Effect of kennel noise on hearing in dogs

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Objective—To evaluate the degree of noise to which kenneled dogs were exposed in 2 typical kennels and to determine whether a measurable change in hearing might have developed as a result of exposure to this noise.

Animals—14 dogs temporarily housed in 2 kennel environments.

Procedures—Noise levels were measured for a 6-month period in one environment (veterinary technical college kennel) and for 3 months in another (animal shelter). Auditory brainstem response testing was performed on dogs in the veterinary kennel 48 hours and 3 and 6 months after arrival. Temporal changes in the lowest detectable response levels for wave V were analyzed.

Results—Acoustic analysis of the kennel environments revealed equivalent sound level values ranging between 100 and 108 dB sound pressure level for the 2 kennels. At the end of 6 months, all 14 dogs that underwent hearing tests had a measured change in hearing.

Conclusions and Clinical Relevance—Results of the noise assessments indicated levels that are damaging to the human auditory system. Such levels could be considered dangerous for kenneled dogs as well, particularly given the demonstrated hearing loss in dogs housed in the veterinary kennel for a prolonged period. Noise abatement strategies should be a standard part of kennel design and operation when such kennels are intended for long-term housing of dogs. (*Am J Vet Res* 2012;73:482–489)

The deleterious effects of noise, particularly noise-induced hearing loss, are well-known in human medicine.[1,2] Within the past 40 years, legislation has been passed and criteria established in the United States to protect against occupational and environmental exposure to potentially hazardous noise levels.[3]

Constant noise can have physiologic and psychological effects in several nonhuman species.[4,5] However, few investigations have focused specifically on the deleterious effects of environmental noise on the auditory system in dogs. Whether constant noise can affect dogs, particularly working dogs that are relied upon for their enhanced sensory capabilities (eg, those used in military operations or search and rescue), is important to determine, and the conditions or environments that can impair these sensory capabilities need to be better understood.

Although anatomic differences among various animal species lead to well-understood differences in hearing,[6] the basic physiologic processes underlying the detection and sensation of sound are essentially identical between humans and dogs.[7] Noise-induced hearing loss is one of the most common causes of exogenously acquired sensorineural hearing loss in adult humans,[8] and there are no obvious anatomic or physiologic reasons to suggest that dogs would not also be susceptible to similar deleterious noise effects.

Although the situations in which dogs might be exposed to substantial, persistent noise may be few, they do exist. For example, military working dogs that are being transported by helicopter to combat landing zones are subject to high noise levels within the helicopter. In such situations, the people in the helicopter wear hearing protection because noise levels may reach 100 dBA SPL or higher but the dogs do not. Threats to hearing ability also reportedly exist for any dog placed in a typical kennel environment, in which the noise level is potentially harmful.[9]

Typically, the acoustic environment is not considered in the architectural design of kennels. These structures are usually built with concrete block walls and concrete floors with metal or hard ceilings that can be washed and sanitized easily. In addition, ventilation

Abbreviations

ABR	Auditory brainstem response
dBA	A-weighted decibel
Leq	Level equivalent
LORL	Lowest observable response level
nHL	Normal (unimpaired) hearing level
peSPL	Peak equivalent sound pressure level
PTS	Permanent threshold shift
SPL	Sound pressure level
TTS	Temporary threshold shift

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systems are usually powerful, with required rapid intake and outflow of air adding to the ambient noise.[10] Addition of animals to such an environment can yield sound levels > 100 dB SPL.[9,11] As a complicating factor, the typical construction materials and mechanical systems used in kennel construction combine to create an environment that is not only noisy but highly reverberant. Reverberation (eg, echoing or ringing of sound) contributes to the deleterious effects of a noisy environment by contributing to sustained, short bursts of sound caused by continuous reflection of the sound from hard, nonabsorbent surfaces. Noise levels in kennels can be intense enough to mandate the use of hearing protection devices by animal care staff as per 1983 Occupational Health and Safety Administration guidelines.[3]

The purpose of the study reported here was to further characterize kennel noise levels through sound level measurements in 2 kennel environments. A second objective was to provide initial data on the effects of kennel-based noise exposure on the canine auditory system through assessment of hearing ability in dogs prior to and following a 6-month stay in a typical kennel environment.

Materials and Methods

Dogs—A portion of the study was conducted at a holding kennel at a veterinary technology school, and the other portion was conducted at an animal shelter kennel. Dogs had been provided to the veterinary technology program by a research breeder and supplier and were all of mixed breed. Twenty-two dogs between 2 and 3 years of age were housed at this kennel for the duration of the study. Dogs with health problems as assessed by the project veterinarians were excluded from the hearing assessment portion of the study. The dogs served as subjects for students in the veterinary technology program and were adopted by community members at the end of the 6-month training cycle.

Dogs in the shelter kennel where noise assessments were made were provided by a research breeder and vendor and were of mixed-breed ancestry. Twenty-two dogs were brought to this kennel after the initial noise evaluation was made. These dogs were not included in the hearing assessment portion of the study because of the transient nature of their residence within the shelter.

