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A Comparative Study of Insert Earphones and Circumaural Earphones in the Brainstem Auditory-Evoked Response Test of Dogs

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Abstract : We aimed to investigate the differences in the efficacy of insert and circumaural earphones when performing the brainstem auditory evoked response (BAER) test with dogs. Hearing loss may occur congenitally or secondarily in dogs. The BAER test, unlike the classical ethological method, is the most reliable diagnostic tool to assess canine auditory function. Furthermore, there are certain advantages of using insert earphones rather than the standard, circumaural earphones. We subjected eight dogs to the BAER test with insert earphones and circumaural earphones. The result revealed that the latency of waves was delayed with an insert earphone. The inter-peak latency did not show any significant differences between the two transducers, and the threshold was higher when using an insert earphone. Moreover, the circumaural headphones produced a greater degree of crossover effect than the insert earphones, and this cross-over effect could affect the outcomes of the BAER test. Considering these results, we concluded that insert earphones may be more appropriate when performing the canine BAER test.

***Key words* :** dog, auditory function, brainstem auditory evoked response, insert earphone, circumaural earphone, cross over effect.

Introduction

Hearing loss occurs commonly in dogs (17,23), with the primary cause being congenital sensorineural deafness, which has been reported in at least 90 species of dogs (13,14). The exact reason for congenital hearing loss in certain breeds is unclear; however, autosomal recessive and polygenic mechanisms have been suspected (13,24).

Hearing loss may also occur secondarily from ear or brain diseases. The external ear canal could be narrowed by edema of the otitis externa, subsequently reducing in sound conduction. Additionally, dogs with otitis media may have reduced hearing because of the damage to the tympanic membrane or the accumulation of inflammatory exudation in the middle ear (12). Central nervous system diseases, including brain tumors and hydrocephalus, can cause secondary hearing loss in dogs (1,22).

Previously, the classical method to evaluate canine auditory function was to use an ethological response, such as the Preyer reflex. The Preyer reflex refers to the dog's response of moving its back ears to the direction of the sound (17). However, this approach is inappropriate for diagnosing unilateral hearing loss or auditory dysfunction, along with the fact that this method cannot elucidate the extent of hearing loss (17,29). Additionally, this behavioral response may easily be affected by the level of consciousness, sound vibrations, and visual stimulation occurring simultaneously during the test. Therefore, it cannot be considered as an appropriate diagnostic tool to evaluate canine auditory function (17,29).

Repetitive sound stimulation travels through the cochlea and is delivered to the cerebral cortex via the brainstem, following which electrical impulses that are specific to the sound waves are generated. The BAER test records the changes in electrical signals that are generated along this auditory pathway. The electrophysiological changes appearing during the first 10 ms are analyzed to evaluate the auditory function (14,17,19,29).

Currently, the BAER test is the most reliable diagnostic tool to assess canine hearing. Both ears can be independently evaluated, and reliable results can be obtained even under sedation or anesthetic conditions. Furthermore, considering its advantages such as the objectivity of the outcomes, short testing time, and non-invasiveness than the other tools, it can be applied in a number of cases to diagnose canine auditory function (13-15,17). The BAER test is a good option to understand canine congenital deafness and secondary hearing loss caused by diseases of the central nervous system (13,17). The BAER test can be used by veterinarians to locate brainstem lesions suspected of causing secondary hearing loss (4,7,13).

Regardless of the species, BAER consists of 7 positive waves that are released within a period of 10 ms, consistent with the sound stimulus. Generally, the first wave is detected in 1.0-1.5 millisecond, with the next waves being formed in 0.5-1.0 millisecond interval in order, having an amplitude of

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1 μV-6 μV. Each wave is defined as a number in order, but not all waves are always observed. The wave IV is frequently not detected and is combined with wave III, and wave V. Wave VII is also often hardly detected. Among the seven waves, only the first five waves have any form of clinical significance (17,29). Previously, all waves were assumed to have their neural generators in the brainstem. However, recent studies have revealed that waves are generated by multiple structures, except for waves I and II (29).

