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Assessment of Latency and Amplitude Based on Polarity Change in Auditory-Evoked Brainstem Responses of Normal Hearing Individuals

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Abstract

Auditory brainstem response (ABR) evaluations yield different results depending on the polarity. Which polarity should I prefer in ABR evaluations? In individuals with normal hearing, we are trying to find a solution to the problem by assessing wave latencies, interwave latency values, amplitudes and morphology obtained through changes in intensity and polarity. A total of 39 people (20 males, 19 females) aged 18–45 (with a mean of 29.06 ± 9.56) with normal hearing participated in this study. Pure-tone audiometry, immitansmetric measurements, Otoacoustic emission (OAE) and ABR tests were administered to all participants after an ear-nose-throat examination. In the ABR test, the latencies of waves I, III, and V, the interwave latency values of I–III, III–V, and I–V, and amplitude values of wave V were evaluated at 70 dBnHL intensity level through the alternate, rarefaction and condensation polarities. The wave latencies, interwave latencies and amplitude values obtained through the alternate, rarefaction and condensation polarities were compared. Repeated measures Analysis of variance (ANOVA) was used for differences between groups. At 70 dBnHL intensity, the latencies of waves I and III were obtained the earliest through the rarefaction polarity, while the latency of wave V was obtained in the shortest amount of time through the alternate polarity ($p<0.05$). At 20 and 50 dBnHL intensity levels, the latencies of wave V were obtained the earliest through the alternate polarity method, although there was statistically significant 50 dBnHL intensity ($p<0.05$), there was not statistically significant 20 dBnHL intensity ($p>0.05$). There was no statistically significant difference in the interwave latency values regarding the polarities ($p>0.05$). At 20 and 50 dBnHL intensity levels, the highest amplitude values of wave V were obtained through the rarefaction polarity ($p<0.05$). At 70 dBnHL intensity, the highest amplitude values of wave V were obtained through the alternate and condensation polarities, although these were not statistically significant ($p>0.05$). There was no statistically significant difference between the demographic characteristics of individuals and the polarities. Based on the findings, different latency and amplitude values are observed between polarities. When creating normal values in clinics or using the present normative data, the preferred polarities should be taken into account. Variables depending on polarities are of great importance in terms of diagnosis in ABR evaluations.

Keywords: Auditory Brainstem Responses (ABR); Polarity; Latency; Normal hearing

Introduction

Auditory brainstem responses (ABRs) are the far-field potentials in which synchronous responses of a large number of neurons in the cochlear afferent nerve and subsequent auditory pathways are recorded. Although ABR provides information about the neural integrity in the hearing system [1-4], there are differences between the pure tone and ABR thresholds [5]. This is due to the reason that the ABR records are the combination of responses that are obtained from the areas where neural dysfunction is present and from the normal areas [5].

ABR is one of the electrophysiological methods with high validity and is used both for the assessment of hearing and for the diagnosis of some neurotological diseases in clinics [6]. There are many reasons for its common use in clinics such as its being an objective and noninvasive test method and independence of some influential factors like sleep, sedation, anesthesia and old age. ABR is also frequently used in the assessment of hearing of newborns and difficult cases (adults and children) [5,6].

The clinical application areas of ABR include neonatal babies those with no hearing thresholds, organic pathologies, mentally handicapped individuals, medico-legal events, auditory neuropathy, conduction as well as sensorineural hearing loss, and surgical monitoring.

With ABR, both hearing thresholds and current pathologies (acoustic neurinoma, auditory neuropathy, etc.) can be detected [7]. As the origins of each individual wave in ABR are different, important information is also obtained about the localization of the pathology. Thus, the distinction between cochlear and retro-cochlear pathologies can be drawn easily [8].

In ABR measurements, click or tonal stimuli are used. The click stimulus is a type of stimulus that is rectangular in form. It is a one-way voltage with a wide band of frequencies and instantaneous rise and fall times. A click stimulus is used to determine the hearing thresholds. The use of tonal stimuli is needed because it reflects the activation of the high frequency region, and it does not provide frequency-specific information. When a tonal stimulus type is used, the responses are frequency-specific and provide information about the hearing functions at the frequencies of the stimulus [8-12].

