Hearing loss in dogs is relatively common. Congenital deafness has been identified in > 80 breeds of dogs,1 and dogs (similar to humans) are subject to acquired hearing loss associated with a variety of causes (eg, middle ear disease, aging, infection, ototoxic medications, and noise exposure). Assessment of auditory function in dogs is important for a number of purposes, such as screening in puppies at high risk for congenital hearing impairment and assessing auditory function in working dogs (eg, police dogs, hearing dogs for the deaf, and guide dogs for the blind). Researchers interested in auditory genetic research in dogs or the use of dogs for the study of hearing loss in humans2–4 assess the auditory system as a component of their research. Pet owners may have concerns regarding safety risks or social behavioral problems related to hearing impairment in their pets. Methods used in the assessment of the auditory system in dogs include behavioral tests, otoscopy, several physiologic measurements (eg, acoustic immittance measurement, BAERs, and otoacoustic emissions), and imaging techniques (eg, magnetic resonance imaging).

Breeders sometimes use informal behavioral observation to help identify deafness in newborn puppies, but this technique can be problematic in that it is possible that a dog may not respond to a sound even though the auditory system is intact. On the other hand, a chance or random movement can be interpreted incorrectly to be a response to sound. In addition, when hearing impairment is unilateral, hearing loss can be missed because responses reflect hearing function in the unimpaired ear. Observers using informal behavioral observation can often misidentify dogs with hearing impairment as dogs that have normal hearing.5 More accurate behavioral testing can be conducted with training-conditioning techniques, and these techniques have been used successfully with dogs.6 However, auditory assessment involving training requires considerable time and special equipment and is not well suited for clinical purposes.

It is important to mention that behavioral measures are the criterion-referenced standard of hearing assessment because behavioral responses reflect what an animal can hear. Physiologic measures, such as acoustic

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**Evaluation of otoacoustic emissions in clinically normal alert puppies**

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**Objective**—To evaluate distortion product otoacoustic emission (DPOAE) measurements in puppies with normal hearing.

**Animals**—23 clinically normal 7.5- to 10.5-week-old puppies.

**Procedures**—A cross-sectional study was performed. The DPOAE measurements were obtained with a commercially available distortion product otoacoustic measurement system and were performed in a quiet, non–sound-attenuated room. All measurements were obtained from alert puppies and were repeated 1 or 2 times to ensure that the measurements were replicable. Results that were a minimum of 8 dB higher than the noise floor were accepted. Values from the first trial in which emissions were obtained at all test frequencies were used for analysis.

**Results**—Otoacoustic emission measurements were easily obtained, robust, reliable, and consistent with auditory brainstem response and behavioral results.

**Conclusions and Clinical Relevance**—Hearing screening in alert puppies can be accomplished reliably and rapidly with otoacoustic emissions testing. Results supported the possibility of the use of DPOAE measurement in hearing screening of dogs. (Am J Vet Res 2011;72:295–301)

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**ABBREVIATIONS**

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Definition</th>
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<tr>
<td>BAER</td>
<td>Brainstem auditory-evoked response</td>
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<tr>
<td>dBnHL</td>
<td>Decibels normalized hearing level</td>
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<tr>
<td>dBSPL</td>
<td>Decibels sound pressure level</td>
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<tr>
<td>DPOAE</td>
<td>Distortion product otoacoustic emission</td>
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<tr>
<td>NF</td>
<td>Noise floor</td>
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<tr>
<td>SPL</td>
<td>Sound pressure level</td>
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<tr>
<td>TEOAE</td>
<td>Transient-evoked otoacoustic emission</td>
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imittance measurement, BAERs, and otoacoustic emissions, provide information regarding the status of various portions of the auditory system and can be used to estimate or predict hearing sensitivity, but these measures are not measures of hearing per se.

Acoustic immittance measurements (ie, tympanometry and acoustic reflex testing) are used to evaluate middle ear mobility and to obtain information regarding auditory function. For example, acoustic reflexes are abnormal when there is severe to profound cochlear hearing loss or middle ear dysfunction (or both). Research in dogs suggests that immittance testing provides reliable and accurate assessment of the integrity of the tympanic membrane and the status of the middle ear system (eg, detection of reduced mobility related to middle ear fluid). The BAER can also be used to assess auditory system function. Clinical applications in dogs have included auditory-vestibular assessment, ototoxicity evaluation, and neurologic evaluation. Sedation is sometimes used, but measurements can be obtained without sedation of an animal. Responses are often evoked with click stimuli, which do not yield frequency-specific information; however, frequency-specific responses can be obtained in response to tone-burst stimuli and can be used for threshold estimation. Normative click- and tone-burst-derived BAER data are available for adult dogs. Click-evoked auditory brainstem response testing in dogs can be completed in 10 to 15 minutes, but frequency-specific testing requires more time. In auditory brainstem response evaluations, conductive hearing loss (eg, hearing loss associated with middle ear dysfunction) can be differentiated from sensorineural hearing impairment through comparison of responses evoked by air-conducted and bone-conducted stimulation (the latter essentially bypasses the conductive mechanism). The ability to differentiate conductive from sensorineural impairment is important for diagnosis, treatment, and prognosis.