BAER equipment is now computer-based and is divided into a stimulus component and recording component. The display screen, electrode, amplifier, and signal average belong to the recording component, while the stimulus generator and transducer belong to the stimulus component. We used the insert earphones or circumaural earphones designed for humans for the canine BAER test. Recently, bone conductive earphones have also been used (16,17,29).

In humans, there are some known advantages of using insert earphones rather than standard earphones. Insert earphones reduce the electrical artifact, prevent ear canal collapse that may occur when using standard earphones, and are more convenient for patients (5,6). For humans, many studies compare the efficacy of insert earphones and circumaural earphones when performing the BAER test. However, there is little research on the differences between the two transducers in veterinary medicine. Therefore, this study aimed to investigate the differences in the efficacy of insert and circumaural earphones when conducting the BAER test with dogs.

Materials and Methods

Subjects

We included 8 young adult dogs, which consisted of 2 small-sized dogs (2.8 kg, 4.2 kg), 5 middle-sized dogs (10-14 kg), and 1 large-sized dog (27 kg). The subjects aged between 2 and 4 years with no specific prior medical history. The 2 small-sized dogs were all chihuahuas, 4 of the middle-sized dogs were beagles, and the other one was a mix, while the one large-sized dog was a retriever. Six male dogs and 2 female dogs were used in this study.

Before the BAER test, an otoscopic examination, ear smear screening, and blood tests were conducted for each dog, the results of which were normal. No structural disorders that may affect auditory function were confirmed by radiography.

All dogs were treated following the guidelines approved by the Institutional Animal Care and Use Committee (IACUC) of Gyeongsang National University (approval no. GNU191111-D0057).

Measurement techniques

Several minutes before the BAER test, all dogs received intravenous medetomidine (10 mcg/kg). The test was conducted with dogs monitored using an echocardiogram (ECG). Body temperature was maintained at approximately 37-39°C using a heating pad.

In all cases, alternative clicks of 100 μs were given at 10 click/sec for the stimulus. We used a mask noise and the sound intensity ranged from 90 to 20 decibel hearing level (dB HL), subsequently decreasing the intensity by 10 dB HL. All BAER records were made using a computerized electrodiagnostic system (Nihon Kohden Neuropack M1) under sedation.

Four subcutaneous stainless-steel needles were inserted in the vertex, forehead, and mastoid levels of both ears. Electrical activity was amplified to 100-2,000 Hz, and an AC filter was used. Approximately 300-500 sweeps were conducted depending on the intensity of noise with a sampling time of 100 μs.

We used the Nihon kohden YE-103J as the insert earphone, and Elega DR-531 was used as the circumaural earphone (Fig 1).