There are three different polarities used in ABR measurements. These are the positive polarity (condensation), the negative polarity (rarefaction), and the alternate polarity (a combination of the negative

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and positive polarities). The condensation polarity contains a positive electric pulse. The diaphragm of the device by which the stimulus is given creates a movement towards the eardrum. As a result of this, positive pressure waves occur in the Outer ear canal (OEC) and in the middle ear. Because of the way this stimulus occurs, the response differs from the response of the rarefaction click stimulus [1,13,14].

A negative electrical pulse is used in the rarefaction polarity. The diaphragm of the device, which delivers the stimulus, creates a motion moving away from the eardrum, resulting in negative pressure waves in the outer ear canal and in the middle ear. Movement of the tympanic membrane toward the outer ear canal leads to changes in the cochlea and in the basilar membrane. Generally, the alternate polarity is preferred to minimize the stimulating artifact [15,16]. The alternate polarity is a form of polarity that occurs when the rarefaction and condensation polarizations are administered successively [1,13].

Interpretation of ABR requires the examination of latencies (ms), interwave latencies (ms), amplitudes (μV), waves V/I amplitude ratios and waveform morphologies. Latency is the time interval that elapses until the positive or negative peak of the complex that forms the wave after the stimulus is given. Amplitude is the vertical distance between the positive and negative peaks of the complex forming the wave, and the amplitude value is assessed in microvolts. Waveform morphology represents the shape of the wave. There are two important evaluation criteria for determining the waveform or wave complex in general. These can be grouped as qualitative and quantitative. Qualitative evaluations are completely subjective. For quantitative evaluations, very difficult methods like spectral analysis are used. For this reason, quantitative evaluations are not preferred in clinical practice [1,13].

The aim of this study is to evaluate latency and amplitude values based on polarity changes in ABR tests of individuals with normal hearing. The purpose is to generate the normative data of the findings depending on the polarity used in clinics.

Methodology

This study was carried out at Turgut Özal University Medical Faculty Hospital, Department of Otorhinolaryngology, Audiology and Speech Disorders Unit. The study was approved by the decision of the Ethical Evaluation Commission of Turgut Özal University Medical Faculty with the decision no. 01 on January 13, 2016 (No. 99950669/101) (Appendix 1). A total of 20 males and 19 females aged between 18 and 45 who had normal hearing and audiologic findings participated in the study. The average age of participants was 29.06 ± 9.56. All the participating individuals signed the "Informed Voluntary Consent Form". After an ear-nose-throat examination, immitansmetric measurements, acoustic reflex tests, and Otoacoustic emission (OAE) tests were administered prior to the ABR test.

The individuals also had no neurological, systemic or vestibular problems, no history of exposure to noise, and pure tone averages were maximum 20 dB between 250-8000 Hz. Type A tympanogram was obtained from all participants in tympanometric examination and ipsilateral and contralateral acoustic reflexes were observed.

For the pure-tone audiometry testing, the "Industrial acoustics company (IAC)" double-wall quiet booths were used. Those who had a pure-sound average within the normal range (≤ 20 dB) were included in the study. Using an Interacoustics AT235H clinical tympanometer, the middle ear pressure and acoustic reflexes were measured at 226 Hz probe tone, and 85 dB SPL magnitude. In evaluations that were done automatically, pressure was applied between +200 daPa and -400 daPa, and tympanogram types of all participants were obtained. Ipsilateral and contralateral acoustic reflex thresholds were evaluated as present/absent. TEOAE measurements were taken using the computer-based Otodynamics DP Echoport ILO 292 instrument, ILO V6 (Otodynamics, London) version while OAE measurements were performed for all individuals in the study group. The ABR (Interacoustics Eclipse EP25 Assens, Denmark) test was administered to patients with normal audiologic findings. The ABR parameters that were used are shown in Table 1.

Surface electrodes were used to obtain ABR records in the study. Skin cleansing was performed prior to electrode placement, and 4 disposable Ag/AgCl electrodes were used in each recording. Before starting the test, the electrodes were placed properly. In this study, the parameters that were evaluated by making three polarity (alternate/rarefaction/condensation) changes are shown in Table 2.

Data analysis

SPSS (Statistical package for social sciences) for Windows 23.0 software package program was used for statistical analyses. Repeated measures ANOVA was used for differences between the groups.

