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Evaluation of four common electronic mosquito repellers on *Aedes albopictus* and *Culex pipiens*

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Abstract
Introduction. Mosquitoes represent a way of spreading infectious diseases, as vectors of pathogens. Many types of ultrasonic devices have recently been promoted as effective and suitable alternatives to the use of biocides known as toxic to humans and environment.
Materials and methods. Four ultrasonic mosquito repellers have been analysed and tested on females of two species, *Culex pipiens* and *Aedes albopictus*, in laboratory conditions. The behavior of the mosquitoes of reaching the attractant, with the repellers both at ON and OFF, was observed.
Results. The total mean number of *Cx. pipiens* interested to attractant when the repellers were ON was 2.8 versus 2.9 at OFF. The total mean number of *Ae. albopictus* interested to attractant when the repellers were ON was 5.5 versus 6.1 at OFF.
Conclusions. The repellence efficacy resulted not significant (P>0.05) in all the electronic ultrasound repellers tested. The number of mosquitoes of both species, displaying the attractant's search behavior appeared independent from the switch ON/OFF mode. Open questions remain: the need of conducting further research to establish a relationship between ultrasonic emission and mosquito effective disturbance.

Key words
- mosquito acustic repellers
- ultrasounds
- efficacy

INTRODUCTION

Widespread attention, at a global level, for the use of pest-repeller devices sustainable for the environment and attentive to animal welfare has translated into a broad and continuous commercial proposal of devices not based on biocides. Sonic pest devices are noisy sound tools designed to repel unwanted animals including insects, various birds and mammals, mainly rodents. These devices cover a wide range of the acoustic spectrum from below what humans perceive (infrasonic, characterized as sound below 20Hz), to above our hearing range (ultrasonic, characterized as sound above 18,000 Hz), depending on the target species. Ultrasonic devices are typically aimed at repelling arthropod and mammal pests, whereas devices targeting birds operate within the human normal hearing range. Many of the instruction booklets use vague wording to describe how the devices operate, such as "the device controls pests with high-frequency sound" or "it repels pests", at least without reporting the operating frequencies of the devices. Moreover, the actual effectiveness is currently supported by conflicting results. Many studies have been conducted to test the effectiveness of sonic pest devices, with most concluding that the devices are ineffective. A comprehensive set of studies conducted by Kansas State University tested five commercially available devices (one of which developed by the University itself), on nine groups of arthropod pests [1, 2].

The most common commercial ultrasonic devices on the market are purposed to repel mosquitoes (Diptera: Culicidae), but most of them are not supported by scientific studies of efficacy; indeed, the devices evaluated by laboratories or field tests failed to repel different species of mosquitoes [3-9]. Up to now frequencies within the range of 20-60 kHz emitted by different commercial ultrasonic devices were evaluated but none showed a clear

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repellent effect. However, despite the almost absence of publications confirming their efficacy, the sale of new electronic mosquito repellent devices is widely spread in many countries, probably due to a lack of a regulatory system by the local authorities. Moreover, the sincere aspiration of consumers to reduce the use of chemicals perhaps encourages the purchase of these devices to limit the problem of mosquito bites. In the present work, we evaluated four commercial devices, claimed to be electronic mosquito repellers, which have not yet been dealt with in the scientific literature. We evaluated the efficacy of the devices on *Aedes albopictus* and *Culex pipiens,* the most common mosquito species of health concern in Italy, as vectors of respectively potentially circulating arboviruses such as Chikungunya [10] and Dengue [11], and seasonally circulating as the case of West Nile [12].