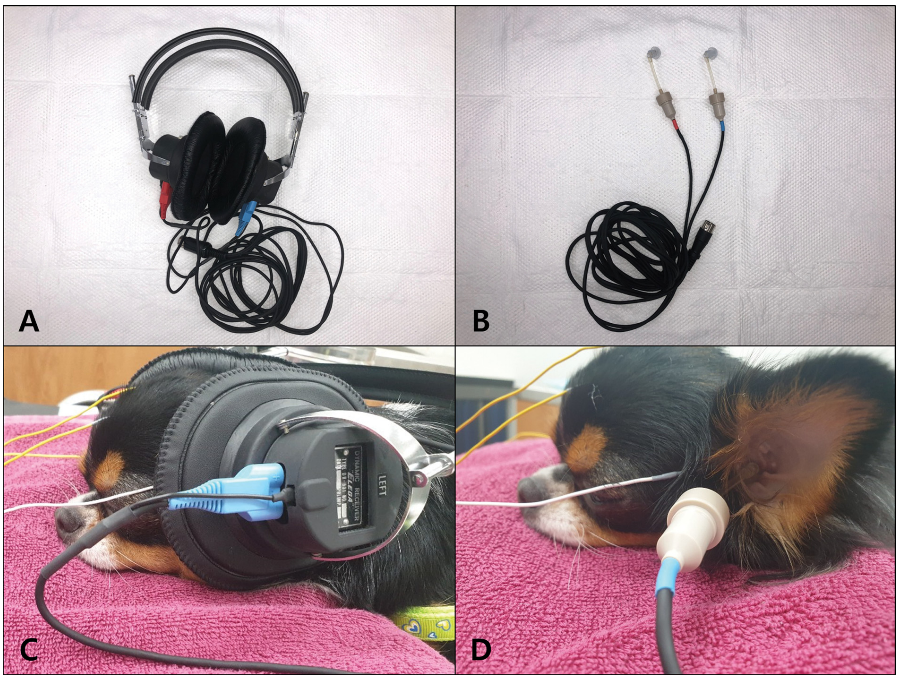

Fig 1. The circumaural earphone (A, C) and the insert earphone (B, D) which used in this study.

Experiment

The experiment consisted of 3 groups. Insert earphone were used in group 1, and the circumaural earphone in group 2. In group 3, the earplugs were installed in the non-test ear and a circumaural earphone was used.

In groups 1 and 2, waves I, II, III, and V latency, and waves I-III interpeak latency (IPL), III-V IPL, V amplitude, and threshold were measured with 10-dB intervals from 90 dB to 20 dB. In group 3, only the wave V amplitude was measured with 10-dB intervals from 90 dB to 20 dB. Each measurement was made according to the level of the decibels, to the point at which the waves were no longer observed. The sound intensity was reduced by 10 dB from 90 dB to 20 dB, and the average between the decibel at which wave V was not detected for the first time and the decibel immediately preceding the same was recorded as the threshold value.

Other than the type of transducers and earplugs used in group 3, all conditions were identical for the three groups. All dogs were placed in a sternal position. All noise was eliminated except for the computer and footsteps of people passing through the corridor.

Statistics

The statistical significance of all differences was tested using the paired t-test and Wilcoxon rank-sum test. SPSS 25 (IBM Co., Armonk, NY, USA) software was used for the analyses.

Results

Linear graphs for the mean latency of waves I, II, III, and V for the insert earphone group and circumaural earphone group are presented in Fig 2.

Latencies for both earphones increased with the decrease in sound intensity. Additionally, there was a trend for a degree of greater standard deviation at low sound intensities in both earphones. The most significant difference was the higher latency of the insert earphone group. This difference does not appear to be sound intensity-dependent.

The mean latency difference and standard deviation for the waves I, II, III, V, IPL, and IPL between the insert earphone and circumaural earphone are presented in Table 1. This table also contains the number of ears identified by each wave in both earphones. The difference was calculated by subtracting the latency obtained with the circumaural earphone from latency observed in the insert earphone.

The results showed that the mean latency of waves I, II, III, and V was higher for the insert earphones at all decibels. The mean of all latency differences between the insert and circumaural earphones was 0.083 ms. The mean difference between the two earphones showed a statistical significance in the 60-90 dB range of waves I, II, III, and V. The mean

