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Analysis and effectiveness of deer whistles for motor vehicles: frequencies, levels, and animal threshold responses

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Abstract: Whitetail deer (*Odocileus virginianus*) are common across much of the United States. In areas where deer populations are prevalent, there is a propensity for interactions with automobiles. Various methods have been suggested for reducing the number of automobile-deer collisions, including acoustic devices such as deer whistles. Six different whistles were tested in the laboratory and on motor vehicles. Frequencies and intensities generated by the devices when mounted on vehicles at speeds from 30 - 45 mile per hour were determined. The primary frequency of operation of the closed end whistles on vehicles was determined to be approximately 3.3 kHz with little variation with changes in air pressure. Open-end whistles had a primary frequency of about 12 kHz, with significant variation with changes in air pressure. The best frequency range of hearing for whitetail deer appears to be between 2 and 6 kHz. The effectiveness of these devices was concluded based on the comparison of the acoustical attributes of the devices to deer hearing thresholds and acoustic behavior.

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1. Introduction

Of the many methods that have been suggested to reduce the number of automobile-deer collisions, including visual deterrents (reflectors)(Ford and Villa, 1993), barriers (Feldhammer et al., 1986), and acoustic means such as deer whistles (Risenhoover et al., 1997; Romin and Bissonette, 1996) the latter are currently being promoted in many states as the deterrent of choice. Manufacturers advocate these devices on the premises that they are humane, inexpensive, easy to use, and scientifically sound (Bomford and O'Brien, 1990). To date, there have been relatively few technical studies of these devices. Three particular studies concluded that of the acoustical devices tested, not all were in the ultrasonic range as stipulated by the manufacturer (Schwalbach, 1989; Lawhern, 1990, and Romin and Bissonette, 1992). This study was designed to determine: 1) actual frequencies generated by the devices; 2) if those frequencies are generated with the device mounted on a vehicle at speeds between 48.2 - 72.4 kilometers per hour (30 - 45 mile per hour); 3) at what relative intensity they are produced, and 4) to compare those frequencies with the hearing abilities of deer. Animal acoustic behavior was also considered.

The deer whistle may be categorized as a communication device. The purpose of these devices is to act as an alarm signal, which fall into three categories (Bradbury and Vehrencamp, 1998): flee alarms, assembly alarms, and alert alarms. Alert alarms do not cause the receivers to flee or to gather but to remain stationary and become observant. If the signal is linear, that is, combines readily with others, it will combine additively without distortion from the sound produced by the automobile. This would be the intent of the deer whistle. All of the alarm devices tested had the same statement regarding the anticipated response of deer to their sonic components and, in general, are viewed as acoustic "attention-getters", alleged to elicit a response, not of flight but of attentiveness. This would allegedly preclude the animal from bolting in front of the vehicle. In a few cases, the manufacturer's statement indicated that the device may "startle" the animal; however, most indicated that the animal was likely to acknowledge the vehicle (the sound of the whistle) by remaining still while "looking up and turning its ears."

2. Methods

In this study six alarm devices were tested. All manufacturers generally stated that these alerting devices were "ultrasonic" (>20 kHz). In two cases out of six, the frequency range of 16 - 20 kHz was given. The remaining four devices did not specify any particular frequency or frequency range, but described the emission as a high frequency. Although no intensities were reported, the devices were designed to be heard from as far away as 2 km to as close as 100 m. "Best distances" were based upon weather conditions and cleanliness of the devices, according to the information on the packages. Finally, to achieve the stated frequency and warning distance (as a function of frequency and intensity) the vehicle was required to be moving at a minimum speed of 30 miles per hour. Six different deer whistles were tested in the lab. Tests consisted of forcing air directly into the mouth of each whistle until a strong sound was emitted. Recordings were made on a Sony TCD-8 digital audio tape recorder (calibrated to a 1000 Hz tone) with a dynamic microphone. For road tests, the two "loudest" whistle pairs were mounted on two separate cars on the front bumper per manufacturer's directions. Recordings were made from a single point along a closed road at the university campus. After recording ambient noise conditions (no vehicles present), the drivers made ten duplicate runs past the microphone at speeds of 30 mph, 35 mph, 40 mph, and 55 mph. The recordings were analyzed as power spectra using a dynamic signal analyzer and by personal computer (PC) using Spectra Plus software. SpectraPLUS is one 32-bit Windows application that allows you to perform complex audio signal analysis with a Windows compatible sound card, available from Sound Technology, Inc. The relative intensities were only valid when compared to one another and compared to ambient conditions. The acoustical signal elements of concern included: predominant frequency, intensity, and variation of the signal at speed. Once the predominant frequencies (those clearly exhibiting the highest intensities) had been identified, the recordings were evaluated at those frequencies in a 1/3-octave band for comparison to hearing threshold information as given by evoked potentials (Risenhoover et al., 1997). This analysis was duplicated using Spectra Plus software. Plots were made for each of the devices tested and the predominant frequency and relative intensity information were tabulated.