Dogs from the veterinary kennel that were selected to undergo ABR testing received a complete physical examination including otoscopic examination and measurement of rectal temperature and heart rate. None had signs of health problems, and otoscopic examination revealed no signs of otitis externa or ear canal occlusion due to cerumen buildup. These dogs had been used to train veterinary technician students on simple health maintenance procedures, and the dogs' ears and teeth were cleaned on a weekly basis.

Kennel environment—The veterinary kennel environment was split into 2 areas: one (approx 39 m^2) housed the male dogs, and the other (approx 45 m^2) housed the female dogs. The 2 kennel areas were closed rooms constructed of concrete blocks with poured concrete floors and solid ceilings. The side for male dogs had direct access via a metal-clad door to an area outside that was used as an exercise yard. The door between the male and female sides was made of metal. The side for female dogs was completely inside the building with no outdoor access, although direct access to a common hallway for dogs and personnel between the male and female sides was provided. Overhead ventilation was provided by the building heating and cooling system.

The shelter kennel environment was newly constructed and housed male and female dogs together. It was constructed of coated concrete block walls and terrazzo floor and a solid ceiling. This kennel had some small windows above each cage, and each cage had a small access panel through which dogs could go outdoors. The kennel also had a door with outdoor access.

Kennel environment noise assessments—The noise level within the veterinary kennel was assessed before the dogs arrived and 48 hours and 3 and 6 months after arrival. A sound level meter[a] that was compliant with International Electrotechnical Commission standards 60804 and 61672 and American National Standards Institute standard S1.4 was used to measure continuous and instantaneous kennel noise levels. This meter was calibrated by use of a sound level calibrator[b] at a frequency of 1 kHz at 94 dB SPL in conformance with International Electrotechnical Commission 60942 standard class 1 specifications. Continuous equivalent sound level (dBA Leq) readings (defined as the mean sound level with the A-weighting scale integrated across the period of the measurement) were acquired for 60 minutes during each of the 4 assessment periods. In each period, measurements were obtained during 8 randomly selected 60-minute intervals for each measurement between 9 AM and 4 PM 1 d/wk. Random measurement times were selected via a random number generator to select the time of day. Measurements were obtained with microphones suspended in the kennel area, with no humans present during the recordings. This time frame was selected as representative of the kennel during fully staffed and populated operations. In addition to measuring the dBA Leq, the sound level meter also measured the maximum SPL (in linear mode), which yields an absolute value that represents the physical pressure of a sound referenced to 20 μPa of pressure.

Noise recordings were also made by use of a digital audio tape recorder[c] and a high-quality microphone.[d] Noise samples were recorded randomly for 2- to 5-minute intervals during the 4 recording sessions. Because these data are not deterministic (ie, there is no way to predict exact values of the noise levels at future times by an explicit equation), the random character of the data must be described in terms of probability and means. This requires inspection of the results of repeated samples with identical results that are within the limits of experimental error. The samples must be randomized to ensure accuracy in this manner. The noise samples were analyzed to determine the power spectrum by use of specialized software.[e]

The following one-third octave band frequencies were routinely analyzed and recorded from the power spectral analysis: 31, 63, 125, 250, 500, 1,000, 2,000, 4,000, 8,000, 16,000, and 18,000 Hz. These frequencies were purposely chosen to assess the contribution on overall noise of the heating, air conditioning, and ventilation systems; fans; and canine vocalizations. The sound level meters and recorder were placed in the same position (ie, suspended from the ceiling at approximately the middle of the kennel, 1.8 m above a centrally located desk) for each of the measurements.

Noise assessment of the shelter kennel environment was completed within 1 visit. Because this kennel was continuously at or near full capacity for the duration of the study in full operation, the sole noise assessment was made with dogs present. The same protocol was used as for the veterinary kennel noise assessment.

Accounting for reverberation—Reverberation is the persistence of sound in a space due to reflection of sound waves from nonabsorbent surfaces.[12] Its presence and decay time are based on the level of incident sound and the sound energy absorption characteristics of the walls, ceiling, and floor construction materials and methods. Because of the contribution of reverberation to the overall noise level measured in an environment, reverberation time was calculated for the 2 kennels by use of the Sabine equation:

$$RT60 = (0.049 \bullet V/a)$$

in which RT60 is the time required for a test signal to lose 60 dB in intensity, V is the volume of the space in cubic feet, and a is total room absorption at given frequency (the sum of all the surface areas in the room multiplied by their respective absorption coefficients [ie, the quantity used to describe how easily sound penetrates a specific medium]).