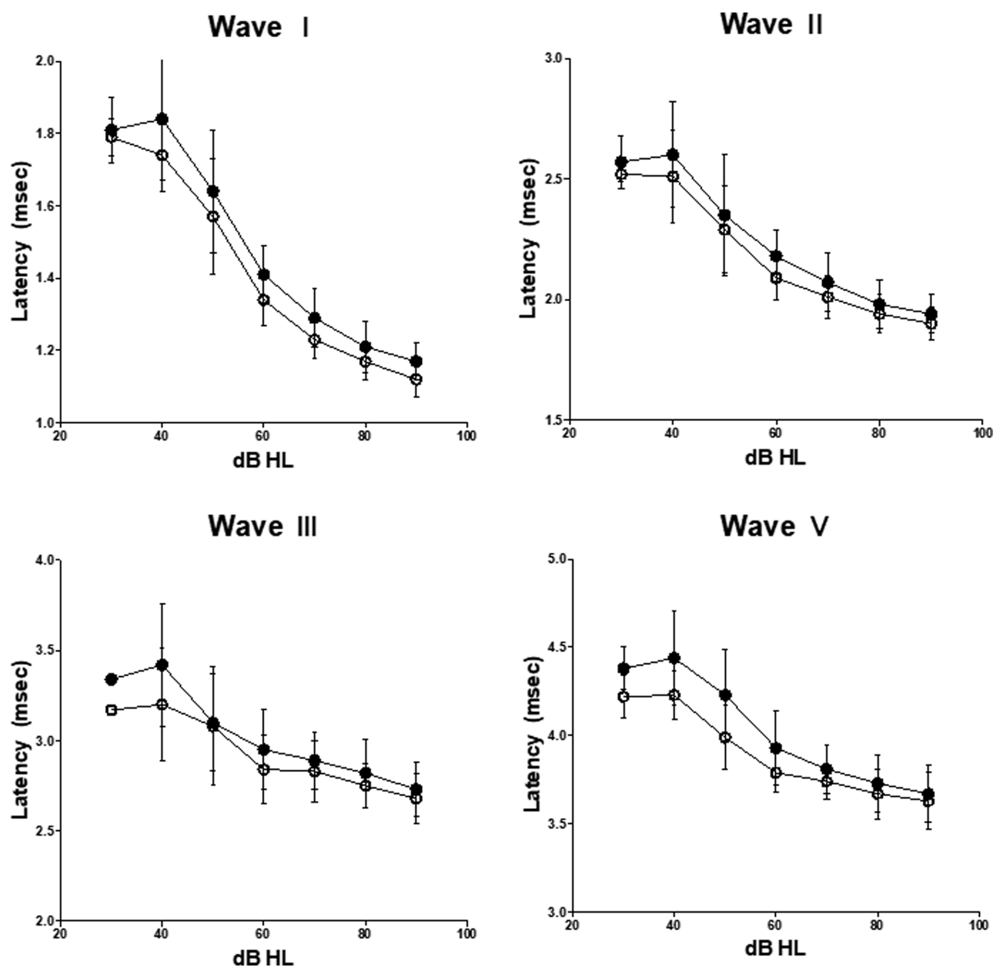

Fig 2. Mean wave I, II, III, and V latencies for the insert earphone (●) and circumaural earphone (○). Error bars represent ± 1 SD.

Table 1. Mean latency difference of wave I, II, III, V and I-III IPL, III-V IPL between the insert earphone (YE-103J) and circumaural earphone (DR-531) in each decibel

Difference between two transducers (Insert earphones - Circumaural earphones)				
	dB	x̄	SD	N
WaveI	90	0.04***	0.03	16
	80	0.04***	0.04	16
	70	0.06***	0.05	16
	60	0.07***	0.05	16
	50	0.07	0.14	13
	40	0.10*	0.11	8
	30	0.02	0.12	5
	20			0
WaveII	90	0.04***	0.02	16
	80	0.04***	0.04	16
	70	0.06***	0.04	16
	60	0.09***	0.06	16
	50	0.06	0.19	14
	40	0.09	0.13	8
	30	0.06	0.14	5
	20			0
WaveIII	90	0.05***	0.04	16
	80	0.07**	0.10	16
	70	0.06***	0.05	16
	60	0.11*	0.09	8
	50	0.02	0.29	6
	40	0.22	0.19	3
	30			0
	20			0
WaveV	90	0.04***	0.04	16
	80	0.06***	0.05	16
	70	0.07***	0.06	16
	60	0.14***	0.13	16
	50	0.24**	0.20	14
	40	0.21**	0.19	12
	30	0.17	0.19	6
	20			0
I-III IPL	90	0.01	0.04	16
	80	0.03	0.08	16
	70	0.00	0.06	16
	60	0.06	0.09	8
	50	−0.04	0.16	5
	40	0.09	0.27	3
	30			0
	20			0
III-V IPL	90	−0.01	0.03	16
	80	−0.01	0.09	16
	70	0.01	0.08	16
	60	0.06	0.11	8
	50	0.15	0.38	4
	40	−0.03	0.22	3
	30			0
	20			0