Another evoked-potential method that can be used to estimate auditory thresholds in dogs is the recording of auditory steady-state potentials, which are elicited by amplitude-modulated stimuli. Evidence suggests that this technique may yield frequency-specific thresholds up to 8 kHz more rapidly than can be achieved with BAER testing.

Otoacoustic emissions testing is another method used in assessment of the auditory system, specifically the outer hair cells in the cochlea. Otoacoustic emissions are sounds that originate in the normal cochlea. They are thought to be by-products of nonlinear response properties of a normal cochlea that are related to outer hair cell function. Otoacoustic emissions can be spontaneous or evoked. Spontaneous emissions are not used clinically in humans partly because they cannot be measured in all normal ears. With appropriate equipment, otoacoustic emissions can be evoked and detected easily and reliably in normal ears by use of a probe inserted into the external acoustic meatus. It requires only a few minutes to complete frequency-specific measurements. For clinical purposes, emissions are evoked by transient stimuli (eg, clicks [TEOAE]) or by tone pairs (DPOAE). Both types of emissions yield frequency-specific information. In TEOAE testing, the stimulus has a broad spectrum and evokes a broad-spectrum response that is detected in the external auditory meatus and spectrally analyzed. In DPOAE testing, several sets of tone pairs are provided to evoke responses at different locations on the cochlea. Otoacoustic emissions may be quite useful for clinical assessment and for screening of the auditory systems of dogs in that congenital deafness in dogs often involves cochlear atrophy.

Currently, testing of otoacoustic emissions is not widely used in private veterinary practice, and in contrast to the large amount of information in the human literature, there have been relatively few studies on evoked otoacoustic emissions in dogs. These studies include a report concerning a spontaneous otoacoustic emission for a dog and more recent studies in which investigators have evaluated TEOAEs and DPOAEs in anesthetized and euthanized dogs. The purpose of the study reported here was to obtain DPOAE data in clinically normal alert puppies.

Materials and Methods

Animals—Twenty-three puppies (6 males and 17 females) from 8 litters under the care of a local humane shelter were included in the study. Puppies ranged from 7.5 to 10.5 weeks of age, as determined on the basis of medical records used to provide the date of birth. Body weights of puppies ranged from 1.32 to 5.45 kg (mean ± SD, 2.50 ± 0.59 kg). None of the puppies had a known history of ear surgery, noise exposure, or treatment with ototoxic medications. Experimental procedures were performed in compliance with all applicable federal and institutional animal use guidelines. The study was approved by the Auburn University College of Veterinary Medicine Institutional Animal Care and Use Committee. Written informed consent allowing participation of the puppies in this study was obtained from the humane shelter.

Experimental procedures—All measurements were performed in a quiet, non–sound-attenuated room. Measurements were performed in alert (ie, non–sedated) puppies. Otoscopic examination revealed no abnormalities (abnormalities of the external acoustic meatus or cerumen impaction) that would preclude measurement.

Behavioral observations—Behavioral responses to sound were informally assessed. Investigators observed head turns of puppies in response to sounds provided in the horizontal plane at ear level outside of the field of view.

BAER measurements—The BAER measurements were obtained with a commercially available auditory evoked potentials system. Calibration was performed in a 2-mL coupler (which is representative of an external acoustic meatus in an adult human) with a 0.5-inch type I microphone. Stimulus intensities in this system were provided in units that reflected normal...
hearing sensitivity of humans for clicks, rather than peak equivalent dBSPL. Because it is difficult to measure short-duration, rapid-onset stimuli such as those used in BAER stimulation, peak SPL of these stimuli is related to the dBSPL for pure tone stimuli (ie, the peak of the waveform is compared with the peak for a pure tone of a known intensity in dBSPL and is referred to as the peak equivalent value SPL). The dBnHL units are referenced to normal human hearing. In this system, 0 dBnHL corresponds to a root mean square peak equivalent value of 25.6 dBSPL.