Hearing assessment protocol—To quantify any deleterious effects of kennel noise level on the housed dogs, the decision was made to perform hearing assessments by measuring the ABR of each dog housed in the veterinary kennel. Auditory brainstem response provides a measure of neural responses (from the cranial nerve VIII and lower brainstem auditory nuclei) to auditory stimuli through use of surface or subdermal electrodes. The technique is a widely used objective measure of auditory system function in humans and has also been used extensively in the auditory assessment of dogs.[13]

The protocol was to perform ABR testing on 3 occasions to correspond to the times at which noise level assessments were performed. The first session occurred at 48 hours after dogs arrived in the kennel to allow them to acclimate to the environment. The second session took place after the dogs had been housed in the kennel for 3 months, and the final session was completed at or near the end of the 6-month stay in the kennel. No information was available regarding noise in the environment in which the dogs were housed prior to delivery to the kennel. Therefore, the ABR findings obtained for each dog after kennel admission were used as the baseline values for determining the amount of hearing change that developed because of exposure to the known environment.

On each occasion, ABR testing was performed in one of the animal examination rooms at the veterinary technology clinic. Although the examination room was not strictly a controlled acoustic environment, sound level measurements indicated that the ambient noise level (ie, 42 dBA Leq) in the room was acceptable for completion of the ABR protocol as designed for the study. The hearing test protocol was approved by the University of Cincinnati Institutional Animal Care and Use Committee.

In designing the ABR protocol, it was decided that all ABR tests would be performed on the right ear only. The decision to measure only 1 ear/dog was governed by the need to test all dogs on the same day, while they were sedated. The decision to test only the right ear was made to simplify the preparation process for the dogs and was deemed an acceptable method because it could be assumed that any hearing loss due to noise would affect both ears in a similar manner.

A typical ABR involves 5 waves occurring within 6 to 15 milliseconds following the evoking stimulus.[14] The fourth and fifth waves in the sequence will on occasion merge into 1 broad wave, making identification of all 5 waves impossible. The second wave in the sequence (ie, wave II) is often of sufficiently small amplitude that it is masked by the background recording noise and therefore not readily identifiable.[14,15] These variances in the morphology of ABR recordings are not considered unusual and likely result from an interaction between the selected electrode placement sites, acquisition parameters, and electrical transmission characteristics of the various tissues interposed between the neural generators and the electrode recording site.[14]

When ABR testing is used to quantify hearing levels, the most commonly used interpretation metric involves identification of the lowest stimulus intensity at which the fifth peak in the sequence, or wave V, can be identified (ie, the wave V threshold). In lieu of measuring actual wave V thresholds for each dog in the present study, each dog was tested at 5 predetermined intensities and the ABR was quantified in terms of the lowest click level at which wave V could be reliably detected (ie, LORL). A minimum of 2 sets of ABR waveforms were required at each stimulus intensity level to establish acceptable replication criteria (ie, identified wave V peak or trough within 0.1 milliseconds across the 2 tracings).[15]

The equivalent stimulus intensities to be tested were 53.5, 59.3, 72.3, 77.3, 86.6, and 93.3 dB peSPL for the specific electrophysiologic test unit.[f] Given that the convention in describing click intensities for human ABR testing is to relate the intensities to behavioral thresholds for click stimuli in humans with unimpaired hearing (ie, 0 dB nHL), these dB nHL values are of questionable use in testing dogs. Although it is likely that the dB nHL values achieved for the click stimulus in humans are similar to what might be achieved in dogs, this has not yet been fully evaluated. For these reasons, the decision was made to relate the stimulus levels used to the actual peSPL being generated by the click stimulus. As a point of reference, the stimulus intensities used generally corresponded to nHL values of 30, 40, 50, 60, 70, and 80 dB, which encompass the range of intensities commonly used in human hearing assessments.

The lowest stimulus level to be tested (ie, 53.5 dB peSPL) was equivalent to 30 dB nHL. It is widely recognized in clinical application of ABR in humans that the wave V threshold measured with click stimuli will be detected at a level within 10 to 15 dB higher than the behavioral pure tone thresholds in the 2,000 to 4,000-Hz range.[15] Accordingly, a person with a repeatable wave V at 30 dB nHL would be expected to have unimpaired pure tone thresholds (ie, 15 to 20 dB hearing level) in the 2,000 to 4,000-Hz range. Given the anatomic and physiologic similarities between the human and canine auditory systems, we presumed a comparable relationship between wave V and behavioral thresholds would exist for dogs, although such a relationship has not yet been reported. Although 30 dB nHL will provide a general confirmation of unimpaired hearing in mid to high frequencies, it is possible in a well-controlled acoustic environment to complete ABR testing at lower stimulus intensities for purposes of establishing an absolute wave V threshold. Outside of a well-treated (ie, high-attenuation) sound booth, however, use of stimulus intensities < 30 dB nHL (53.5 dB peSPL) would likely have been impractical because ambient noise levels can potentially mask the test stimulus, leading to errant results. Given the environment in which the hearing testing was completed (ie, examination room off of main kennel space), there was no access to a well-controlled acoustic environment, so testing was not completed at intensities < 53.5 dB peSPL. This compromise was deemed acceptable because clinically normal wave V responses at 53.5 dB peSPL were considered a viable baseline from which to demonstrate changes in wave V responses following noise exposure.