x̄ = mean difference; SD = standard deviation; N = sample size. *** indicate significance at $p < 0.001$, ** indicate significance at $p < 0.01$, * indicate significance at $p < 0.05$.

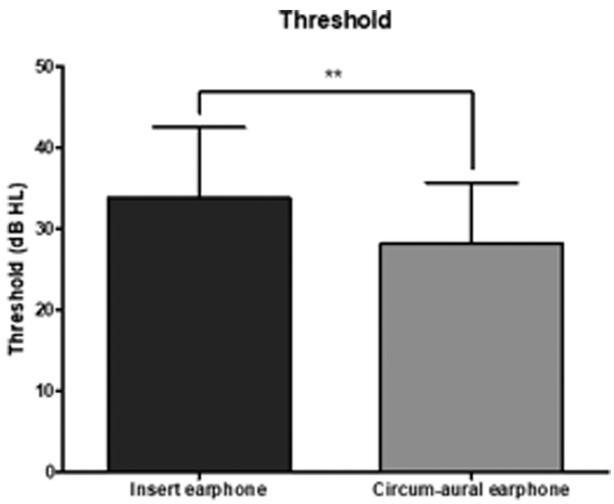

Fig 3. Threshold for the insert earphone and circumaural earphone. ** indicates statistically significant at $p < 0.01$.

difference of wave V latency showed statistical significance at the 40-90 dB range.

There was no significant difference between the two earphones with regard to the I-III IPL and III-V IPL. The largest difference was that of 0.15 ms at 50 dB of the III-V IPL. All differences between the two earphones of the I-III IPL and III-V IPL were not statistically significant at all dB levels.

The mean threshold and standard deviation are presented in Fig 3. The results showed that the mean threshold was 6 dB higher in the insert earphone and that the mean difference was statistically significant. The lowest difference was 2.56 dB, with the highest being 8.68 dB.

The mean of the wave V amplitude and the standard deviation of all groups at each decibel level are shown in Fig 4.

The wave V amplitude in the insert earphone group decreased normally, considering the fact that the sound intensity was lowered. In contrast to the insert earphone group, the mean of wave V amplitude in 90 dB was 0.075 μV lower than the mean amplitude of 80 dB in the circumaural earphone group. Both groups demonstrated a higher mean wave V amplitude value at 30 dB than at 40 dB. This is because the wave V had not been readily identified by most ears at 30 dB, and only the relatively high values were averaged.

We suspected a crossover effect for lower amplitudes in the case of circumaural earphones in 90 dB. We verified this hypothesis by using earplugs to seal the non-test ear from the sound generated from the opposite ear transducer and reevaluated wave V amplitude. As observed in Fig 4, using earplugs prevents the occurrence of this abnormally low amplitude.

Discussion

Insert and circumaural earphones are typically used for canine BAER test. However, few studies have attempted to compare these two transducers when performing BAER with dogs. A particularly old study (27) had compared insert earphones with circumaural earphones. However, this study did not have standardized inter-group conditions, except for the transducers. In that study, the insert earphone group was

