Artykuł przeglądowy *Review*

BAER hearing test: Principles of operation and interpretation for dogs and cats

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Summary

The nervous system of animals is a focus of interest of multiple research centres. The evolution of medical engineering, the development of new research techniques and the improvement of existing ones increase our understanding of the nervous system. One of the diagnostic methods which can be used to help detect hearing disorders of varying severity in animals and humans is the study of brainstem evoked potentials known as BAER (brainstem auditory evoked response), BAEP (brainstem auditory evoked potentials) or ABR (auditory brainstem response). Although this method has existed for decades and is used in many countries around the world, the knowledge gathered by doctors over the years lacks proper systematization, and neither standard parameters nor a coherent implementation strategy have yet been established. Various modifications of this method are also available, which suggests directions for further research and facilitates an increase in the pool of knowledge concerning the physiology of hearing. Unfortunately, the lack of established recommendations for the practical implementation of hearing tests using the BAER method makes it difficult to compare test results and to broaden the scope of application of this method in dogs and cats. For the most part, this problem results from a random selection of test parameters by researchers who do not have sufficient knowledge about the physics of hearing. This work aims to summarize the results obtained in this field by various authors around the world and to determine the best-performing variants of the BAER method. The optimization and systematization of the parameters not only increases the reproducibility of the results and makes them more transparent and uniform for both doctors and animal keepers, but also renders them more reliable. This could aid in the creation of a worldwide database resulting in beneficial outcomes over time and may also allow veterinarians to determine the most effective approach for conducting a study depending on many variables that need to be taken into account.

Keywords: BAER, hearing examination, dogs, cats

Before the BAER method had been established and optimized, hearing performance was determined by simple behavioural tests, which did not require any equipment, but were also a very imprecise diagnostic method. In a typical test, the animal's behaviour in response to sounds produced by natural surroundings or by the doctor or the animal's owner is observed. The animal's ability to hear is determined based on its response to sounds of diverse intensities and frequencies. Most often, veterinarians look for Preyer's reflex, that is, a flexion of the pinnae in response to an unexpected trigger, such as a hand clap. One disadvantage of this method is that pets in a clinic are often exceedingly anxious, so their alertness to the examiner may be diminished. In addition, while certain animals may exhibit involuntary movements in response to sound stimulation, it is important to note that a startle response may also be triggered by the sense of vibration rather than the sense of hearing.

Spontaneous responses may also appear even when a substantial hearing impairment exists and thus camouflage different degrees of deafness. In 2013, Mason et al. (18) sought to determine the validity of the aforementioned tests by comparing their outcomes with those of the more accurate BAER testing. The owner's observations seemed to be accurate when there was no hearing failure, but were erroneous in cases in which there was some deterioration in this sense (18). That study confirmed that behavioural testing is an important and rapid method for the initial testing of hearing quality in animals, but cannot be used as the sole testing method, as it has a low accuracy and a high error rate.

This is especially important in the case of single-sided deafness. Dogs cope very well with this condition in the environment and adapt to one-sided hearing to such an extent that the owner is usually unaware of his pet's problem. Behavioural tests do not detect this disorder as the dog reacts normally and this may easily lead to a misdiagnosis (37). A series of experiments have been performed to compare BAER results recorded at different sound hearing levels regarding the parameters of waves I, II, III and V in healthy ears of unilaterally deaf dogs with values obtained from dogs with normal bilateral hearing. Results indicate no meaningful differences in these parameters, except wave III amplitudes at 75 dB, which were higher in unilaterally deaf dogs (22).

The fundamentals of BAER testing were established by Casseday et al. (3), who performed tests on cats. The animals were trained to be able to locate sounds in space. Then they were grouped and subjected to the following surgeries: trapezoid body transection, unilateral and bilateral transection of the lateral lemniscus as well as unilateral and bilateral transection of the brachium of the inferior colliculus. The outcomes demonstrated that even after the bilateral transection of the lateral lemniscus and a deep bilateral transection of the brachium of the inferior colliculus, some region of the ascending auditory system was still unbroken above the medulla, as the animals were still competent enough to localize the sound source. The sole influence of the unilateral transection of the lateral lemniscus or brachium of the inferior colliculus was a slight loss of precision in sound localization. It was also discovered that, as the binaural analysis emerges at the level of the medulla due to the occurrence of trapezoid body failure, this results in a permanent loss of capability to localize sounds (3). These experiments provided a basis for understanding that the process of hearing and sound localization is functionally determined by many centres in the brain, and changes in their operation cause various effects in the form of impaired hearing. In the following years, these changes could be observed and precisely interpreted using wave records produced by the BAER method. However, despite considerable expansion in knowledge about the anatomy and physiology of the auditory system, some aspects of its functioning remain unknown.