Insert-type earphone transducers were coupled to 13-mm foam tips. The foam tips were compressed and then placed in the horizontal portion of the external acoustic meatus and allowed to expand. Rarefaction click stimuli were provided at intensities of 60 and 40 dBnHL (20 dBnHL when necessary) to confirm identification of wave V because wave V is robust and correlates highly with audiometric thresholds. Specifically, as intensity decreases, there is a shift in the latency at which the waveform appears. In cases of a small latency shift, 20-dBnHL stimuli were used to confirm identification of the waveform. Clicks were provided at a rate of 13.3 clicks/s. The amplifier gain setting was 75,000X, and artifact rejection was 50%. For filtering, a 30-Hz to 1.5-kHz bandpass was used. Maximum number of sweeps was 2,000, and the minimum number of sweeps was 600.

Three 0.4-mm stainless steel needle electrodes were inserted SC at the vertex of the cranium and over the left and right parietal bones. The area over the parietal bones was used to facilitate ease and symmetry of placement in an alert puppy. This placement was effective for recording sufficiently large responses to serve the purpose for which BAER recording was performed. Data were recorded on a personal computer with a dual core processor and that was equipped with accompanying software to support data acquisition.

Measurements for otoacoustic emissions—The DPOAE testing was performed with a commercially available distortion product otoacoustic measurement system. The ratio of the stimulus frequencies (ie, F2 to F1) was 1.2. The sampling rate was 48 kHz in 4,096 bins. Each bin constituted a sample within a frequency domain. The bandwidth of each bin was 11.72 Hz. Measurements were obtained at each frequency for a maximum of 16 seconds, and the fast Fourier transformed noise limit was 95%. Results that were a minimum of 8 dB higher than the NF were accepted. This value was consistent with results reported in another study. Settings for the stimulus frequency F2 were 1.5, 2, 3, 4, 6, 8, 9, and 10 kHz. Stimulus values selected were 65 and 55 dBSPL at the plane of the probe for stimulus frequency F1 and F2, respectively. A commercially available compressible foam tip (13 mm) was trimmed so that the port of the tubing in the center of the foam was flush with the probe assembly port. This foam tip was then attached to the instrument probe unit. The port of the foam tip was placed at the center of the entrance to the horizontal portion of the external acoustic meatus, and the foam was allowed to expand to provide the necessary seal.

For each trial, the data recorded included the frequencies for F1 and F2, frequency of the distortion product, the distortion product, NF, DPOAE amplitude, and noise values. In addition, a graph indicating the DPOAE amplitude as a function of the higher tone (ie, F2) of the tone pair was provided. The graph included a measure of the associated noise or NF.

All measurements were repeated 1 or 2 times to ensure that they were replicable. Values from the first trial in which emissions were obtained at all test frequencies were used for analysis.

Statistical analysis—Paired sample t tests were used to compare amplitudes between left and right ears and between males and females. A repeated-measures ANOVA was used to assess differences in DPOAE amplitude across frequencies. Results were considered significant at values of P < 0.05.

Results

Behavioral observations—All puppies accurately turned their heads in response to sounds provided in the horizontal plane at ear level outside of the field of view.

![Figure 1](image-url)
BAER screening—All subjects used for DPOAE testing in the study had BAER results consistent with normal hearing (Figure 1). This determination was based on the identification of wave V in at least 2 of the tracings evoked by a click stimulus at 60, 40, or 20 dBnHL. For all puppies, wave V was easily identifiable at a typical latency and amplitude in response to a click stimulus at 60 dBnHL, and wave V latencies shifted and amplitudes decreased in response to lower-intensity stimuli. Recorded wave V latencies were consistent with values reported elsewhere.19

DPOAE testing—The DPOAE measurements were obtained from both ears in 22 puppies, but from only 1 ear in 1 puppy because excessive movement precluded obtaining measurements at all test frequencies in the other ear. A graph of individual test results was generated for each ear (Figure 2). It typically required < 5 minutes to complete measurements for both ears of each puppy.

Mean DPOAE amplitudes did not differ significantly between the left and right ears at any frequency. In the left ears, DPOAE amplitudes ranged from 9.5 dB SPL at an F2 of 1.5 kHz to 31.0 dBSPL at an F2 frequency of 9 kHz. In the right ears, the DPOAE amplitudes ranged from 8.0 dBSPL at an F2 of 1.5 kHz to 31.0 dBSPL at an F2 of 9 kHz. The DPOAE amplitudes increased significantly for increasing F2s in the right (Wilks lambda F [7, 11] = 15.33) and left (Wilks lambda F [7, 11] = 20.24) ears.