3. Results

In all cases, tests determined the primary frequency of operation of the closed-end whistles to be approximately 3.3 kHz with significantly higher harmonics. The open-end whistles had a primary frequency of about 12 kHz, but this was found to vary significantly depending on how hard the whistle was blown. In the laboratory tests air pressure was applied directly to the whistle and recorded in a quiet room. Fig. 1 a shows sample frequency spectra for a typical pair of whistles as tested in the lab using forced air whereas Fig. 2 shows the results of a single road test power spectrum. Analysis of the spectrum level referenced to 20 uPa at the dominant frequencies of the whistles is shown in Table 1.

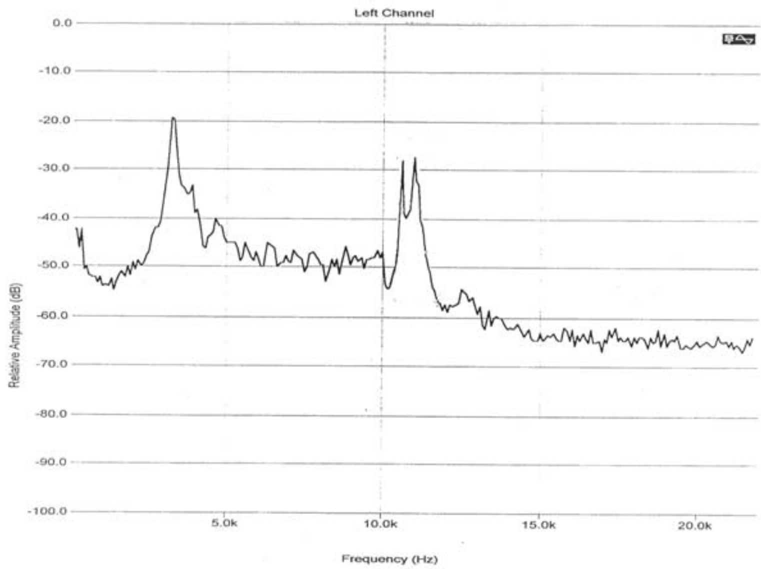

Fig. 1. Frequency spectra for closed-end and open-end deer whistles, respectively, in lab tests

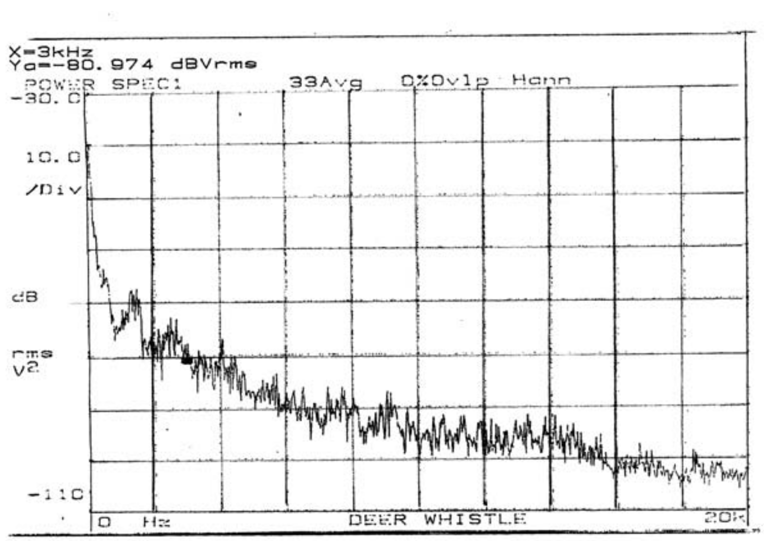

Fig. 2. Power spectrum for vehicle-mounted deer whistle (predominant frequency is 3.3 kHz at 4 dB re 20 uPa)