After that experiment (3), to the best of the author's knowledge, no other large-scale surgical study was performed to confirm the localization sites and the effect of the excision of specific areas of the brainstem of dogs or cats on the hearing process. It is on the basis of the results of the aforementioned experiment that the principles of the BAER method were established. Since its repeatability has not been confirmed over many years of analysis, various theories have been developed from BAER records on the basis of observations by numerous authors (24, 26, 28, 38) and experiments regarding the generation centres of individual waves. The high level of complexity of animals' brains and the possible lack of precision of surgeries at that time mean that those results are now regarded as indicative rather than definitive.

Currently, researchers focus on the need to repeat extensive localization studies and examine the impact of damage to specific areas of the brain on the physiology of hearing. The most frequently raised recommendation is the use of a non-invasive magnetic resonance imaging or the EEG method (23). As the brain consists of an enormous number of neural pathways, which often run both ipsilaterally and contralaterally, crossing and forming branches, the same effect can sometimes be achieved by different procedures performed on the brain without necessarily yielding a definitive and precise location diagnosis; rather, it points to a broader area or field of the brain (Fig. 1).

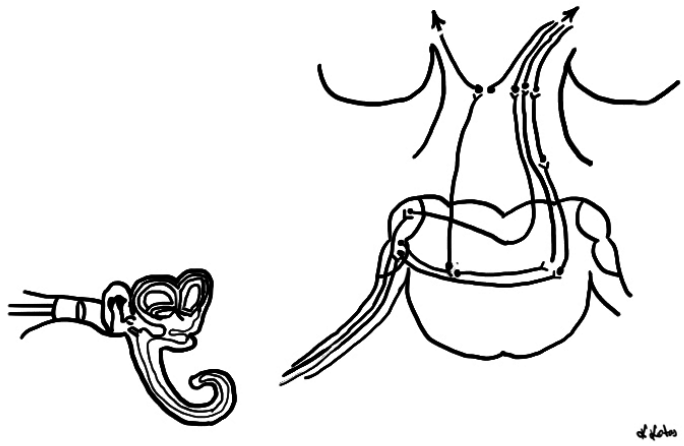

Fig. 1. The complexity of the auditory pathway. Author: Kinga Kotas

Years after these experiments were conducted and the era of behavioural research began, the BAER method is now at the forefront of hearing testing.

The BAER method is concerned not only with hearing disorders in dogs, as hereditary deafness is a major problem among many animal species. Phenotype predispositions that significantly increase the risk of hearing problems include white pigmentation of the skin and hair. Some genes associated with these problems have been identified (21): the merle gene is connected, among others, with deafness in the Shetland Sheepdog and the piebald gene is linked with this condition in several breeds, including Dalmatians, Beagles and Bulldogs. Among dogs, congenital deafness has been reported in more than 100 dog breeds, and their list is growing as research progresses. This information can be found on the webpage https://www.lsu.edu/deafness/breeds.html. Many kennel associations endeavour to limit this phenomenon and publish recommendation concerning BAER testing in dogs. However, neither the Federation Cynologique Internationale nor the Polish Kennel Club makes it obligatory to test the hearing of dogs, even for breeds with a particularly high percentage of animals with unilateral or bilateral deafness. Recommendations of the Polish Kennel Club can be found at https://www.zkwp.pl/regulaminy/Regulamin_Hodowli_Psow_Rasowych_Zalacznik_nr_10.pdf. This problem concerns, among others, a particularly significant percentage of Dalmatians, German Shepherds, Toy Poodles, Chihuahuas, Cocker Spaniels, Beagle and Australian Cattle Dogs. The full updated list of the affected breeds has been created by Louisiana State University and can be found online at https://www.lsu.edu/deafness/breeds.htm. In the United Kingdom, an investigation was conducted to reduce the prevalence of congenital sensorineural deafness among Dalmatians using BAER testing. The study screened 8955 Dalmatian puppies between 1992 and 2019, and the results showed an overall prevalence of 17.8%. Patients with the highest genetic risk were excluded from breeding, which reduced the prevalence of deafness (16). Between 2000 and 2018, a screening study was conducted in the United Kingdom on English Setters to determine the prevalence of hearing impairment in puppies and its association with their sex and phenotype. The results showed that 95.5% of dogs did not have any hearing impairment, while the prevalence of unilateral deafness was 3.6% and that of bilateral deafness was 0.9%. The study also found that females were 3.3 times more likely to suffer from any hearing impairment (17).

