many harmonics at multiples of its fundamental frequency, related to the pulsed output of its oscillator. The less obvious pulsing of device D gives rise to fewer harmonics and its output in the audible range is mostly the second harmonic at 10 kHz. As the distribution of harmonic peaks indicates, both pitch and quality (timbre) of all 4 sounds are audibly different from each other. The right-hand side of the spectra in Fig. 1

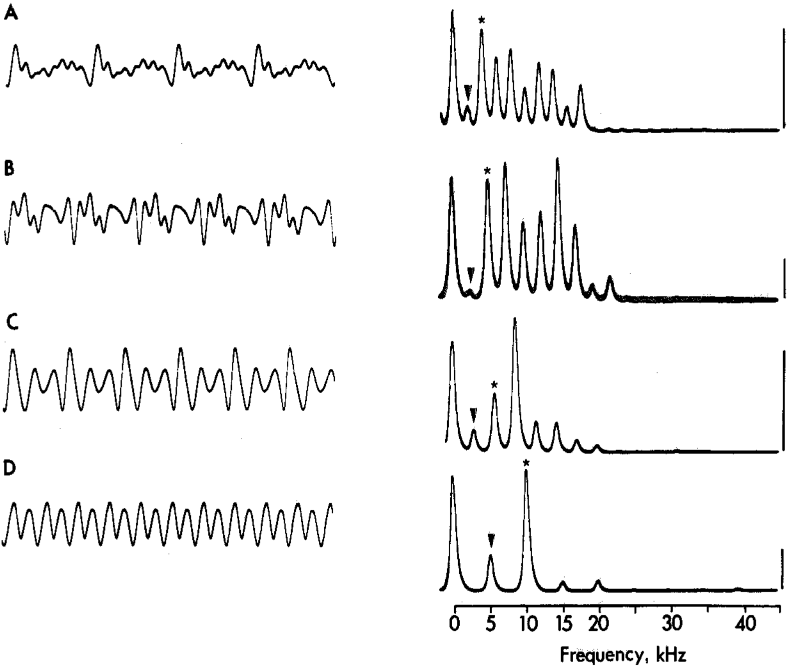

Fig. 1. Left traces, oscillograms of 2 msec of the sound from devices A, B, C and D, respectively. Right traces, spectral analyses of sounds at left; fundamental frequency arrowed, second harmonic with an asterisk and higher harmonics to the right. The vertical calibration represents 50 mV RMS output from the spectrum analyzer showing reduced amplification for traces B and D.

show slight deflections which indicate that ultrasonic frequencies are present in the output of all 4 devices.

The sounds are not particularly intense, their pressure, at a distance of 1 cm, and their fundamental and highest amplitude harmonic frequencies are shown in Table 1.

Table 1. Characteristics of the sound of the 4 devices tested.

Device	Sound pressure	Fundamental frequency	Peak harmonic
A	74 dBA	2.0 kHz	4 kHz
B	68	2.5	15
C	84	3.0	9
D	72	5.0	10

Sounds of this intensity are not audible at distances of more than about 1 m, over the background noise of a "suburban living room" (Broch 1969). Nevertheless they are about 50–100 times louder than the sound of a female mosquito which is about 40 dBA at 1 cm (Wishart and Riordan 1959) and they are several hundred times less intense than that of an echolocating bat which is about 100 dB at 30 cm (Belton and Kempster 1962).

Between 70 and 87 of the caged *Ae. aegypti* landed and were probing the exposed hand at the end of each 1-min test and the numbers were not significantly different whether any of the devices was on or off. Between 3 and 14 of the 50 *Cx. pipiens* landed and probed the rat. In the test of device B, fewer mosquitoes landed when the sound was on, however, the χ^2 value (with Yates' correction) of 2.13 indicates that this could have occurred by chance in 1 trial out of 10. In the field tests there were no significant differences in numbers landing in 5-min periods whether one or more of the devices was switched on or off. The landing rates on one arm were between 2 and 7/min. Mosquitoes were mostly *Ae. hexodontus* Dyar, with a few *Ae. cataphylla* Dyar and *Culiseta inornata* (Williston).

DISCUSSION

The acoustic waveforms of devices A, B and C are pulsed like that of the Bug-Shoo and are consistent with a unijunction oscillator. Kutz (1974) and Singleton (1977), both investigated device B and described its output as a sine wave, however, they may not have used sufficiently precise equipment to describe the waveform accurately. The acoustic characteristics of transistor-radio earphones are variable even from the same manufacturer and it is probable that the amplitude and quality of the sounds of some of the devices vary from unit to unit but this was not investigated. None of these 3 devices correspond in frequency with the flight sounds of female North American mosquitoes. Certainly they could not be expected to work on the principle of repelling females with the same sound that attracts males. Device D, which was designed to mimic the sound of a male mosquito, on the hypothesis that it would repel mated females, produces a frequency 10 or more times higher than that of any North American male mosquito tested. A preliminary investigation of the antennae of females indicates that they are less sensitive to sound than those of males and are tuned to a frequency around 100 Hz, a fiftieth of the fundamental frequency of device D. Sound at the wing beat frequency of the male, loud enough to be heard by the females, would probably be as annoying to humans as the bites themselves.

The results of the laboratory and field tests confirm those of previous investigators (Garcia et al. 1976, Gorham 1974, Helson and Wright 1977, Kutz 1974, Rasnitsyn et al. 1974, Schreck et al. 1977, Snow 1977). The devices had no consistent repellent effect. The 3 species encountered in the field were different from those investigated in previously published field tests but were similar in their lack of response. The unpleasant nature of the 4 sounds, as perceived by the human ear, may be due to the presence of some ultrasound in the output of all the devices tested but the negative results of all laboratory and field tests indicate that ultrasound at these levels is, like the audible component, not significantly repellent to mosquitoes. Greenlee's Bug-Shoo can be tuned to an inaudibly high frequency and he states that "all mosquitoes seem to be repelled by a high frequency, above 10,000 Hz." Mosquitoes may have mechanoreceptors sensitive to high frequencies but no physiological research has been done to locate them. There is, at present, no scientific proof that the behavior of female mosquitoes is affected by any sound frequency but this should not discourage further research into the effect of ultrasonic frequencies and also of frequencies lower than that of the wingbeat, to which the antennae of female mosquitoes are sensitive.

I can find no scientific basis for any of the claims made for the mode of action of any of the repellers that have been marketed up to the present. On the contrary, most observers exposed to high biting populations of mosquitoes know that, although they may jostle for position, flying or walking mosquitoes do not repel each other. My experience of working near swarms of male mosquitoes is that their sound does not deter females from biting and in fact there are several species in which both males and females are attracted to hosts with no mutual repulsion.

CONCLUSIONS

All 4 putative insect repellers were ineffective in laboratory and field tests against the aforementioned mosquito species although their frequencies extended well into the ultrasonic range. Because of their high fundamental frequency, none of them could work, as Greenlee (1970) suggested they do, by reproducing a sound that attracts male mosquitoes. Only one sample of each device was tested.

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