MATERIALS AND METHODS

The tested electronic repellers were signed with the four letters A, B, C, D. The determination of sonic frequency was done in an acoustic isolation room of CNR-INM Labs at Tor Vergata Research Area. The devices were characterized according to the ISO 3744 and ISO 3745 standards [13, 14]. The characterization was conducted inside the treated chamber measuring 19.5 m^2 and 2.8 m in height, with a volume of 54.6 m^3. The devices were connected to the 220V electrical socket located on the wall and placed in the center of the wall, simulating typical use. Measurements and recordings were carried out using the Sinus Apollo Class I sound level meter (ISO 61672-1) [15] with the Samurai management software (SINUS Messtechnik GmbH). It supports Class 0 1/3 octave filter bands according to IEC 61260-1 [16]. The microphones connected to the sound level meter were two ¼ MP401 (BSWA Technology Co, Ltd), with a cut-off frequency of up to 80 kHz. Mathworks® Matlab and Microsoft Excel were used for numerical processing and some graphic representations. *Ae. albopictus* and *Cx. pipiens* mosquito colonies were reared at 26±2 °C and 80±5% relative humidity, offering a sucrose-saturated solution as food. For each assay, 10 *Ae. albopictus* and 10 *Cx. pipiens* females 1 week old were used. A test chamber, made with few adaptations from how described in literature [17], was used to observe the behaviour of mosquitoes in the presence of the ultrasonic signal. The plastic structure used for the test consisted of two sections joined by a tube. The hand of the operator was inserted into a 30×30×30 cm plastic box, connected by a plexiglass 10 cm diameter, 1 m long tube with a section 20 cm diameter, 25 cm long. *Ae. albopictus* and *Cx. pipiens* females were released in the plastic pot section and allowed to fly in the tube towards the sonic waves emitted by each repellers placed close to the hand in section box. Ten repetitions of 10 minutes each for every switch position for five trials ON/OFF for each species and each device were measured. The number of mosquitoes attracted during a 10-minute interval with the devices or software turned off or turned on, was counted. Statistical analysis was done with a χ^2 test [18], comparing the number of females arriving at section C for each switch position (ON/OFF) of the devices. Repelling ability was calculated according to the formula R=100–(ON×100)/OFF, where ON represents the mean percentage of mosquitoes attracted when the repeller was turned on, and OFF the opposite option [9].

RESULTS

Characteristics of the electronic repellers

The sound emissions of the tested devices are very different from each other in terms of both time and frequency levels, as shown by the sound pressure levels and sound power levels (*Table 1*). Some devices emit at fixed frequencies (C) but vary in intensity over time (A and C), while others emit at variable frequencies (A, B and C) (*Figure1A-C*). The maximum noise level measured at a 1-meter distance across the entire spectrum varies from 38.1 dB to 94.1 dB, while in the main frequency band, it varies from 20.6 to 93.9 dB, depending on the devices. *Figure 1B* shows the radiation pattern of each

Table 1
The table shows the main characteristics of the four repellers named A, B, C, D in this study

Device	Working voltage [V]	Frequency range [kHz]	Main frequency[1] [kHz]	Frequency trend	Signal period [s]	L_{eq_f} @ 1m [dB][2]	L_{eq} @ 1m [dB(A)][3]	L_w[4] [dB]
A	220 V	20÷80	25	Symmetrical increasing and decreasing frequency variation at equal times. It has harmonics	2.14	93.9	64.7*	110.2
B	Battery 3 V	6÷80	6.3÷8	Symmetrical frequency ramp ascending and descending at equal times. It has harmonics	60	35.5	36.0	50.8
C	220 V	22÷73	25	Constant frequency. It has harmonics	0.1	33.4	24.2	49.9
D	220 V	4÷62	20	Symmetrical frequency ramp up and down, with different rise and fall times. It has harmonics	52	10.4	24.8	25.5

1: Main emission frequency 1/3 octave band; 2: Equivalent spressure level emitted in the main emission frequency 1/3 octave band, f; 3: Measured in the range 20Hz ÷ 20kHz; 4: Sound power level.
*the device also emits at 20 kHz at the extreme end of the audible band (not all people can hear it).