In the case of cats, this list is definitely shorter and includes Norwegian Forest Cats, Ragdolls, Siberians, White Turkish Angoras and more, although cases of congenital deafness can also be found among different breeds of cats with different fur colours. The webpage https://www.fci.be/en/provides information on this subject. It is also worth noting that the loss of pigmentation in the form of white fur colour caused by retrovirus insertion in the KIT – FERV1 gene located in locus W is closely connected with deafness and the blue colour of the iris. More informations can be accessed on the website of an international genetic laboratory https://www.genomia.cz/en/test/locus-w/.

In Poland, breeders are increasingly aware of the value of hearing tests in animals and the benefits of reducing the frequency of deafness. However, the lack of information available outside veterinary circles means that many of them are still unaware of the possibility of conducting such tests, and, as a result, some unilaterally or bilaterally deaf animals continue to be sold as „healthy". In 2016, 243 dogs were tested in Poland for unilateral and bilateral deafness. Among them, 19% had abnormal BAER recordings: 11% were unilaterally deaf, and 5% were bilaterally deaf. This experiment proved that sensorineural deafness is a problem in the Polish dog population (21).

It is also important to mention that hearing examinations are an important element of a neurological examination, which should be carried out regularly not only in animals showing signs of hearing impairment, but also in those with problems of the nervous system in general, so in their case a hearing test may indicate the need for further diagnostics.

In order to correctly interpret BAER recordings, it is essential to understand the anatomy and physiology of sound conduction.

Sound and its conduction

The ear has an extremely complex structure, which is responsible for the appropriate functioning of both the sense of hearing and equilibrium. A sound wave is a mechanical wave that enters the hearing organ through the auricle, the first structure of the outer ear. It collects, concentrates and directs the acoustic wave, which is then directed to the external auditory canal and amplified. It also plays a crucial role in localizing the direction of the stimulus and protecting the ear canal. The dog's ear canal includes a right angle turn that separates the canal into two portions: the vertical canal and the horizontal canal. At the point where the horizontal canal deviates, a prominent cartilaginous ridge, called Noxon's ridge, marks the transition from the vertical to the horizontal canal (3, 10).

The next component of the ear involved in this process is the tympanic membrane, which is a boundary between the external and middle auditory canals. This structure terminates the horizontal canal. It can be of various sizes, from 30 mm^2 to 55.3 mm^2, depending on the size of the dog. The grey pars tensa and pink pars flaccida are visually distinguishable parts of the tympanic membrane. A bulging pars flaccida may be a sign of infection in the middle ear. Beyond this structure, there is an air-filled space: the tympanic cavity (*bulla tympanica*). Thanks to its flexibility and elasticity, as well as its continuity, it can vibrate and transmit acoustic waves to the auditory ossicles.

In the middle ear, there are bones: the malleolus, the incus and the stapes, which are connected by joints and ligaments. Their size in a dog varies from 7.2 to 8.45 mm for the malleolus, from 2.85 to 3.45 mm for the incus and from 2.1 to 2.55 mm for the stapes. The manubrium of the malleus articulates with the tympanic membrane, while the head of the malleus articulates with the body of the incus to form the incudomalleolar joint. The lenticular process of the incus then hinges with the head of the stapes at the incudostapedius joint. Those ossicles bound in a chain move in response to vibrations of the tympanic membrane caused by sound waves. The stapes then articulates with the oval window at the vestibule of the inner ear. The stapedius muscles and the tensor tympani muscles are the middle ear muscles activated as a reflex to an intense sound. Their contraction aids in the reduction of sound transmission through the middle ear, which protects the organ of Corti from overstimulation.

