Detection of Deafness in Puppies Using a Hand-Held Otoacoustic Emission Screener

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ABSTRACT

The purpose of this study was to evaluate the use of a hand-held otoacoustic emissions screener to detect deafness in puppies. Specifically, distortion product otoacoustic emissions were recorded from 34 puppies (both sexes) of a variety of breeds, from 6–10 wk of age, and the results were compared to brainstem auditory evoked responses (BAER) recorded from the same puppies. Recordings were obtained from both ears in awake or lightly anesthetized puppies, and the results from each ear were compared. In all 62 ears that had normal BAERs, the distortion product otoacoustic emissions screener gave a response of “Pass.” The three puppies that had flat BAER recordings in one or both ears provided a screener result of “Refer.” In two ears with unusual BAERs (waveforms with reduced amplitudes and prolonged latencies) and a “Refer” response from the screener, there was compacted debris in one external ear canal, and the other ear canal was normal. The screener technology has proven application in human infants and is an attractive alternative to BAER testing in puppies because of expense and ease of use. (J Am Anim Hosp Assoc 2017; 53:000–000. DOI 10.5326/JAAHA-MS-6528)

Introduction

At least 48 breeds of dogs are affected by hereditary deafness; therefore, dog owners and conscientious breeders are interested in assessing the hearing status of their puppies. Perspective buyers often require some evidence of normal hearing prior to purchase. The most widely accepted and recommended method for assessing hearing in dogs is the brainstem auditory evoked response (BAER), also called an auditory brainstem response. This procedure involves recording signal-averaged neuroelectric potentials (brain waves) from scalp electrodes in response to moderately intense, short-duration stimuli such as clicks. BAER tests provide definitive evidence of hearing loss in affected pups by 6 wk of age. However, BAER equipment is expensive, and responses may be challenging to obtain in fractious puppies, especially in test areas like veterinary hospitals with high noise levels (acoustic and/or electrical).

Acoustic ambient noise and/or electrical signals produced by equipment, as well as bioelectrical signals from active muscles near recording electrodes, create significant, confounding artifacts in BAERs. Records obtained under these conditions can be difficult to interpret, leading to a recommendation by the Orthopedic Foundation for Animals that BAER recording be performed by board-certified veterinary neurologists or other highly qualified professionals.

An alternative screening method for detecting hearing loss in canines is otoacoustic emission (OAE) testing, initially described in human audiology literature in 1978 by David Kemp. Evoked OAEs are present in 99.9% of human ears with normal hearing (20 decibels [dB] hearing level [HL]) and normal middle ear function and not observed typically in ears with hearing thresholds greater than 35 dB HL. In normal ears, the auditory system emits sound
energy measurable in the outer ear. These responses are not present in ears with cochlear deafness. An OAE can only be recorded when the cochlear outer hair cells, middle ear, and outer ear canal are functioning normally. Otoacoustic emissions are classified into two groups: spontaneous OAEs (emitted from the ear without stimulation) and evoked OAEs (recordings in response to a stimulus). Evoked OAEs have been used extensively to screen for sensory hearing loss, particularly with the advent of universal newborn hearing screenings.

Evoked OAEs are obtained when acoustic stimuli are presented to the test ear via a small probe assembly placed in the external ear canal. A sensitive microphone in the probe records an acoustic response that arises from outer hair cells in the cochlea and travels in a retrograde manner through the middle ear into the external ear canal. Because stimulation and recording is accomplished through the probe, surface or needle electrodes are not necessary. Evoked OAEs are recorded reliably in normal-hearing dogs and cats and hearing health predictions are consistent with those obtained from BAERs. Although OAEs are not confounded by electrical noise, they can be masked by external acoustic noise. Relative to BAER screening data, OAE tests are frequency-specific, non-invasive, obtained in less than 2 min per ear, easily interpretable (pass/refer), and inexpensive to perform. These attributes make OAEs a viable option for use by veterinarians and licensed veterinary technicians in daily practice across multiple settings, as well as by veterinary neurologists in colleges of veterinary medicine or specialty practices. Although researchers have recently studied the feasibility of using evoked OAEs to identify hearing impairment in puppies, OAEs are still currently underutilized in veterinary medicine.