Mean DPOAE amplitudes did not differ significantly between males and females. In males, the DPOAE amplitudes ranged from 8.7 dBSPL at an F2 of 1.5 kHz to 28.1 dBSPL at an F2 of 8 kHz, whereas in females, the DPOAE amplitudes ranged from 8.8 dBSPL at an F2 of 1.5 kHz to 32.0 dBSPL at an F2 of 9 kHz.

Data for left and right ears and for males and females were combined for computation of mean and SD for 45 ears (data were incomplete for the right ear of 1 dog); associated mean noise values were also computed. Mean DPOAE amplitude ranged from 8.8 to 30.8 dBSPL, and mean signal-to-noise ratio ranged from 11.5 to 32.2 (Figure 3).

Discussion

Results of the study reported here provide DPOAE data in clinically normal alert puppies. The absolute DPOAE amplitudes obtained in the present study are similar to those reported for anesthetized adult dogs.31,33 The DPOAE amplitudes typically increased with increasing stimulus frequency, which is consistent with findings in another study.31 Results of the present study indicated similar amplitudes between left and right ears and between males and females, which is consistent with results in other studies.36,37 In the present study, BAER testing was used in conjunction with informal behavioral observations solely to screen for possible hearing impairment in puppies being tested for DPOAEs.

Evidence indicates that canids are able to hear frequencies up to 32 or 47 kHz.6,17,18 It is important to consider whether currently available clinical DPOAE equipment, which typically measures emissions up to 10 kHz, is clinically useful in dogs. Although currently available clinical equipment does not measure emissions in the ultra-high frequencies, outer hair cell dysfunction for some of the frequencies in the best region of hearing in dogs would be detectable.6,17,18 Because

![Figure 2](image-url) Results of 2 trials (trial 1, dashed lines; trial 2, solid lines) during a typical DPOAE test session for a representative clinically normal alert puppy. The amplitude of the emission (lines with crosses) is graphed as a function of the higher tone (ie, F2) of each stimulus tone pair. The graph also includes a measure of the associated noise or NF for each trial (lines with squares).

![Figure 3](image-url) Mean (solid line) ± SD (dashed lines) DPOAE amplitudes and associated NF (dotted line) obtained from testing of 45 ears in 23 clinically normal alert puppies.
severe degeneration of the Organ of Corti is common in dogs with congenital deafness, it is likely that cochlear regions corresponding to 1 to 10 kHz would be affected in these dogs and that DPOAE testing would detect them. In addition, research in humans suggests that DPOAE measurement has the potential to be useful in detecting the onset of cochlear pathological changes in ultra-high frequencies. In a study in humans, DPOAEs in the 1- to 8-kHz range were higher in amplitude in subjects with good hearing at ultra-high frequencies (9 to 20 kHz) than in subjects with poor hearing at ultra-high frequencies. Systematic research in canids would be necessary to determine whether DPOAE measurement would be similarly useful in early detection of age-related and noise-induced hearing loss in dogs; age-related hearing loss starts and proceeds most rapidly in the middle to high frequencies (8 to 32 kHz).

For diagnostic purposes, DPOAE measurement, when used in combination with other diagnostic methods such as BAER testing, can be helpful in determining the site of lesions. It is important to recognize that it is possible for DPOAEs to be measurable in some types of deafness. For example, in a report of a Rottweiler puppy with neuroepithelial degeneration, there was early and extensive degeneration of the spiral ganglion and inner hair cells with relative sparing of outer hair cells. In that report, otoacoustic emissions were not measured, but otoacoustic emissions measurement could have been used to confirm the functionality of the outer hair cells. When BAERs are abnormal, detection of DPOAEs can be useful in diagnosing conditions that selectively affect inner hair cell or neural function. Other examples of conditions that can selectively affect inner hair cell or neural function include hypoxia, ischemia, and otoferlin gene mutations. In one of these studies, outer hair cell function was monitored by measurement of otoacoustic emissions and cochlear microphonics and inner hair cell function was monitored with neural testing (BAER measurement) during a 2-hour period of mild hypoxia. Otoacoustic emissions remained detectable, and the brainstem response deteriorated substantially.

In contrast to comprehensive diagnostic hearing evaluation, screening of hearing in dogs is designed to determine whether there is a high probability of hearing loss. Currently, BAER screening is commonly used for hearing screening in dogs. The DPOAE measurements also can potentially be used alone or in combination with BAER testing for screening purposes. Despite the fact that DPOAE measurements do not detect dysfunction at the highest frequencies at which humans are sensitive, DPOAE measurement has been found to be an excellent screening tool in humans and is likely to be similarly useful in dogs. One potential advantage of the use of otoacoustic emissions screening concerns the preparation time necessary to yield frequency-specific results. In comparison with DPOAE measurement, frequency-specific BAER testing requires considerably more time, and it may be necessary to sedate the animal. In addition, it is important to mention that electrical artifact from muscle movements and other sources can interfere with BAER recording in an alert puppy, whereas they are not problematic for otoacoustic emissions testing. Also, needle electrodes are typically used for BAER recording in dogs. Otoacoustic emissions recording can be performed with less invasive foam ear inserts.