After this, the wave propagation medium changes from air to a liquid environment in the inner ear. It is an extremely stable environment: only very extraordinary electrolyte changes in the body can alter its parameters, such as viscosity, density or sound conductivity (5, 32).

The petrous portion of the temporal bone protects the cochlea, which is housed in a bony labyrinth. The bony labyrinth consists of three semicircular canals, the spiral cochlea and the vestibule, which is placed between them. The cochlear ducts, which lie within the spiral cochlea of the bony labyrinth in the membranous labyrinth, contain the actual organs of hearing: the organ of Corti, tectorial membrane, vestibular membrane and sensory cells bathed in endolymph. These organs are located in space called the middle stairs (scala media). They are filled with endolymph and are connected to the stapes via the oval window. The cochlea on both sides contains ducts called the vestibular stairs (scala vestibuli) and the tympanic stairs (scala tympani) filled with perilymph, a fluid that communicates directly with the cerebrospinal fluid of the subarachnoid space. The basilar membrane separates the scala vestibuli from the middle stairs. On the surface of the organ of Corti, the inner and outer hair cells are located, which connect to the spiral ganglion and thus transmit impulses to the cochlear nerve.

As the ossicles interact with the oval window, perilymph within the scala tympani and scala vestibuli becomes displaced, resulting in the shearing of the hair cells along the basilar membrane in the organ of Corti. This shearing action causes ion channels to open, thus depolarizing the hair cells, which then transmit an electrical signal to the cochlear branch of the vestibulocochlear nerve via synapses at the bases of the hair cells (15, 32).

Stereocilia are the mechanosensitive organelles of hair cells that respond to the movement of liquids. Hair cells convert fluid pressure and other mechanical stimuli into electrical impulses through the numerous microvilli that constitute the rods of these organelles.

The spiral limbus is located medial to the organ of Corti. This is where the covering membrane (membrana tectoria) of the middle cuticle begins. Within it are the immersed ends of the stereocilia of the outer hair cells. On the outer wall of the middle scale, there is a vascular stria, which is responsible for endolymph production. Endolymph contains a high concentration of potassium and a low concentration of sodium, which is the exact opposite of potassium and sodium concentrations in perilymph. This difference is responsible for the intracochlear potential, that is, an electrical potential of about +80 mV between the endolymph and the perilymph, which sensitizes the receptor. Endolymph is formed from perilymph during selective ion transport through the epithelial cells of the Reissner membrane. As sound vibrations pass through the middle ear and push the oval window inwards, perilymph in the vestibule of the scales is compressed, and the basement membrane is pulled back. The deviation of the basement membrane results in the bending of the cilia embedded in the tectorial membrane. The bending of the cilia depolarizes the hair cells, which stimulates the spiral ganglion nerve fibres that merge at their base. Damaged hair cells can inhibit the generation of electrical signals, which results in a sensorineural hearing loss (6, 15).