The two most common evoked OAEs are transient-evoked OAEs (TEOAEs) and distortion product OAEs (DPOAEs). Transient-evoked OAEs are recorded following a transient stimulus, such as a click or toneburst. The most common TEOAE technique involves a click stimulus at a moderate intensity. Approximately 12 msec after the stimulus presentation into the ear canal, acoustic waveforms are generated and computer averaged. Transient-evoked OAEs are displayed and evaluated based on amplitude in dB sound pressure level (SPL), percentage reproducibility at each frequency, and amplitude-to-noise ratio for each frequency. McBrearty and Pendris found that TEOAEs correctly identified all deaf ears with a sensitivity of 100% and specificity of 78%. In accord, Rogers et al. demonstrated consistent and reliable TEOAE responses from dogs with normal hearing. Distortion product OAEs were also found to be easy to measure, repeatable, and consistent with BAER findings in the same ears of clinically normal puppies. Distortion product OAEs are recorded in response to the presentation of two simultaneous pure-tone stimuli, designated as L1 and L2. The stimulus levels presented to the ear are typically below 70–75 dB SPL so as not to create technical distortion or stimulate the inner hair cells. The test frequencies are specially selected and designated as f1 and f2. When f1 and f2 occur at a specific time interval, there is an interaction of the two pure-tone stimuli, resulting in an output of energy or “distortion” from the cochlea. This evoked distortion undergoes reverse transduction through the middle ear and is converted into acoustic energy that is measured by the probe microphone in the ear canal. The predominant DPOAE is generated at the frequency value 2f1-f2. The computer analyzed results are displayed in terms of distortion product (DP) amplitude in dB SPL and noise floor (NF) amplitudes as a function of f2. The expectation is that the amplitude of the physiologically evoked sound will exceed the amplitude of the NF by 8 dB SPL.

For both TEOAEs and DPOAEs, the recordings are compared to norms and then evaluated at each frequency as normal or abnormal. However, most screening technology incorporates automated response detection, eliminating the need for individual test interpretation. When an OAE is recorded, one can expect normal/near-normal cochlear function, which in turn supports normal/near-normal hearing.

The purpose of the current study was to compare BAER and DPOAE data from the same ears in lightly anesthetized and unanesthetized puppies across several breeds to determine if the test results were consistent. If data from both procedures are in agreement, then DPOAEs should be promoted to veterinarians as a viable, quick, noninvasive, less-expensive method than BAERs for assessing hearing in puppies.

Materials and Methods
A total of 68 ears from 34 puppies (seven litters), including nine bull terriers and 25 Dalmatians (16 males and 18 females), were used for this study. All puppies (6–10 wk of age) were admitted for a routine hearing evaluation. Prior to testing, the puppies had health screenings, which included a brief history of previous veterinary care, an auscultation of the heart, and examination of the oral cavity. All subjects were deemed healthy for participation in the study. The contemporary standard of care was provided to each puppy, and animal use was consistent with acceptable practices as described in the American Animal Hospital Association policy statements. Written informed consent for participation was obtained from owners prior to testing. If the litters consisted of a large number of puppies or they were fractious and/or noisy, light anesthesia was used. This occurred in 29 puppies. Prior to anesthesia, lubricant was placed into each eye. A mask was placed
over the puppy’s nose and mouth (Figure 1A). A light plane of anesthesia was induced with 4.5% Sevoflurane and maintained with 2% or less. Oxygen only was delivered just prior to the end of the procedure to insure quick recovery, usually within 5 to 10 min. Spontaneous breathing and heart rate were monitored continuously. Because ambient noise can interfere with recordings, all testing was completed in a quiet room. The puppies were placed in sternal recumbency on a padded table. For the nonanesthetized puppies (five puppies), a veterinary technician embraced the puppy in a blanket on a padded examination table. Distortion product OAEs and BAERs were recorded from both ears. The order of recordings was randomized.

**DPOAEs**

Distortion product OAEs testing was completed using a handheld screener. A probe assembly was fitted with a soft foam tip (13 mm) and connected to the handheld screener (Figure 1B). While compressing the foam tip, the upper portion of the pinna was grasped and gently pulled upward and backward while the foam tip was inserted into the external ear canal. Once the foam tip was fully expanded, OAE testing was initiated. The speakers within the probe assembly generated two pure-tone stimuli, L1 and L2, with L1 = 65 dB SPL and L2 = 55 dB SPL at one point per octave ranging from 2000–5000 Hz. For each tone pair, the frequency ratio (f2/f1) was 1.22 and the artifact level was 30. Measurements were obtained at each set frequency for a maximum of 12 sec. The recording device used algorithms for calculating the DP amplitudes and NF levels. Numeric results for DP, NF, and DP-NF values were recorded at each frequency. These numbers were automatically compared to criteria norms for humans with and without hearing loss, and a result of “Pass,” “Refer,” or “Noisy” was displayed on the screener device. In order to receive a result of “pass” using a handheld screener system, the minimum absolute amplitude of the DP was $-6$, $-5$, $-8$, and $-7$ dB SPL for 5,000, 4,000, 3,000, and 2,000 Hz, respectively. The DP-NF value was 6 dB SPL at all frequencies, and the number of frequencies to pass a screening was three. For equivocal results, the screener displays “refer” (Table 1). If a puppy did not pass the DPOAE screening, the OAE probe assembly was removed, and the external ear canal was otoscopically examined. The DPOAE was then repeated. Each recording took approximately 50 sec.