The distinction between screening and comprehensive diagnostic evaluation is important one. Failure to pass DPOAE or BAER (or both) screening tests indicates a high probability of auditory system abnormality, and full characterization of the hearing loss is advised in those animals. This involves a comprehensive diagnostic evaluation, which is currently conducted primarily at referral facilities.

It is important to recognize that screening with DPOAE or BAER testing, even when they are used in combination, can fail to identify some animals with hearing loss. For example, in a study in humans, 21 babies who had failed otoacoustic emissions screening tests and passed an automated BAER screening test (click value of 35 dBnHL) were subsequently found to have permanent hearing impairment. As mentioned previously, for animals with some types of deafness, it is possible for DPOAEs to be present even though BAERs are absent. The BAER screening test detects these latter affected animals, but it is important to recognize that even the presence of a normal BAER does not ensure normal hearing. The BAER measurement is a test of auditory system integrity through the level of the brainstem, and normal results do not ensure normal function at more central locations. Middle- and late-latency evoked potentials and imaging are useful in identifying such affected animals.

Measurements in the present study were obtained in a quiet, non–sound-attenuated room. This test environment is typical for most hearing screening of human infants and other auditory assessment of humans. Although only puppies were used in the study reported here, in our experience, DPOAE screening can also be performed in adult dogs that are lightly sedated with acepromazine or in unsedated alert adult dogs. Currently, BAER systems suitable for screening of dogs are available for use in veterinary practice. Otoacoustic screening could complement BAER screening or serve as an alternative method for diagnosis. In humans, DPOAE thresholds are significantly correlated with behavioral thresholds. With moderate stimulus intensities (such as those used in the present study) at L1 frequencies > 500 Hz, the probability of correct identification of an ear with hearing loss ranges from 85% to 95%. For the purposes of the present study, the F2-to-F1 ratio selected was 1.2. This value has been found to yield large-amplitude DPOAEs in dogs and laboratory animals.

Use of a 2-mL coupler (which is representative of the external auditory meatus of an adult human) with a 0.5-inch type 1 microphone for calibration was deemed to be acceptable for the study. The purpose of the study was to screen for abnormalities of the auditory system through the level of the brainstem, but the study was not designed to evaluate threshold estimation. Moderate stimulus intensities were used in the present investigation because researchers in 1 study...
found that moderate stimulus intensities are optimal for distinguishing normal from impaired hearing, and responses to high-level stimulation (ie, > 70 dB SPL) may be more resistant to cochlear insult than moderate to low-level stimulation. Specifically, DPOAEs in response to low-level stimulation are highly vulnerable to trauma and seem to be dependent on a large endo-cochlear potential and normal outer hair cell function. In contrast, some DPOAEs, although low in amplitude, are still observable in response to stimuli > 75 dB SPL after combined gentamicin and ethacrynic acid treatment. These DPOAEs were detectable for approximately 7 hours after death and may have reflected a passive response of the cochlea.32

It is important to emphasize the role of BAER testing in the present study. The puppies used were healthy and had no indications or risk factors for hearing impairment, but click-evoked BAERs and informal behavioral observations were conducted to evaluate the status of their auditory systems. Click-evoked BAERs can be used in clinical neurologic evaluations.10 For example, abnormally long response latencies to click stimuli may indicate a tumor or other neurologic problem. In addition, click-evoked BAERs can be used in threshold estimation, but the relationship between click-evoked thresholds and audiometric thresholds is complicated and incomplete. Good agreement between BAER threshold and hearing sensitivity at 2 and 4 kHz in humans has been reported.13 Click-evoked BAERs do not yield frequency-specific information regarding hearing loss associated with ototoxicosis or presbycusis. However, frequency-specific information can be obtained from toneburst-evoked BAERs that, in dogs, yield information up to 32 kHz.17

We concluded that results of the study reported here provided data in clinically normal alert puppies and revealed that DPOAE measurement in nonsedated puppies can be performed easily and rapidly (< 5 minutes) in ambient noise conditions typically found in many veterinary practices. The DPOAE measurements can be used for diagnostic purposes in combination with other techniques, such as otoscopy, BAER testing, immittance testing, and imaging (eg, magnetic resonance) for auditory system assessment, and may also have applications for hearing screening in dogs when used alone or in combination with BAER testing.

References