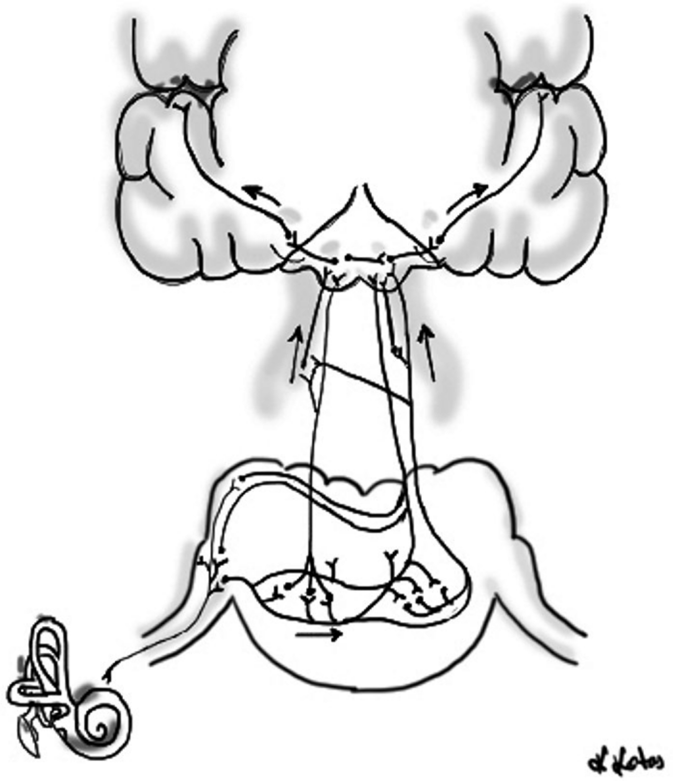

Fig. 2. Auditory pathway. Author: Kinga Kotas

The helical ganglion cells of the cochlea are the first neuron of the afferent auditory pathway (sensory division of the peripheral nervous system) (Fig. 2). From the spiral ganglion, impulses are transmitted through the cochlear nerve to the brain. Impulses from the cochlear nerve are transmitted to the cochlear nuclei within the medulla oblongata. The pathways from the cochlear nuclei lead to the contralateral and ipsilateral side and pass through the nucleus of the trapezoid body, the brainstem lateral lemniscus nucleus, the dorsal olive nucleus and the caudal colliculus nucleus of the tegmentum of the midbrain (the pathways pass to the same and the opposite sides) to the medial geniculate nucleus (corpus geniculatum) of the thalamus. The medial nucleus of the geniculate body, located in the thalamus of the diencephalon, is an element of the fourth afferent neuron of the auditory pathway. From the thalamus, impulses are transmitted to the cerebral cortex. They are important for conscious sound recognition.

The efferent pathway (motor division of the peripheral nervous system), in turn, begins in the pyramidal neurons of the auditory cortex. The olive-cochlear centrifugal pathway originates in the dorsal olive nucleus complex and reaches the cochlear nerve (6, 12, 15, 32).

BAER Parameters

Sound is a wave. It consists of pressure fluctuations propagated through an adjustable medium, such as air or liquid. The rate at which the pressure oscillates in time is termed frequency (the number of cycles per second), and the unit of frequency is the hertz (Hz).

An important feature of a sound wave is also its amplitude, or intensity. This is expressed in decibels with the use of a logarithmic scale. A bel is a 10-fold increase in the energy of a sound. One tenth of a bel is called a decibel (dB).

The intensity of a sound stimulus applied to the ear can be measured by the decibel sensation level (dBSL), decibel hearing level (dBHL), decibel peak equivalent sound pressure level (dB SPL) or decibels (dB). When an individual ear is examined, dBSL units are used, and when a group of healthy animals are used to establish the normal level of hearing for a given species, dBHL units are preferred. Both of these parameters, however, are fairly subjective (8, 29).

The most objective unit is dB SPL. It was established through the measurement of the headphone sound response amplitude. The air within the external ear canal is a medium of low impedance (a measure of the resistance of a medium to a sound wave propagating within it), whereas the fluid in the inner ear has a high impedance – about 4000 times as large as that of air. The impedance differences between these two media necessitated another structure that would compensate for them, since energy transfer is optimal only if specific media impedances are equal. These structures are the tympanic membrane and the middle ear ossicles. The environment in the external ear canal is also characterized by stiffness. When the stiffness of the conducting medium increases, the transmission of low frequencies weakens. Solid masses, such as polyps, decrease transmission at high frequencies however. The stiffness depends directly on the volume of air. A body of air with a small volume will have a greater stiffness. The inverse of impedance is compliance. This parameter can also be clinically useful in the measurement of mobility. Both parameters are expressed in cubic centimetres of air. One example of a stiff system is when sclerosis or ossification occurs, which may produce a high impedance. Conversely, loose systems, such as soft tissue or exudates, will have a high compliance. There is commercial equipment available consisting of external ear canal probes with acoustic generators, microphones and positive-negative air pumps with a nanometer. It seals the external ear canal, ensuring that air is trapped, and the oscillator then produces a sound with a preset Hertz value, the nanometer controls the pressure, and the microphone can then be used to measure the sound pressure level (SPL). The SPL is expressed as the mobility/compliance of the tympanic membrane. A high SPL indicates a low compliance. It is essential to check the electrode impedance before testing, as it may change the outcome of the test significantly (29).