ABR testing—The dogs were removed from the kennel for ABR testing for ≤ 2 h/d (total time out of the kennel, 6 h/wk). Areas of intended electrode insertion were swabbed with 70% isopropyl alcohol, and topical creams containing 2.5% lidocaine and 2.5% prolocaine were applied. Each dog was sedated by administration of acepromazine (0.5 to 0.7 mg/kg, IM). Previous studies have shown acepromazine to have no observable effect on ABR recordings in dogs,[13] and the use of sedation was intended to optimize the ABR recording quality by reducing artifacts due to muscle activity.[14] Three subdermal silver-chloride needle electrodes[g] were placed such that the positive electode was at the vertex-frontal midline and forehead (stop of the forehead), the negative electrode was at the mastoid process of the right temporal bone, and the ground electrode was located dorsally between the scapulae.

The ABR tests were performed by use of standardized recording parameters: a 100-microsecond broadband rarefaction click stimulus at a rate of 19.7 clicks/s with an artifact rejection rate of < 10% and filter settings of 100 to 3,000 Hz. The stimulus was delivered via an insert earphone[h] in the right ear.

Power spectral analyses were completed from the noise level recordings,[12,16] and power values were converted to dB SPL. The spectrum analyzed was across the frequency range capability of the recording equipment and represented the range of human hearing and the portion of the audible spectrum of sound of interest to potential threshold shift in dogs.

Results

Dogs—Of the 22 dogs housed in the veterinary kennel, 8 were excluded by the project veterinarians because of health concerns, leaving 14 dogs (7 males and 7 females) for ABR testing. The dogs were of mixed breed with a mean body weight of 15.9 kg.

Noise levels in kennels—The results of the noise assessments in the veterinary kennel spaces indicated that the continuous Leq (mean of the 4 measurement

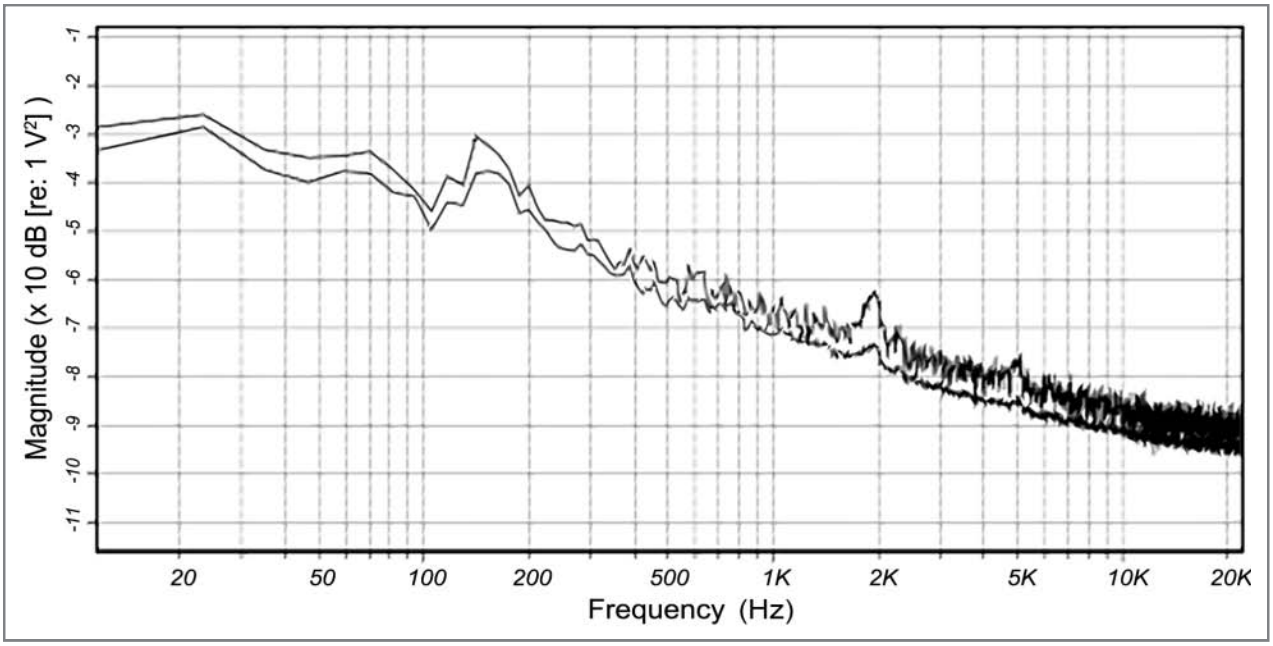

Figure 1—Power spectrum analysis for noise levels within the area of a veterinary kennel in which male dogs (n = 14) were housed. K= 1,000.