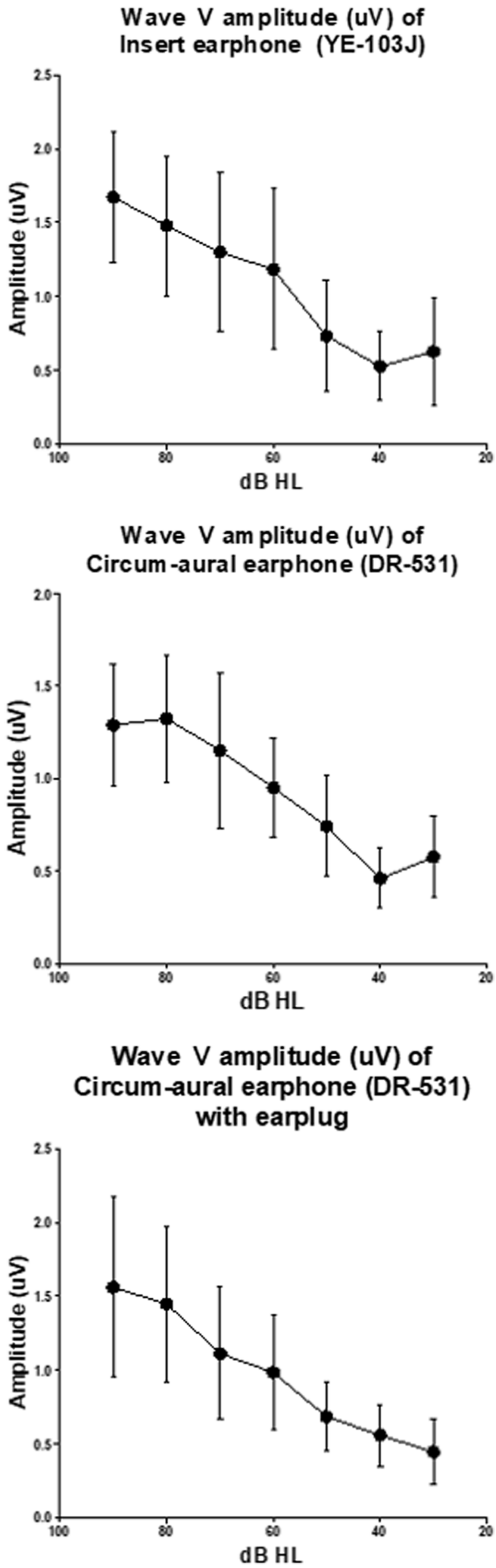

Fig 4. WaveV amplitude of insert earphone (top), circumaural earphone (middle), and circumaural earphone with earplug (bottom). Error bars represent 1 SD.

tested under sedation, but the circumaural earphone group was tested without sedation. Therefore, the results of this study were likely influenced by these differences, and the comparison between the two transducers may not have been accurate.

We compared the insert and circumaural earphones through the BAER test under identical conditions except for the use of different transducers. Diseases that may affect auditory function were excluded for all dogs via various tests. It is generally agreed that the BAER test is not affected by sedation or anesthesia (11,18), and medetomidine can be used when performing the BAER test (2,13,21). Therefore, we sedated the dogs using medetomidine. Since the latency of the waves is known to significantly rise in cases of a body temperature lower than 36ºC, a heating pad was used to maintain the dog's body temperature between 37 and 39ºC (4,29). A series of comparisons revealed several significant differences between the use of insert and circumaural headphones for the canine BAER test. There is a report that the difference between the left and right ears was not significant between the two transducers in dogs (27). To illustrate, the data from both ears suggested the presence of first significant differences between the two transducers. We observed that between the insert earphone group and the circumaural earphone group the latency was delayed by 0.083 ms on average when using the insert earphones. In the 90 dB-60 dB range where all waves were mostly observed, this outcome was found to be statistically significant. This latency delay has already been confirmed in a previous study with human participants (3,26). In veterinary medicine, this difference has been found in certain studies, but it is absent in others (2). The latency delay of the insert earphones could be explained by a plastic tube attached to the insert earphones. Compared to circumaural earphones, insert earphones have an additional 280 mm long plastic tube to deliver the sound to the ear. The velocity of sound is approximately 340 m/s, thereby requiring more time (approximately 0.08 ms) to pass this plastic tube, which explains why a latency delay occurs when using insert earphones (17,26,27). Therefore, such a delay should be considered when using insert earphones in the canine BAER test.