It is recommended that dB SPL units be used, where the reference for a 0 dB peak sound pressure is 20 μPa. For any sound, this reference is equal to 20 times the logarithm to the base 10 of the ratio of the sound pressure measured to the reference pressure; a typical reference for 0 dB root mean square SPL is 20 μPa (25).

The essential electrical system used to perform the BAER (brainstem auditory evoked responses) examination includes a computer with appropriate software, an acoustic stimulator, a signal amplifier, a signal averaging device, an analogue-to-digital converter, filters, artefact eliminators, electrodes and audiometric headphones.

Currently, cutoff filters in the range of 50-3000 Hz (38) are recommended.

The primary parameters used to characterize the stimulus and influence the test record are the polarity, intensity and frequency of the stimulus. The most frequent type of stimulus used is a click, which has the desirable characteristics of a wide power spectrum and a short sound pressure rise time. As a result, the entire basilar membrane of the cochlea is stimulated. This excitation, which is non-specific in frequency, makes it possible to synchronize a large bunch of auditory nerve fibres and obtain a high-amplitude potential. This illustrates the activity of the auditory system over a broad range of frequencies (2000-4000 Hz). However, frequency-dependent disorders, such as senile deafness, cannot be detected this way (7, 13, 26, 33).

Stimulus polarity can also severely affect BAER records. The movement of the sound membrane towards the eardrum is called condensation. The opposite is rarefaction. Most commonly, the refraction method is used, but a controlled reverse can help the examiner distinguish between artefacts, as they should reverse in polarity, whereas BAEP (brainstem auditory evoked potentials) should not. The most severely affected by stimulus polarity changes is wave I, which, with rarefaction, produces a shorter latency and a higher amplitude. An additional advantage of refraction is improved demarcation between waves III, IV and V. Wave V, however, may not even be seen until the stimulus polarity is reversed. The most frequently used polarization of the stimulus is the one causing the expansion of air in the external auditory canal (29, 32, 38, 39).

The masking noise level has also been studied in dogs. It is currently known that a contralateral noise level of 30 dB below the click level delivered to the ear may be sufficient (23).

The frequency of clicks in the range of 5-50 Hz does not cause significant changes in the latency of waves, but increasing it to 91 Hz shortens this parameter (38).

The decibels normal hearing level (dBnHL) is the level of hearing for an average person. In this case, 0 means the quietest sound that can be heard by a healthy individual, regardless of the frequency of the sound. For non-tonal stimuli, such as a click, this value will be reported in dB nHL. During tests in the intensity series, a gradual disappearance of waves for values below 50 dB nHL may be observed. This process starts with waves I, II and III. Wave V is the last to disappear. The BAEP threshold is the limit value of sound intensity at which wave V is still present. The appearance of those waves and the exact physiology of their generation will be explained later in the paper. In healthy dogs, it should not exceed 25 dB nHL (19, 33, 34, 37). The threshold is lowest when clicks and 4 kHz tone bursts are used. The use of tone-burst sounds as stimuli is considered to have been appropriate because it allowed researchers to acquire information concerning both the frequency and the BAER waveform (34).

The most frequently used stimuli are clicks. The sound is directed into each ear, usually beginning with an intensity of 70 dB nHL, 33 clicks/sec. This level is similar to a scream. Then, analysis begins. When a normal waveform is recorded, the stimulus should be reduced by 10 dB steps, and a repetition should be performed until no response is generated. After that, the intensity of the sound should be increased in increments of 5 dB until the lowest decibel level producing a repeatable positive response is achieved. This level is called the "threshold". The threshold is always different and depends on the species, breed, age and health status of the animal, as well as on temperature and other factors. In the case of dogs, if there is no response at 70 dB nHL, the sound signal is increased in steps of 10 dB nHL until a maximum level is reached, which according to different authors may amount to 90 or 95 dB nHL.

Canines in which correct recording can be measured at 40 dB HL or above have a mild hearing loss, whereas 60 dB HL and above is defined as a moderate hearing loss. Dogs with normal recordings at 75 dB HL or above have a severe or profound hearing loss (4).