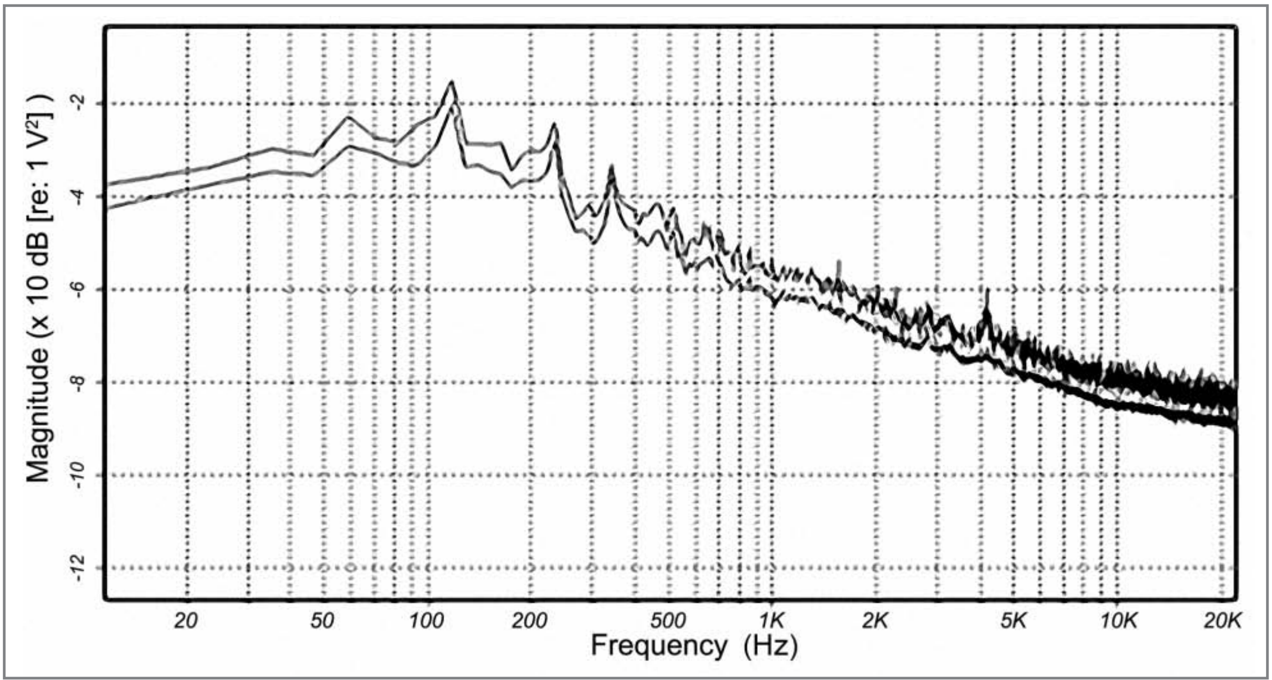

Figure 2—Power spectrum analysis for noise levels within the area of the kennel in Figure 1 in which female dogs were housed. K = 1,000.

Table 1—Wave V LORLs (dB peSPL) measured via ABR testing for 14 healthy mixed-breed dogs at admission to a veterinary technology college kennel (baseline) and 3 and 6 months afterward.

Dog No.	LORL Baseline	LORL 3 months	LORL 6 months	Minimum change in LORL from baseline to 6 months
Male				
1	53.5	77.3	77.3	23.8
2	53.5	59.3	77.3	23.8
3	53.5	59.3	77.3	23.8
4	53.5	53.5	59.3	5.8
5	53.5	59.5	59.3	5.8
6	53.5	59.3	59.3	5.8
7	53.5	77.3	86.6	33.2
Female				
1	53.5	59.3	77.3	23.8
2	53.5	59.3	77.3	23.8
3	53.5	59.3	77.3	23.8
4	53.5	59.3	59.3	5.8
5	53.5	59.3	59.3	5.8
6	53.5	59.3	77.3	23.8
7	53.5	59.3	77.3	23.8

intervals) of the area for female dogs was 102 dBA and that of the area for male dogs was 110 dBA. These measurements were obtained with all 22 dogs present. Prior to admission of the dogs, the ambient continuous Leq values were 75 and 68 dBA for the female and male areas, respectively. Differences between the 2 areas included that the female dogs were housed more interior within the building than were the male dogs and that the male dogs had an access to the outside exercise pen, whereas the females did not.

Absorption coefficients values previously derived for the range of 125 to 4,000 Hz for the construction materials in the kennel environment[17,18] were used to calculate a mean reverberation time of 3.4 seconds for the female side of the kennel and 2.6 seconds for the male side; a numeric analysis of the spectrum data (**Figures 1 and 2**) revealed the highest levels of noise occurred between 30 and 2,000 Hz.

Results of the noise assessments in the shelter kennel indicated that the continuous Leq (mean of the 4 measurement intervals) was 100 dBA. The mean calculated reverberation time for the shelter kennel was 2.0 seconds. Power spectral analyses revealed high levels of noise over frequency ranges that exceeded the ranges known to be damaging to human hearing.[18,19]

ABR testing—Lowest observable response levels for wave V of the ABR for the 14 dogs tested at 3 points during the 6-month study period were summarized (**Table 1**). All 14 dogs had a baseline LORL of 53.5 dB peSPL and had actual wave V thresholds that were at or lower than the baseline level recorded at kennel admission, suggesting unimpaired hearing. At the 3- and 6-month assessment intervals, all dogs had LORL shifts from baseline of between 5.8 and 33.2 dB SPL, indicating changes in the wave V LORL and therefore poorer hearing than when they were admitted to the kennel. One dog had an LORL shift at 6 months of 33.2 dB, and 8 had shifts of 23.8 dB at the same point. The remaining 5 dogs had smaller shifts during the study period.