Table 1. Deer whistle road tests for predominant operating frequencies

Whistle frequency	Ambient noise (dB re 20 uPa)	Whistle level (dB re 20 uPa)	Warring road noise	
3.26	69.20	70.40	64.00	Mean
3.30	69.00	70.00	64.00	Median
3.30	69.00	70.00	64.00	Mode
0.13	0.63	0.70	None	Std. Dev.
12.01	35.70	60.90	None	Mean
12.00	36.00	60.00	None	Median
12.00	36.00	60.00	None	Mode
1.2345944	0.674948558	1.595131482	None	Std. Dev.

4. Conclusions

Very little is known about the dynamic range or hearing thresholds of whitetail deer. Using the information available in the literature (Risenhoover et al., 1997) hearing threshold aliases, based on auditory-evoked potentials of five deer, were used as a base from which to compare the relative intensity levels of the road test recordings Fig. 3 shows a hearing threshold curve based on the findings of Risenhoover et al. (1997). These reported deer threshold levels showed the best sensitivity of hearing for the deer to be between 2 kHz and 6 kHz. The "best sensitivity of hearing" is defined by the lowest threshold area or greatest sensitivity on the curve. They also compared well with recordings of typical deer vocalizations, which range from 1 kHz to 9 kHz (Risenhoover et al., 1997). Specifically, evoked potentials were indicated at intensities of up to 95 dB re 20 uPa at 12 kHz. This was based on tests at frequencies of: 500 Hz, 1000 Hz, 2000 Hz, 4000 Hz, 6000 Hz, 8000 Hz and 12,000 Hz. Evoked potentials were indicated at an intensity of 85 dB re 20 uPa at 16,000 Hz (Risenhoover et al., 1997). Animals should easily hear the sound of the oncoming whistle provided the signal is not overly attenuated, that is, presuming low transmission loss and ambient noise levels. The effectiveness of the devices tested was judged by comparing the predominant frequencies and intensities with the deer's best sensitivity of hearing to see if they fell at or above the threshold. Atmospheric transmission loss was considered using transmission loss from Table 2 as a guide. Although sound transmission in the atmosphere can vary significantly, even over short distances, considering the two principal components of spreading and absorption one may make meaningful estimates. Spreading loss will be 3 dB per doubled distance from the source of a transmission duct is present, to 6 dB per distance doubled for spherical spreading at short ranges (Cowan, 1994).

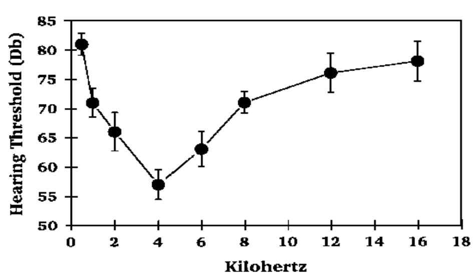

Fig.3. Hearing threshold curve of whitetail deer (From Risenhoover et al. 1997) showing the "best sensitivity of hearing" range from 2 to 6 kHz.

Attenuation of sound in air depends on the second power of the frequency and becomes very large at high frequencies. In practical terms, one or the other of these conditions dominates. If spreading loss is the dominant factor, longer ranges are possible. When absorption becomes dominant, the range becomes very limited. Table 2 shows the variation of transmission loss and range in the typical frequencies of deer whistles and was used in calculating the effectiveness of the deer whistle's signal. Both spherical and cylindrical spreading regimes are taken into consideration over the propagation distance. Four vehicle speeds were run for each with estimated road noise levels taken from Warring (1972) using the truck curve as the source to make the noise level equitable with U.S. highway traffic.