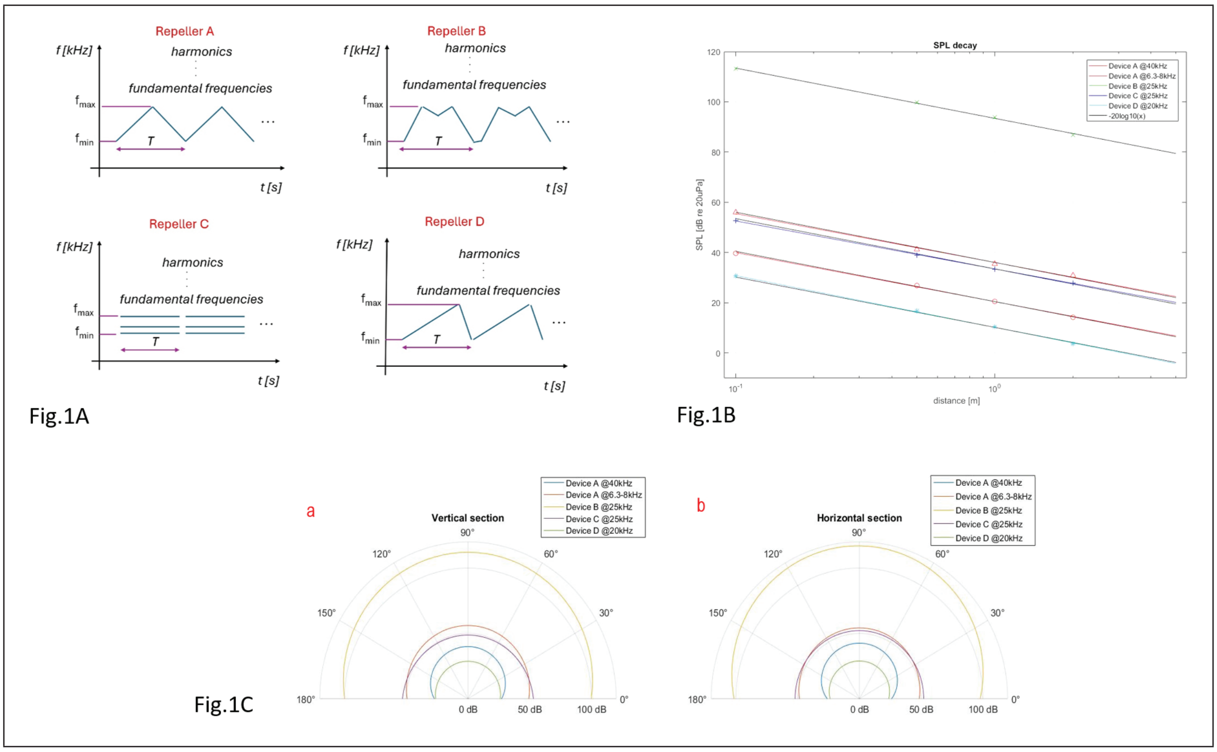

Figure 1
Characteristics of the emissions of the repellers.
Figure 1A: The shaping of the temporal spectra emitted by the tested repellers; *Figure 1B*: Radiation pattern of the tested repellers, a) vertical section perpendicular to the wall, b) horizontal section parallel to the floor; *Figure 1C*: SPL measured inside the acoustical treat chamber at differet distance from the repeller.

repeller, while *Figure 1C* illustrates how the sound pressure level (SPL) changes with distance for each device. Based on measurements conducted in a room without reflections on the walls or floor, the emission appears to be nearly spherical, and the noise levels decay with distance, r, according to the law:

$y(r) = -20 \log10(r)$ dB

equal to the law of geometric divergence for point sources.

Some devices, in addition to emitting in the ultrasonic band, also emit in the audible band, producing a high-frequency whistle or buzz. In *Table 1* the main characteristics of devices under test are reported.