The procedure

Evoked potentials (EP) are the averaged reaction of multiple neurons to some external stimuli. The type of stimulus used defines the area from which the response will arrive, and the principal classification of evoked potentials is based on the type of stimulus applied. Thus it is possible to distinguish between auditory evoked potentials (AEP), somatosensory evoked potentials (SEEP), visual evoked potentials (VEP) and motor evoked potentials (MEP) (27). Regardless of the factor generating the potentials, they can be classified according to the period of latency, that is, the time that elapses from the moment the stimulus is triggered to the appearance of responses. Thus they are categorized as short latency responses (SLR), medium latency responses (MLR) and long latency responses (LLR), with response times of less than 10 ms, 10-100 ms and 100-300 ms, respectively (18). BAEPs are far-field, short-latency potentials. This term is due to the remoteness of locations at which potentials are generated in response to a given stimulus and the location of their collection. Increasing stimulus intensity at a constant stimulus rate reduces wave latencies in canines (20).

Clicks are the most frequently used stimulus. They are delivered in a series of broadband clicks, with a centre frequency of 2-4 kHz. They can be applied by headphones coupled over the auditory meatus or by earphone transducers placed inside the auditory meatus. In comparative studies conducted on dogs, it was observed that earphones cause an increase in the latency of waves at all routinely used sound intensities, while inter-peak latencies remain unchanged. The threshold is another factor that increases when an insert transducer is used. It has also been claimed that circumaural headphones produce a greater degree of crossover effect, which could affect the results of BAER tests. Research conducted in 2020 revealed a difference between these two types of earphones: latency was 0.083 ms longer and the mean threshold was 6 dB higher for earphones. It is worth noting that headphones used in human audiometry are strictly designed to fit the anatomy of human ears. Currently, there are no specific headphones for dogs, which may distort the results. Moreover, putting pressure on headphones that do not fit results in ear canal compression, which prolongs wave latencies. It was measured to increase them by 0.8-1.0 ms (11).

During the BAER test, the patient is placed on the sternum (Fig. 3). Audiometric headphones (the insert type) are placed in the external ear canal and adjusted to its diameter. Subcutaneous needle electrodes can be positioned variously according to different authors (1, 10, 24, 36). According to the standard recommended by the University of Life Sciences in Lublin, one

Fig. 3. Electrode connection points. Author: Kinga Kotas

should place the active electrode at the vertex of the skull, reference electrodes at the level of the mastoid processes of the temporal bones on the left and right side, and the grounding electrode medially between the eyes or at the height of the third cervical vertebra (36).

The impulses are registered electronically and transmitted to the computer, where appropriate programs convert the data into a legible waveform.

The traditional time over which the signals are recorded is 10 ms. During that time, the auditory stimulus emerges as a multipeak wave, typically consisting of five to seven peaks (Fig. 4). Each peak illustrates neuroelectric activity in the auditory pathways (10, 34).

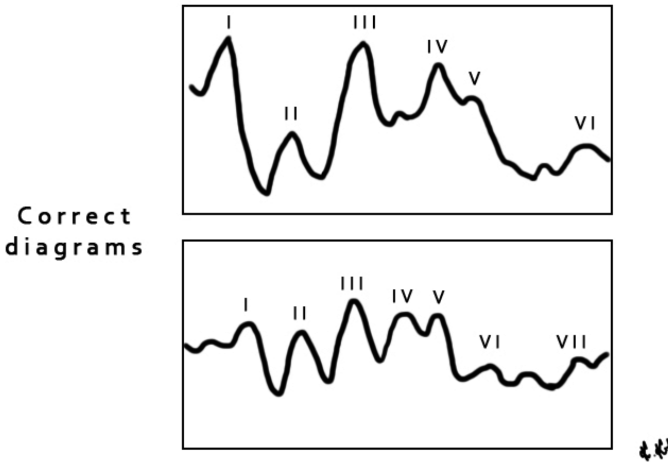

Fig. 4. Correct diagrams. Author: Kinga Kotas

Interpretation

A normal BAER recording in animals is a five-peak waveform known as a Jewett sequence (9).

The waves mirror periods when the ear electrode tip is positively charged. For dogs, the first wave begins 1-1.5 milliseconds after the sound stimulus is received, and the subsequent waves arise at intervals of about 1-5 ms. Their amplitudes range from less than 1 µV to approximately 6 µV. Also, the earlier waves (I, II, III) are larger than the later waves (IV, V) (2).