Table 2. Sound transmission loss in air

Distance	Loss due to Cylindrical Sp.	Loss due to Spherical Sp.	Loss a @ 3.3 kHz.	Loss a @ 10kHz
2 (meters)	3 (dB)	6 (dB)	.01 (dB)	.1 (dB)
512	27	54	5.11	51.1
1024	30	60	10.23	102.3
2048	33	66	20.47	204.7

cylindrical spreading = 3 dB/distance doubled
spherical spreading = 6 dB/distance doubled
absorption α = 0.01 dB/meter @ 3,300 Hz. and 0.1 dB/meter @ 10,000 Hz.
[reference distance = 1 meter]

In comparison with the stated frequency ranges claimed by these devices the predominant frequency of all six tested was 3.3 KHz for closed-end whistles and 12 kHz for open-end whistles as opposed to ultrasonic or near-ultrasonic frequencies of 16 - 20 kHz as stated. The harmonics are likely not to be heard unless it was broadcast at very high intensities in accordance with Dirichlet's rule, which states that for periodic signals with few major discontinuities in their waveforms, the energy in higher harmonics of the corresponding frequency spectrum will tend to deteriorate exponentially with the frequency of each harmonic (Bradbury and Vehrencamp, 1998). One of the predominant frequencies of the whistles, 12 kHz is clearly outside the best frequency of hearing of the deer. The average sound pressure level at 3.3 kHz was determined to be around 70 dB re 20 uPa when the device was bumper-mounted at 40 mph and was totally lost to the road noise produced by the car since it falls within the range of car noise (Warring, 1972). At this frequency, deer and humans should hear the whistle very clearly. In all tests of the whistles mounted on automobiles, the sound pressure levels of the devices were inaudible to the testers. Since these devices are specifically meant to "alert" deer and not "startle" them into flight the signal produced by the devices must be of a sufficient level for the animal to hear it while the vehicle is at a reasonable distance but not at a level that will cause a flight reaction. Consider a vehicle traveling, minimally. At 40 mph, it will cover 2,296 feet in the first minute leaving little time for the animal to move. Additionally, the hearing threshold must be considered along with attenuation to determine the signal strength required to make the device viable as a warning. Results indicate that audio frequencies could reach significant warning distances if a transmission loss of 100 dB were assumed but ultrasonic signals would be restricted to lengths of 100 m or less. If a realistic maximum total transmission loss of 100 dB is assumed, a whistle operating at 3.3 KHz would suffer significantly less than 100 dB loss at the maximum range shown in Table 1, (2048m or 6714 feet) regardless of which spreading loss applies (a loss of 33 for cylindrical + 20.47 absorption = 53.47dB, or a loss of 66 for spherical + 20.47 for absorption = 86.47dB). At 12 kHz, a range of only one-fourth that of 3.3kHz was be obtained (~512m or 1,679 feet). For example, if the hearing threshold of the deer was 0 dB at

3.3 kHz and the transmission loss was 53.47 dB then the device should be very easily heard and would broadcast out to 2048 meters. At 12 kHz the loss due to attenuation would be minimally 204 dB above the animal's hearing threshold of 85 dB by auditory evoked potential (Risenhoover, 1997). This would require signal strength of greater than 289 dB just for the animal to hear the sound. Taking into effect the noise made by the vehicle at 3 kHz (Warring, 1972), it would be expected that the source would require a level of 76 dB re 20 uPa or better to be heard at highway speed (>40 mph). This can only be achieved at the lower frequency. Another factor affecting the ability of animals to detect and use acoustic signals is the wavelength. Deer should favor narrow band, low-frequency signals over ultrasonic signals. Signals must have wavelengths of 2 - 4 times the inter-ear size of the animal to allow for coupling in air, since body size limits the auditory ability to determine arrival time differences, differences in loudness, and directionality. Thus, the greater the wavelength, the lower the intensity necessary to reach threshold and the more optimal the signal would be. In this case, a signal of 3.3 kHz will yield a wavelength of only 0.1 meters. In addition, vehicle noise will tend to change the spectral composition of the whistle signal by the addition of other frequency components and increased energy. Only the closest sources of noise are useable in terrestrial animal communication. When considering the relationship of noise to acoustic behavior, flight response of the animal must also be considered. Each animal will respond within some "flight distance" when it perceives a change in the environment (Hediger, 1964). The flight distance is a specific amount of space surrounding an animal in which the animal feels at rest. When a perceived source of danger breaches the border of the flight distance, the animal elicits some behavioral response (Hediger, 1964). Behavioral responses are developed in association with signaling codes within species. Animals acquire their signaling codes during their early development. Most developing traits are determined through a mix of environmental and genetically inheritable influences (Bradbury and Vehrencamp, 1998). "Habituation" is a part of this developmental process. To this end, the effectiveness of the deer whistle device may also be compromised in a behavioral sense.

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