**Brainstem Auditory Evoked Responses**

Brainstem auditory evoked responses were recorded on an electrodiagnostic system. Small subdermal electrodes were placed at the vertex (positive) and just rostral to the base of each ear (reference) and over the occipital condyle (ground). At least 512 monaural clicks alternating between condensation and rarefaction (<100 μsec duration) were delivered through a cushion insert at 90 dB HL and a stimulus rate of 20/sec. The nontest ear received a continuous white noise at an intensity of 70 dB. After 500 noise-free averages, the recording was saved. Two separate signal-averaged recordings were overlaid and stored for review. BAERs were examined for waveform morphology, wave amplitudes, latencies, and reproducibility of the two recordings. Each recording took approximately 1 min 30 sec.

**Results**

Brainstem auditory evoked responses and DPOAE procedures were performed successfully in all 68 ears from 34 puppies, and the conclusions from BAER and OAE testing were in agreement regardless of the age, sex, breed, or conscious state of the puppies. Based on the results of dual assessment, 29 puppies were bilaterally normal and five puppies had an abnormality in one or both ears. One puppy had flat BAERs on both sides and screener results of...
refer from both ears. Two puppies had unilaterally normal BAERs and flat BAERs in the opposing ears. The screener results from these puppies were pass from the ears with normal BAERs and refer from the opposing ears with flat BAERs.

Of particular interest were two puppies (numbers two and six) from the same litter, both of which had normal results in the left ears and abnormal responses in the right ears. The OAE screener gave a response of pass for both puppies from the left ears with normal BAERs but refer for both puppies on the right sides with abnormal BAERs (Figure 2). The abnormal BAERs revealed prolonged peak latencies and reduced amplitudes. In puppy number two, the peaks of waves I and V on the right side were about 0.78 msec longer than peaks I and V on the left side. However, the I–V interpeak latencies were nearly identical on both sides. The peak of wave I on the left side was about five times larger than wave I on the right side. This pattern of BAER findings is consistent with a conductive hearing loss and perhaps a superimposed sensorineural loss. Visual examination of the right ear canal in puppy number two revealed debris that prevented

<table>
<thead>
<tr>
<th>Ear/Result</th>
<th>Frequency (Hz)</th>
<th>dBSPL</th>
<th>DP</th>
<th>NF</th>
<th>DP-NF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Left/refer</td>
<td>5000</td>
<td>−13</td>
<td>−19</td>
<td>6</td>
<td></td>
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<tr>
<td></td>
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<td>2000</td>
<td>−11</td>
<td>−12</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Right/pass</td>
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<td>−16</td>
<td>41</td>
<td></td>
</tr>
<tr>
<td></td>
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<tr>
<td></td>
<td>2000</td>
<td>30</td>
<td>−5</td>
<td>35</td>
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</table>

dBSPL, decibel sound pressure level; DP, distortion product; NF, noise floor.

FIGURE 2  Brainstem auditory evoked responses (BAERs) from puppies number two (left) and number six (right) from a litter of seven puppies. The otoacoustic emission screener gave a response of pass for the left ears of both puppies (top recordings) and refer for the right ears in both puppies. Brainstem auditory evoked response results confirmed the normal responses on the left sides in both puppies, and results from the right sides had prolonged peak latencies and reduced amplitudes. An examination of the right ear canals revealed debris in puppy number two that prevented viewing of the tympanic membrane, whereas the ear canal in puppy number six was clean with a normal-appearing tympanic membrane. Arrows mark the introduction of sound stimuli into the external ear canal. Roman numerals label the most prominent BAER peaks. Time and voltage calibrations are provided. BAER, brainstem auditory evoked response.
viewing the tympanic membrane. The pattern of results for puppy number six was slightly different than that from puppy number two. Brainstem auditory evoked responses findings revealed poor morphology, a latency of wave I on the right side that was 0.33 msec longer than the latency of wave I on the left side, and reduced peak amplitudes for all waves, especially wave V. The I–V interpeak latencies from right and left ears were approximately 2.5 msec. This pattern of BAER findings is consistent with a sensorineural loss. Visual examination of the right ear in this puppy revealed a normal appearing tympanic membrane.