Next, we analyzed the IPL between the two groups. IPL is important in BAER analysis. This is because interpeak latency refers to the time taken for the stimulation to be delivered via the hearing pathway (10,28). Delay of interpeak latency can be caused by a conductive problem such as otitis media or by a disease of the brainstem (12,22). The study participants did not demonstrate any significant differences in the IPL values between the insert earphone and circumaural earphone groups. This was the same for all decibel levels demonstrating the waves. This is perhaps an expected result. As previously mentioned, due to the plastic tube of insert earphones, the onset of the BAER wave is delayed. Therefore, IPL, which indicates the interval of each wave may be similar for both the earphones (3).

The threshold was also compared between the insert earphone group and circumaural earphone group. The threshold of hearing in patients can be assessed with BEAR, and generally, the decibel that starts to disappear at wave V is considered to be the threshold (17,19,29). We found that the threshold was significantly higher when using insert earphones, and this difference appeared to be statistically significant. There are some reports that suggest that the threshold was higher when using insert earphones in human medicine, possibly because of the low peak to peak equivalent sound pressure level (peSPL) of insert earphones (3,26). Although we did not compare the peSPL of the two transducers, we assumed that the reason would be the same. Furthermore, differences in the thresholds in our study were a little higher than those observed previously. This could be explained by the fact that in the previous study, the test was conducted by lowering the intensity of sound by 5 dB from the decibel level before the disappearance of wave V. However, we lowered the intensity by 10 dB in all sections, which may have causes of the larger difference than in previous studies. In veterinary medicine, there is a report that the threshold is larger when using insert earphones, but unlike in this study, the result was not statistically significant (27).

Decrease in the sound intensity reportedly decreases the amplitude of each wave (18). We compared the insert and circumaural earphones to reveal that the amplitude of wave V was abnormally lower at 90 dB than at 80 dB when the circumaural earphone was used. This could be explained by the crossover effect. When a high intensity of sound is presented to the test ear, this sound can be delivered to the non-test ear via air or bones in a phenomenon called the crossover effect (20,29). Lesser levels of the crossover effect indicates a higher interaural attenuation. It has been reported that insert earphones have less crossover effect and higher interaural attenuation (20,25). To prove the hypothesis that wave V amplitude decreases at 90 dB with circumaural earphones because of the crossover effect, we inserted an earplug in the non-test ear to seal the sound. We designated this new group as group 3. When the non-test ear was sealed by the earplug, the wave V amplitude was typically higher at 90 dB than 80 dB, and a lower sound intensity could be attributed to a lower amplitude.

During the test with the circumaural earphones, we found that the test sound leaked from the gap between the ear and the transducer. This gap is inevitable when using circumaural earphones since the transducer used was designed for humans. When testing with small-sized dogs, this gap was more prominent. Based on these findings, we concluded that when using circumaural earphones for canine BAER tests, the test sound is more prone to be delivered to the non-test ear by air, which may decrease the wave V amplitude at 90 dB. However, we could not find a similar report in other studies, suggesting that further studies need to be conducted.

There were several differences between the insert and circumaural earphones. First, the plastic tube attached to the insert earphones led to a latency delay, which must be considered when using insert earphones. Second, when using insert earphones and circumaural earphones, IPL seems to have no influence because only the first wave is delayed when insert earphones are used. Third, the threshold was higher when insert earphones were used, possibly attributed to the low peSPL of the insert earphones. Finally, when using the circumaural earphones, the wave V amplitude was lower at high dB because of the larger crossover effect of the circumaural earphones. These findings suggest that insert earphones might be more appropriate to conduct the canine BAER test. However, since the number of subjects used in this study was small, and the subjects were not all similar in size. Therefore, further studies are warranted.

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