In a representative dog, a repeatable wave V in response to the 53.5-dB peSPL click was detected (**Figure 3**). An analysis of the ABR response morphology for this dog at admission revealed a well-formed ABR in response to the 93.3-dB peSPL click. The ABR results at the time of discharge from the kennel indicated differences across the 2 sessions. First, the LORL had shifted to 86.6 dB peSPL because no repeatable wave V could be discerned at any lower level. Second, the morphology of the ABR in response to the 93.3-dB peSPL click had clearly degraded from that of the baseline testing session. Although a repeatable wave V was evident, the

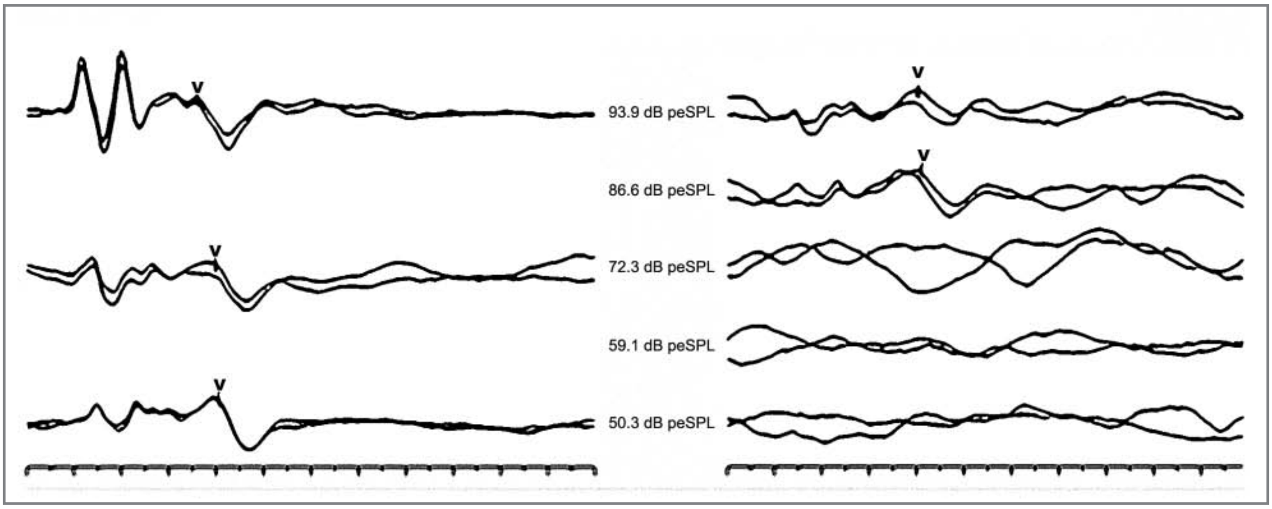

Figure 3—Selected tracings from ABR testing of a representative 17-month-old mixed-breed dog at admission to a veterinary technology school kennel (left; baseline) and at discharge 6 months later (right). Notice the repeatable wave V in response to the 53.5-dB peSPL click in the baseline tracings. The results show a wave V LORL shift of at least 33 dB across the 6 months between recording periods.

earlier waves were identifiable but not nearly as pronounced, suggesting the dog's hearing changed considerably for the worse while the dog was housed in the veterinary kennel.

Discussion

In the present study, noise assessments of a shelter and veterinary kennel housing dogs revealed continuous noise levels > 100 dBA, suggesting that hearing protection would be required for veterinary and husbandry personnel.[10] The noise levels exceeded the 90-dBA limit established by Occupational Safety and Health Administration for human exposure without hearing protection for 8 hours. Assuming that canine auditory anatomy is similar to that of humans, the expectation would be that noise levels achieved in the kennels would also be potentially detrimental to dogs.

The excessive noise in a kennel environment can be attributed to provision of adequate ventilation, gating in and out of the kennel, and barking. Other sources include noise associated with daily cleaning and husbandry activities as well as reverberation resulting from the poor absorption characteristics of the construction materials used in a typical kennel setting. Although most of these factors are challenging if not impossible to control, noise mitigation may be achieved, in part, by reducing the reverberation characteristics of the environment through use of sound absorption techniques. Typical reverberation times for a carpeted room would be on the order of 0.9 to 1.0 seconds, whereas a typical empty gymnasium might have reverberation times of 2 to 4 seconds.[18] Our results indicate a high degree of reflectivity and little absorption of sound in the kennels.

Results of the ABR testing on the dogs in the present study clearly suggested the development of adverse effects on their hearing ability during their 6-month kennel stay. At the end of the study, all of the tested dogs had some degree of hearing change and more than half had shifts in their wave V LORLs of ≥ 20 dB. Noise threshold shift standards do not exist for dogs. The Occupational Safety and Health Administration guidelines governing occupational noise exposure for humans define a threshold shift of > 10 dB as indicating an important change in hearing.[3] When this criterion is applied to the findings of the present study, it would appear that 9 of the 14 dogs had threshold shifts indicative of an important change in hearing while housed in the veterinary kennel.