Discussion

The purpose of the current study was to compare BAER and DPOAE data from the same ears in lightly anesthetized and unanesthetized puppies across several breeds, to determine if the test results were consistent. As anticipated, DPOAEs in this study were in perfect agreement with the BAER results. In all but two ears, DPOAE results of refer were accompanied by flat BAERs. In the two puppies (puppies number two and six) with a refer result in their right ears, the BAERs were not flat but were not normal. This was encouraging because the additional attention given to the ears with a refer result was warranted even though the BAERs were recordable. This also supports a sensitivity threshold of the BAER that is higher than expected in a totally deaf ear. Thus, the result of refer means that hearing may be reduced due to a conduction loss, a sensorineural loss, or both. Puppies with a refer result could be referred to a regional facility for video otoscopy and BAER testing.

In accord, DPOAEs reveal healthy and impaired cochlear functioning in humans.\(^3,11\) Distortion product otoacoustic emissions can take less than 1 min and have test sensitivity of \(>90\%\) and a specificity rate of \(>95\%\) in healthy newborn infants.\(^3,16,17\) Reported sensitivity measures in infants are not closer to 100%, primarily due to poor return rates for follow-up testing, progressive hearing losses, and/or conductive components (i.e., amniotic fluids) at the time of testing. There is sufficient evidence to show sensitivity rates much closer to 100% when babies are screened 3–4 days after birth compared to within the first 24 hr.\(^19\) It is important to note that in human beings, an OAE response does not translate into audiometric data normally expected from a vocal response audiogram. A profound hearing loss could have the same OAE pattern as a moderate hearing loss (e.g., absent responses at frequencies associated with the impairment).

Otoacoustic emissions have also been recorded from animals. The first DPOAEs were reported in cats, guinea pigs, and chinchillas.\(^19–21\) Since that time, DPOAEs have been used to investigate the effects of acoustic overstimulation, hypoxia, ototoxic drugs, and endolymphic hydrops on cochlear function, as well as in the development of hearing.\(^21,22–27\) Just as in human ears, the distortion product 2f1-f2 is the most prominent DPOAE and has been described for cats, rats, guinea pigs, chinchillas, gerbils, rabbits, mice, and monkeys.\(^19,21,23,25,27,28–31\) Results indicate that DPOAEs are recorded reliably in these species following complete basilar membrane maturation and therefore noninvasive means to monitor cochlear function.

Both evoked OAEs and BAERs have been shown to be effective screeners for canine hearing. However, there are many advantages of evoked OAEs over BAERs, especially when considering clinical accessibility of hearing screening for young puppies. First, BAER preparation time is approximately 10 min, requiring the placement of small subcutaneous needle electrodes into the scalp of puppies,

### TABLE 2

Currently Available Handheld Otoacoustic Emissions Screeners

<table>
<thead>
<tr>
<th>Manufacturer/Equipment</th>
<th>Screening Performed</th>
<th>Result Format</th>
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</thead>
<tbody>
<tr>
<td>Otometrics/Accuscreen</td>
<td>TEOAE, DPOAE</td>
<td>Automated screener</td>
</tr>
<tr>
<td>Grason Stadler/GSI Audioscreener</td>
<td>TEOAE, DPOAE</td>
<td>Automated screener</td>
</tr>
<tr>
<td>Grason Stadler/GSI 70</td>
<td>DPOAE</td>
<td>Automated screener</td>
</tr>
<tr>
<td>Grason Stadler/Corti</td>
<td>TEOAE or DPOAE</td>
<td>Automated screener</td>
</tr>
<tr>
<td>Natus Medical Inc./AuDX-Pro</td>
<td>TEOAE, DPOAE</td>
<td>Automated screener, diagnostic protocols</td>
</tr>
<tr>
<td>Natus Medical Inc./Echo-Screen</td>
<td>TEOAE, DPOAE</td>
<td>Automated screener</td>
</tr>
<tr>
<td>Maico Diagnostics/ERO-SCAN</td>
<td>TEOAE, DPOAE</td>
<td>Automated screener, diagnostic protocols</td>
</tr>
<tr>
<td>Otodynamics Ltd./Otocheck</td>
<td>TEOAE, DPOAE</td>
<td>Automated screener</td>
</tr>
<tr>
<td>Interacoustics/OtoRead</td>
<td>TEOAE, DPOAE</td>
<td>Automated screener, diagnostic protocols</td>
</tr>
<tr>
<td>Welch Allyn/OAE hearing screener</td>
<td>DPOAE</td>
<td>Automated screener</td>
</tr>
</tbody>
</table>