Tests with Aedes albopictus and Culex pipiens mosquitoes

The graphs in *Figure 2* and *Figure 3* show the results of experiments obtained for each of the four devices on *Cx. pipiens* and on *Ae. albopictus* respectively. Twenty mosquitoes for each of the 5 trials, within which 10 minutes off and 10 minutes on, were counted. The colours of the histograms represent the minute in which a certain number of mosquitoes entered cage C, for each trial. Concerning the trials on *Cx. pipiens*, the total mean number of mosquitoes (calculated on the observation of all the four devices) that reached the cage C at switch ON was 2.8, while the same parameter at switch OFF was 2.9. Concerning the trials on *Ae. albopictus*, the total mean number of mosquitoes (calculated on the observation of all the four devices) that reached the cage C at switch ON was 5.5, while the same parameter at switch OFF was 6.1. The results of the single trials are reported in *Table 2*. The repellence efficacy resulted not significant ($P>0.05$) for all the electronic repellers tested (*Table 3*), as the number of mosquitoes of both species reaching the C-section was independent from the switch ON/OFF.

DISCUSSION AND CONCLUSIONS

In the present study, we tested four ultrasonic mosquito repellers on *Cx. pipiens* and *Ae. albopictus* female mosquitoes. The trials showed that the emission of the ultrasounds did not dissuade the mosquitoes from reaching the host to bite, although the total number of mosquitoes that reached cage C where the operator's hand was positioned appears slightly higher in the presence of the devices turned off. What has been observed concerns both the mosquito species used and the four ultrasonic devices tested. This result is in line with the existing literature on the topic. In fact, to date, the validity of the principle on which the operation of ultrasonic repellents is based is controversial. However, we believe it is important to evaluate the effectiveness of every possible alternative to chemicals aimed at reducing the risk of contact between humans and mosquitoes. [19] pointed out that female mosquitoes are not believed to respond to acoustic *stimuli*, even though the vibration of antennal hairs of *Aedes aegypti* females provides evidence that they perceive oscillations [20]. *Aedes aegypti* and *Culex quinquefasciatus* male attraction to

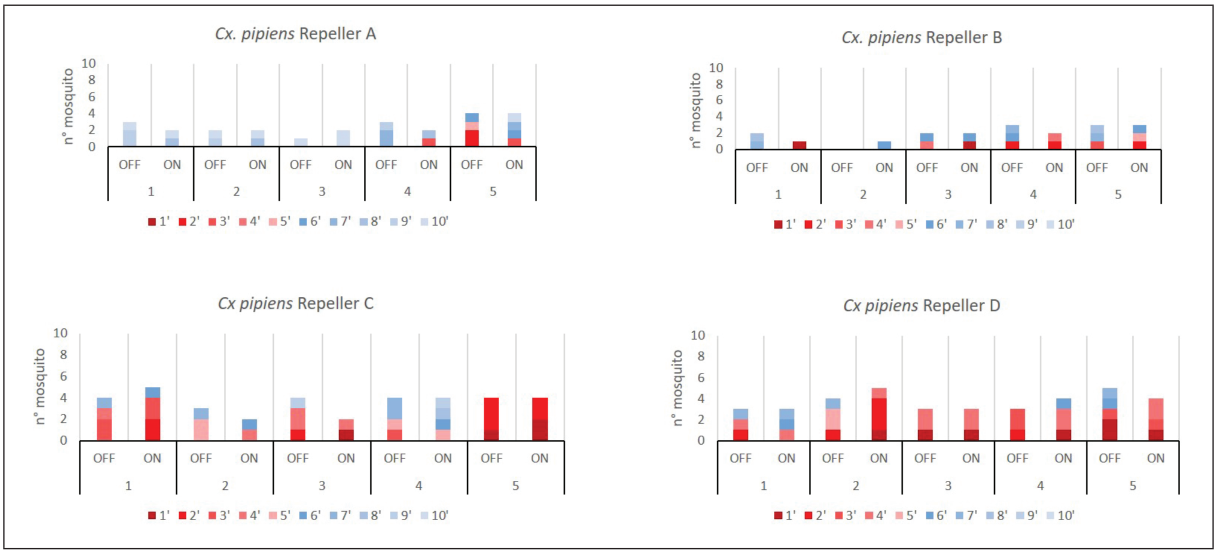

Figure 2
Results of the repellent effect of the four devices on *Culex pipiens*: in the graph, the number of mosquitoes is shown on the y-axis, and the time expressed in minutes on the x-axis.