In order to interpret BAEP wave records, it is necessary to know where each wave is generated. Wave I, which has the shortest latency, is believed to be generated (ipsilaterally) in the vestibulocochlear nerve. Wave II originates (also ipsilaterally) in the cochlear nucleus (which consists of the ventral cochlear nucleus and the dorsal cochlear nucleus). Wave III arises (ipsi- and contralaterally) in the area of the dorsal nucleus of the trapezius body, wave IV stems from the region of the lateral lemniscus, and wave V is generated (ipsi- and contralaterally) close to the inferior colliculus of the midbrain cover. Wave VI is believed to be created in the medial geniculate body of the thalamus, whereas wave VII is marked by the acoustic radiation of the forebrain. It is worth noting that wave IV is rarely present as an autonomous wave because of the closeness of systems generating the neighbouring waves (10, 34).

Occasionally, these waves do not form individual peaks. The multi-peak nature of the first wave may also be visible. The double peaks of wave I may be explained by the fact that potentials are generated when a nerve impulse travels through different conductive media (extracranial to intracranial). There may also be similar changes in wave II records. As the vestibulocochlear nerve has branches leading to cochlear nuclei, all impulses reach both the ventral and the dorsal cochlear nuclei. The position of the recording electrode relative to both and the fact that the number of synapses in the ventral cochlear nucleus is greater than that in the dorsal one might explain the slight differences in wave latency and peak amplitude between waves II and III.

This pattern of wave formation, however, is considered by some authors (14, 30, 38) to be outdated and only approximate. The multitude of nuclei responsible for the transmission of sound, as well as their frequent crossing and passing ipsi- and contralaterally, means that, according to the current state of knowledge, we cannot be completely certain where a given wave is generated. Experiments that sought to identify locations where impulses originate were performed many years ago and have not been repeated or updated since then (3). Nevertheless, the information provided above may be useful in determining an approximate area of the brain that is not functioning properly, which is usually entirely sufficient for diagnostic and therapeutic purposes.

Many articles (7, 18, 24, 26, 28) describe the usefulness and importance of the BAER method in everyday veterinary practice. Often, clinicians performing the procedure obtain results that slightly deviate from the norm and wonder whether their patients are still within the normal range or should be classified as cases of mild deafness. Some authors present results of one of the studies showing physiological deviations and a range of values within which patients are still considered healthy in terms of hearing.

In 2018, an article was published on the evaluation of deafness in 12 apparently healthy dogs with the use of the BAER method. The patients were divided into group I, consisting of healthy dogs, and group II, comprising sick ones, but without ear problems. The band frequencies used were 100 Hz and 3 kHz, and an 85 dB insensitivity was selected. The mean latencies for waves I, II, III, IV and V were 1.78 ± 0,17, 2.74 ± 0.10, 3.70 ± 0.19, 4.69 ± 0.11 and 5.75 ± 0.15 ms in group I and 1.79 ± 0.17, 2.79 ± 0.18, 3.62 ± 0.18, 4.77 ± 0.14 and 5.69 ± 0.17 ms in group II, respectively. The mean inter peak latencies for the I-III, III-V and I-V intervals were 1.91 ± 0.27, 2.04 ± 0.35 and 3.99 ± 0.22 ms in group I and 1.89 ± 0.20, 2.01 ± 0.26 and 3.87 ± 0.24 ms in group II, respectively. These results show that all dogs were free of deafness at the time of testing and that BAER results can be used as a low-cost and rapid method of determining whether some disease has had an impact on the patient's auditory system (28).

Conclusion

The BAER hearing test is indisputably one of the most crucial diagnostic tools in modern veterinary medicine. The work of many scientists has been developing this field of science for years, but the method continues to pose problems due to the absence of unification and standardization of parameters and the uncertainty in result interpretation. Recent reports suggesting the divergence of norms for individual breeds indicate the need for further research and regimens for specific groups of patients. This is particularly important since the development of this method can broaden our knowledge about many neurological and laryngological conditions. Another useful discovery of recent years is genetic research aimed at determining the predisposition to deafness. However, in order to perform this type of diagnostics, a previous screening test is required which meets the conditions of being inexpensive, rapid and non-invasive. These criteria are certainly met by the BAER method.

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