Results

A total of 78 ears of 39 individuals participating in this study were included in the evaluations. Alternate, rarefaction, and condensation polarities were compared in the ABR test that was performed using a click stimulus. The latencies of waves I, III, and V and the interwave latency and amplitude values of waves I–III, I–V, and III–V at 70

ABR parameters	Data
Stimulus intensity levels	70/50/20 dBnHL
Stimulus	Click
Filtering	33–1500 Hz
Rate	21.1 pps
Polarity	Alternate/Rarefaction/Condensation
Averaging	2000 sweep
Earphone	Insertearphone ER/3A
Electrode impedances	Less than 5 kohm
Electrode placement	The non-inverting electrode (+) was placed on the forehead (Fz), the ground (earth) electrode between the two eyebrows (Fpz), and the inverting electrodes were placed on the left mastoid (M1) and the right mastoid (M2).

Table 1: ABR parameters.

Intensity	Wave latencies and interwave latencies
70 dBnHL	Wave I latency
70 dBnHL	Wave III latency
70 dBnHL	Wave V latency
50 dBnHL	Wave V latency
20 dBnHL	Wave V latency
70 dBnHL	Waves I–III interwave latency
70 dBnHL	Waves I–V interwave latency
70 dBnHL	Waves III–V interwave latency
70 dBnHL	Wave I amplitudes
70 dBnHL	Wave III amplitudes
70 dBnHL	Wave V amplitudes
50 dBnHL	Wave V amplitudes
20 dBnHL	Wave V amplitudes

Table 2: Evaluated parameters.

dBnHL intensity were evaluated. The latency and amplitude values of waves I and III were evaluated. Table 3 shows the minimum, maximum, mean and Standard deviation (SD) values of latencies of waves I, III, and V at 70 dBnHL intensity.

The lowest latency values of waves I and III were obtained through the rarefaction polarity, and the lowest latency value of wave V was obtained through the alternate polarity. There was a statistically significant difference between the latency values of waves I, III, and V ($p<0.05$). Table 4 shows the minimum, maximum, mean and Standard deviation (SD) values of latencies of wave V at 50 and 20 dBnHL intensity.

The lowest latency values of wave V at 50 and 20 dBnHL intensity were obtained through the alternate polarity. While there was statistically significant differences of polarities at 50 dBnHL intensity ($p<0.05$), there was no statistically significant difference at 20 dBnHL intensity ($p>0.05$).

Table 5 shows the minimum, maximum, mean and Standard deviation (SD) values of interwave latencies of waves I–III, III–V, and I–V at 70 dBnHL intensity.

At 70 dBnHL intensity, the lowest interwave latency values of waves I–III were obtained through the alternate and condensation polarities. At 70 dBnHL intensity, the lowest interwave latency values of waves III–V and I–V were obtained through the condensation polarity. Despite these values, there was no statistically significant differences between the interwave latency values that were obtained through polarity changes ($p>0.05$).

Table 6 shows the minimum, maximum, mean and Standard deviation (SD) values of amplitudes of waves I, III, and V at 70 dBnHL intensity.

At 70 dBnHL intensity, the highest amplitude values of wave I were obtained through the alternate and rarefaction polarities; the highest amplitude value of wave III was obtained through the rarefaction polarity; and the highest amplitude values of wave V were obtained through the alternate and condensation polarities. Despite these values, no statistically significant difference could be found between the polarity changes and amplitude values at 70 dBnHL intensity ($p>0.05$).

Table 7 shows the minimum, maximum, mean and Standard deviation (SD) values of amplitudes of wave V at 50 and 20 dBnHL intensity.

The highest amplitude values of wave V at 50 and 20 dBnHL intensity were obtained through the rarefaction polarity. There was a statistically significant difference between the polarity change and amplitude values at 50 and 20 dBnHL intensity ($p<0.05$).

Table 8 shows the latency values of waves I, III, and V obtained at 70 dBnHL intensity and the latency values of wave V obtained at 50 and 20 dBnHL intensity through the alternate, rarefaction, and condensation polarities in male and female subjects with normal hearing.

Polarity		Minimum	Maximum	Mean	SD	p value
Wave I	Alternate	1.32	1.85	1.57	0.12	0
	Rarefaction	1.3	1.83	1.55	0.11	
	Condensation	1.35	1.93	1.62	0.12	
Wave III	Alternate	3.41	3.92	3.68	0.14	0.001
	Rarefaction	3.25	3.9	3.68	0.15	
	Condensation	3.25	4.02	3.73	0.19	
Wave V	Alternate	5.24	6.01	5.55	0.21	0.013
	Rarefaction	5.24	6.11	5.58	0.2	
	Condensation	5.29	6.02	5.59	0.24	

Table 3: Latency values (ms) of waves I, III, and V at 70 dBnHL intensity.