conspecific female wing beat was demonstrated by [21] and [22]. However, in some devices, a mechanism is described that would exploit the imitation of the sound of the male's flapping wings to repel conspecific females. It should be noted that the wingbeat frequency for male mosquitoes has been recorded between 400 and 900 Hz [19, 21], quite different from that reported for all repellents evaluated in the literature and also in the present study. In the studies conducted by [20] and by [9, 23], the auditory function of the antennas was excluded. Moreover, some devices marketed to repel mosquitoes have been shown to attract mosquitoes. For instance, an electronic repeller tested under field conditions in Africa [24] gathered, in some cases, larger numbers of *Anopheles* spp. when the device was turned on. In another evaluation, four out of six devices showed a significantly higher attraction when turned on [25]. A study on three commercial sonic devices showed that when turned on the devices were attractive, resulting in an increase in bite-rate by as much as 50% [23, 26], confirming the lack of efficacy of the electronic repellers; other Authors showed similar results [27, 28]. A crucial socio-economic point is shown when such repellent measures are offered for sale in those territories where mosquitoes transmit infectious diseases pathogens. In such contexts, having effective repellence is crucial because interrupting contact between humans and the vector is integral to efforts aimed at limiting the spread of the pathogen. Concerning Italy, in several regions West Nile Virus, transmitted by *Cx. pipiens*, is

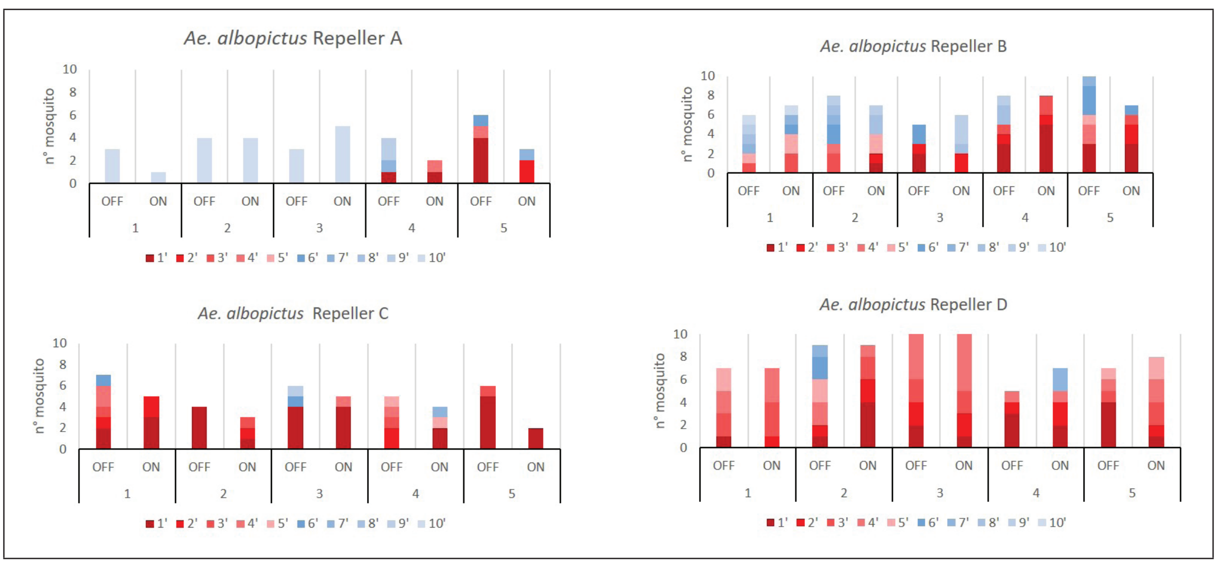

Figure 3
Results of the repellent effect of the four devices on *Aedes albopictus*: in the graph, the number of mosquitoes is shown on the y-axis and the time expressed in minutes on the x-axis.