Because of the study design, we were unable to quantify actual threshold shifts for the dogs. Indeed, it is likely the degree of observed threshold shift was underestimated because at least some, if not all, of the dogs would likely have had actual baseline wave V thresholds well below the lowest click intensity value of 53.5 dB peSPL. Had actual wave V thresholds been determined for the study dogs, the findings may have provided stronger evidence of noise-induced hearing change.

When interpreting the findings from the present study, 2 questions need to be addressed. The first relates to the validity of ABR testing as a measure of auditory threshold changes in dogs. The ABR is well accepted as an objective measure of auditory system function in humans and has been widely used with dogs and other animal species.[13–15] The stimulus that was used for evoking the ABR in the present study was a click. Acoustically, a click, as a transient signal, has a broad spectral signature. As the click stimulus is delivered to a test subject, it undergoes filtering from the transducer used and the outer and middle ears of the subject. In humans, this filtering function results in a stimulus that effectively excites the portion of the aural basilar membrane sensitive to the 2,000- to 4,000-Hz range.[14] Because the initial effects of noise on auditory system function in humans is detected in the 3,000- to 6,000-Hz range, a click can be an acceptable stimulus for determining hearing changes secondary to noise exposure.

The usefulness of ABR testing in the present study can be further supported by other findings that wave V thresholds are often observed in humans within 5 to

15 dB higher than behavioral thresholds in the 2,000- to 4,000-Hz range.[14] In dogs, the transducer filtering function should be no different than that observed in humans given that the insert transducers are identical. However, the filtering function due to outer and middle ear characteristics would likely be somewhat different because of anatomic differences. Also, the frequency range that shows the initial hearing sensitivity loss resulting from noise exposure may be different in dogs than in humans. These potential differences are not known to exist to date, but there is no obvious reason to expect them to be great enough to invalidate the use of ABR as a measure of hearing change secondary to noise exposure or any other pathological change within the auditory system.

A second important point to consider is the nature of the observed hearing loss for the dogs in the present study. Three broad classifications of pathophysiologic changes to the human auditory system following damaging noise exposure can be described. First, acoustic trauma results from exposure to high-impact or high-impulse noises. In humans, impulse or impact sounds ≥ 125 dB SPL can cause acoustic trauma.[1] Although high, the noise levels detected in the present study were not in a range at which acoustic trauma could occur. The other 2 pathophysiologic changes, TTS and PTS, result more from metabolic changes in the auditory system than from direct physical damage to anatomic structures.[1]

Temporary threshold shift and PTS can also be expected in humans following exposure to noise of between approximately 85 and 125 dB SPL.[1] The TTS involves a temporary reduction in hearing sensitivity, which, although variable in time course across individuals, can become evident (in the form of decreased hearing sensitivity) within minutes after exposure onset. Such temporary hearing loss is nearly always reversible (at least in terms of the pure tone thresholds), with recovery intervals generally ranging from 8 to 14 hours.[1] Conversely, a PTS has a slower and insidious onset, with measurable decreases in hearing sensitivity not noticeable for weeks, months, or even years. Such hearing loss is not reversible.[1] The underlying pathophysiologic changes involve cell death among various sensory and support cells in the inner ear, resulting from an oxidative stress reaction due to long-term overstimulation.[20] Similarities between the canine and human auditory systems would suggest that the characteristics and precipitating factors of noise-induced hearing loss for humans would apply, at least to some extent, to dogs.

The question remains whether the hearing loss detected in the present study resulted from TTS or PTS in the dogs. A means of ruling out TTS in studies (or in clinical practice) involves removing the subject from noise exposure for a minimum of 14 to 16 hours prior to reassessment[3]; however, there was no practical means of accomplishing this for the present study. At night, noise levels in the veterinary kennel may have decreased to lower than the 90-dB level used as a cutoff for requiring humans to wear protection by the Occupational Safety and Health Administration, providing at least some time for dogs' auditory systems to recover, but the data to support this supposition were not available. Follow-up testing of the study dogs was originally planned for 3 months after leaving the kennel but was not pursued.

When findings in humans are taken into account,[21] the degree of threshold shift that was evident for many of the study dogs would suggest that some degree of PTS had occurred as well as TTS. The degree of hearing loss in a number of the dogs suggests there would be a risk for PTS development in other dogs housed in an environment with noise levels similar to those in the present study. Additional research is needed to assess the long-term nature of hearing deficits developed from exposure to noise in canine housing facilities. Research involving cats and guinea pigs with classical signs of TTS has shown that permanent changes in auditory sensory receptor were present, indicating that the term TTS may strongly underrepresent the long-term consequence of this phenomenon.[22]

The threshold shifts detected in the present study should be considered evidence of potential compromises in the hearing of dogs exposed to high-noise environments. Such environments may involve dogs that are kenneled daily in preadoption or daycare situations or those used in research. Perhaps more importantly, for working dogs housed in a kennel environment, such threshold shifts may be counterproductive or even hazardous to the extent that the dogs and their handlers rely on hearing to complete their missions. Potentially, a dog's mental readiness, alertness, and physical condition could be altered by previous high-noise exposure. Given the detrimental effects resulting from exposure to potentially damaging noise levels, our findings suggest that, along with sanitary requirements for kennel environments, acoustic safety and noise mitigation strategies should also be mandated for kennel construction and animal care. Additionally, audiological evaluation of dogs housed in kennel environments should be routinely undertaken to monitor hearing status.