DPOAE, distortion product otoacoustic emissions; OAE, otoacoustic emission; TEOAE, transient-evoked otoacoustic emissions.
and sometimes light sedation. Alternatively, evoked OAE preparation time is around 15 sec, requiring placement of a soft foam probe tip in the ear canal and can be completed easily without sedation in a cooperative puppy. Additionally, click-evoked BAERs recorded from dogs may take 10 to 15 min, with more frequency-specific, tone-burst BAER testing taking 4–6 times longer. McBrearty and Penderis found the average test time for TEOAEs and DPOAEs was 69 sec and 123 sec, respectively. Thus, both types of evoked OAEs can be measured quickly, and DPOAEs, in particular, provide frequency-specific information about cochlear function.
function. During evoked OAE test procedures, there are fewer artifacts from muscle movement than with BAERs. These myogenic electrical artifacts often play a significant confounding role in the morphology of BAERs but do not impact OAE results. Still, the fit of the probe tip during OAE is critical, without which, the stimulus parameters will be faulty. Typically, an error message will be displayed if the probe is not inserted properly. Also, while there are only a few commercially available BAER screeners, there are multiple manufacturers of OAE screeners, allowing for flexibility based on need (Table 2). Options for commercially available, portable screeners and full-feature BAER devices have increased with recent advances in technology. However, the economy and noninvasiveness of OAE screeners have clear and distinct advantages compared to BAER equipment.

Finally, based on signal processing algorithms, most OAE screening devices generate a pass or refer for the test ear based on the amplitude and/or phase of the response relative to the amplitude and/or phase of the noise in surrounding frequencies. Therefore, OAE screening devices require little to no interpretation of the results by the operator. Only the most basic BAER screeners generate pass/refer responses. Furthermore, the procedure for recording OAEs is noninvasive and responses are highly repeatable. These attributes make OAEs a viable option for use by veterinarians and technicians in daily practice across multiple settings, not just veterinary neurologists at colleges of veterinary medicine. Figure 3 displays a recommended screening hierarchy for use by veterinary professionals who might want to consider performing hearing assessments on their patients. For a response other than pass, the displayed protocol is suggested.

Conclusion

In the current study, we examined DPOAEs, recorded from the ear canals of awake and lightly anesthetized puppies of multiple breeds and compared these data to those of click-evoked BAERs from the same ears. Currently, the Orthopedic Foundation for Animals reports that the BAER is the only accepted method for assessment of hearing loss in dogs. Distortion product otoacoustic emissions are not widely used in veterinary practices, perhaps because of a lack of exposure to this type of hearing screening technique. However, results from a large number of canine ears presented in this study are in accord with previous findings that BAER and DPOAE screening protocols reveal identical pass/refer identification regardless of the age, sex, breed, or conscious state of the puppies and demonstrate that DPOAE screenings produce identical pass/refer conclusions in a fraction of the time required for BAER screenings.7,8 This is possible because the majority of the BAERS that do not “pass” are flat, and only a few present a variety of changes in wave amplitudes and latencies, requiring interpretation by experienced professionals. Distortion product otoacoustic emissions equipment is portable and inexpensive compared to BAER equipment, and DPOAE screenings do not necessarily need to be performed, or interpreted, by a board-certified veterinary neurologist, neurophysiologist, or audiologist. Although sedation, light anesthesia, or sleeping does not negatively impact DPOAE data, a cooperative awake patient will provide reliable results.

In agreement with the findings cited herein, human data from extensive research over the last several decades led The Joint Committee on Infant Hearing to conclude in their 2007 position paper that screening protocols in the well-infant nursery should include either an automated BAER or evoked OAE as its initial screening measure.32 Therefore, it seems reasonable to suggest that DPOAEs should be added as an accepted method for assessment of hearing loss in puppies. Perhaps agencies such as the Orthopedic Foundation for Animals,33 which makes recommendations about assessment of hearing in animals, would be willing to include DPOAE testing as a valid hearing screening procedure, thus giving dog owners and breeders more options for determining the hearing status of their pets. Specifically, because of their size and portability, significantly lower cost, faster test time, noninvasive nature, and ease of obtaining and interpreting DPOAE versus BAER data, DPOAE screeners are a viable option for use by veterinarians and licensed technicians in daily practice across multiple settings. 

FOOTNOTES


REFERENCES