Table 2
Results of the trials with the four repellent devices, named A, B, C, D in this study, on *Culex pipiens* and *Aedes albopictus*, espressed as mean number of mosquitoes that reached the box with the hand of the operator at switch ON and switch OFF position. Total mean number of mosquitoes observed reaching the box is also reported per species

	Mean number of mosquitoes entering the C cage								Total mean number per species	
Device model/ON-OFF	A/ON	A/OFF	B/ON	B/OFF	C/ON	C/OFF	D/ON	D/OFF	Devices ON	Device OFF
Culex pipiens	2.4	2.6	1.8	1.8	3.4	3.8	3.8	3.4	2.8	2.9
Aedes albopictus	3.2	4	7	7.4	3.8	5.6	8.2	7.6	5.5	6.1

Table 3
Statistical analysis by χ 2 test for *Culex pipiens* and *Aedes albopictus* (P=0.05)

Repellers	*Culex pipiens*	*Aedes albopictus*
A	0.841	0.400
B	1.000	0.814
C	0.739	0.192
D	0.869	0.736

now endemic. Autochthonous *Ae. albopictus* has acted as a vector in two outbreaks of Chikungunya virus in 2007 and 2017 and in three outbreaks of Dengue virus namely in 2020 in Veneto region, in 2023 in the metropolitan territory of Rome both in 2017 and 2023 and in 2024 in Marche region [29]. In these circumstances, relying on a repellent measure whose effectiveness is doubtful or non-existent can be very risky, as reported by Curtis in 1994 [30], who pointed out the risk of malaria infection due to some doctors in the UK prescribing electronic repellers instead of prophylactic measures for travellers to tropical areas. He also mentioned that some manufacturers have been sued and their repellers banned from sale. In the USA, the managers of a Company were charged and prohibited by the Federal Trade Commission (FTC) in 2002 from commercializing their electronic repellers for a period of 5 years. This was due to false allegations and unsubstantiated claims made in their advertisements for electronic mosquito and pest repellers. According to the FTC, the company had advertised that their device repels mosquitoes from the user and provides an effective alternative to using chemical pesticides in the prevention of the West Nile Virus. On the base of these considerations and the results observed in our study, we may assume that the here-tested electronic repellers are ineffective in repelling *Cx. pipiens* and *Ae. albopictus* female mosquitoes. Apps that "simulate" or emit sounds like ultrasound to repel mosquitoes have also recently been introduced on the market. These devices may represent a new challenge for research to determine whether they can serve as valid alternative tools or instead may pose a health problem. Pinto *et al.* [31] reported an episode of hospitalization for Tinnitus in a user who had used an "ultrasound" App to repel mosquitoes.

The Ultrasound App used to repel mosquitoes in Pinto *et al.* [31], was measured under controlled laboratory conditions and the results are available on the Physical Agents Portal website [32]. Important to note that the professional use of equipment that employ physical agents, including ultrasound, requires that the employer provides workers with "training and information couses" to protect their health during the processing phases. A recent publication by the Working Group on Physical Agents specific to Ultrasound is available on the Physical Agents Portal [33].

Based on the information presented thus far, we recommend conducting further research to validate whether there is a relationship between ultrasonic emission and mosquito disturbance. If such a relationship exists, efforts should be made to identify a frequency that could effectively dissuade mosquitoes from landing on the host to bite. Finally, as previously mentioned, government authorities need to regulate the marketing of electronic repellents by requiring the applicant to conduct scientific studies, based on statistically significant and reproducible data on their effectiveness before placing them on the market, similar to the requirement for chemical repellents.

Authors' contributions

LT, FLC: conceptualization, investigation, methodology, software, data curation, formal analysis, writing original draft,; FS, FC: methodology, software, formal analysis; RP, MM, MDiL, MDeL, PS: methodology review and editing. All the Authors have read and approved the final version of the manuscript.

Conflict of interest statement

There are no potential conflicts of interest or any financial or personal relationships with other people or organizations that could inappropriately bias conduct and findings of this study.

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