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[a] 2250 Sound Level Meter, Bruel and Kjaer, Naerum, Denmark.
[b] Type 4321, Bruel and Kjaer, Naerum, Denmark.
[c] TCD-D8 Digital Tape Recorder, Sony, Tokyo, Japan.
[d] 515 Series microphone, Shure, Niles, Ill.
[e] ATSpec Pro software, version 1.51, Taquis Corp, Miami, Fla.
[f] Smart EP, Intelligent Hearing Systems, Miami, Fla.
[g] Rapid-pull 13-mm subdermal electrodes, VIAYSIS, San Diego, Calif.
[h] ER-3A insert earphones, Etymotic Research Inc, Elk Grove Village, Ill.

References

1. CDC National Institute for Occupational Safety and Health. Noise and hearing loss prevention. Available at: www.cdc.gov/niosh/topics/noise/. Accessed Jan 15, 2011.
2. Dobie RA. *Medical-legal evaluation of hearing loss*. New York: Van Nostrand Reinhold, 1993;1–2.
3. Occupational Safety and Health Administration. Occupational noise exposure: hearing conservation amendment. Final rule. *Fed Regist* 1983;46:42622–42639.
4. Hetts S, Clark JD, Calpin JP, et al. Influence of housing conditions on Beagle behavior. *Appl Anim Behav Sci* 1992;34:137–155.
5. Mertens PA, Unshelm J. Effects of group and individual housing on the behavior of kenneled dogs in animal shelters. *Anthrozoos* 1996;9:40–51.
6. Fay RR. *Hearing in vertebrates: a psychophysics databook*. Winnetka, Ill: Hill-Fay Associates, 1988.

7. Strain GM, Myers LJ. Hearing and equilibrium. In: Reece WO, ed. *Dukes' physiology of domestic animals*. 12th ed. Ithaca, NY: Cornell University Press, 2004;852–864.
8. Miller MH, Schein JD. *Hearing disorders handbook*. San Diego: Plural Publishing, 2008.
9. Coppola CL, Enns RM, Grandin T. Noise in the animal shelter environment: building design and the effects of daily noise exposure. *J Appl Anim Welf Sci* 2006;9:1–7.
10. Institute of Laboratory Animal Resources. *Guide for the care and use of laboratory animals*. Washington, DC: National Academy Press, 1996.
11. Sales GD, Hubrecht R, Peyvandi A, et al. *Noise in dog kenneling: a survey of noise levels and the causes of noise in animal shelters, training establishments and research institutions*. Wheathampstead, Hertsfordshire, England: Universities Federation for Animal Welfare, 1996.
12. Beranek LL. *Acoustical measurements*. College Park, Md: American Institute of Physics, 1993.
13. Wilson WJ, Mills PC. Brainstem auditory-evoked response in dogs. *Am J Vet Res* 2005;66:2177–2187.
14. Hall JW. ABR analysis and interpretation. In: Hall JW, ed. *The new handbook of auditory evoked responses*. Boston: Pearson Education Inc, 2007;172.
15. Picton TW. *Human auditory evoked potentials*. San Diego: Plural Publishing, 2010.
16. Welch P. The use of fast Fourier transforms for the estimation of power spectra: a method based on time averaging over short modified periodograms. *IEEE Trans Audio Electroacoustics* 1967;15:70–73.
17. Cowan JP. *Handbook of environmental acoustics*. New York: Van Nostrand Reinhold, 1994.
18. Driscoll DP, Royster LH, Royster JD. Noise control engineering. In: Berger EH, Royster LH, Royster JD, et al, eds. *The noise manual*. 5th ed. Fairfax, Va: American Industrial Hygiene Association, 2003;279–378.
19. Dobie RA. *Medical-legal evaluation of hearing loss*. 2nd ed. New York: Singular Publishing Group, 2001;142.
20. Henderson DH, Bielefeld EC, Harris KC, et al. The role of oxidative stress in noise-induced hearing loss. *Ear Hear* 2006;27:1–19.
21. Behar A, Chasin M, Cheesman M. Auditory and non-auditory effects of noise. In: Behar A, Chasin M, Cheesman M, eds. *Noise control: a primer*. San Diego: Singular Publishing Group, 1999;33–49.
22. Kujawa SG, Liberman MC. Adding insult to injury: cochlear nerve degeneration after "temporary" noise-induced hearing loss. *J Neurosci* 2009;29:14077–14085.