Polarity		Minimum	Maximum	Mean	SD	p value
50 dBnHL	Alternate	5.72	6.61	6.18	0.33	0.05
	Rarefaction	5.72	6.59	6.25	0.35	
	Condensation	5.82	6.75	6.2	0.32	
20 dBnHL	Alternate	7.2	7.99	7.62	0.45	0.09
	Rarefaction	7.25	8.03	7.71	0.54	
	Condensation	7.28	8.12	7.79	0.4	

Table 4: Latency values (ms) of wave V at 50 and 20 dBnHL intensity.

Polarity		Minimum	Maximum	Mean	SD	p value
Waves I–III interwave latency	Alternate	1.96	2.33	2.11	0.15	0.482
	Rarefaction	1.91	2.3	2.13	0.13	
	Condensation	1.96	2.34	2.11	0.17	
Waves III–V interwave latency	Alternate	1.77	2.09	1.86	0.14	0.349
	Rarefaction	1.75	2.06	1.88	0.17	
	Condensation	1.67	2.12	1.85	0.14	
Waves I–V interwave latency	Alternate	3.76	4.15	3.98	0.19	0.366
	Rarefaction	3.73	4.22	4.03	0.18	
	Condensation	3.7	4.23	3.96	0.22	

Table 5: Interwave latency values (ms) of waves I–III, III–V, and I–V at of 70 dBnHLintensity.

Polarity		Minimum	Maximum	Mean	SD	p value
Wave I amplitude	Alternate	0.09	0.19	0.13	0.55	0.77
	Rarefaction	0.1	0.25	0.13	0.55	
	Condensation	0.09	0.23	0.12	0.57	
Wave III amplitude	Alternate	0.15	0.38	0.26	0.76	0.128
	Rarefaction	0.14	0.35	0.27	0.84	
	Condensation	0.13	0.38	0.25	0.8	
Wave V amplitude	Alternate	0.33	0.56	0.43	0.1	0.648
	Rarefaction	0.31	0.53	0.42	0.11	
	Condensation	0.29	0.55	0.43	0.13	

Table 6: Amplitude values (μV) of waves I, III, and V at 70 dBnHL intensity.

Polarity		Minimum	Maximum	Mean	SD	p value
50 dBnHL	Alternate	0.14	0.38	0.19	0.1	0.009
	Rarefaction	0.17	0.45	0.21	0.1	
	Condensation	0.17	0.37	0.19	0.08	
20 dBnHL	Alternate	0.08	0.27	0.14	0.07	0
	Rarefaction	0.1	0.26	0.16	0.08	
	Condensation	0.07	0.23	0.13	0.06	

Table 7: Amplitude values (μV) of wave V at 50 and 20 dBnHL intensity.

Polarity	Gender	Alternate	Rarefaction	Condensation	p value
Wave I latency at 70 dBnHL	Female	1.57	1.56	1.62	0.345
	Male	1.59	1.53	1.64	0.456
Wave III latency at 70 dBnHL	Female	3.66	3.68	3.73	0.253
	Male	3.68	3.67	3.73	0.654
Wave V latency at 70 dBnHL	Female	5.57	5.58	5.58	0.452
	Male	5.54	5.58	5.59	0.554
Wave V latency at 50 dBnHL	Female	6.18	6.27	6.17	0.456
	Male	6.19	6.23	6.23	0.675
Wave V latency at 20 dBnHL	Female	7.62	7.71	7.76	0.512
	Male	7.62	7.68	7.79	0.349

Table 8: Mean latencies of waves I, III and V according to gender.

In the ABR evaluation according to gender, there was no significant difference between the groups of males and females in terms of latencies of waves I, III, and V at 20 dB and 50 dBnHL intensity and in terms of latencies of wave V at 70 dBnHL intensity (p>0.05).

Table 9 shows the interwave latency values of waves I–III, I–V and III–V obtained at 70 dBnHL intensity through the alternate, rarefaction, and condensation polarities in male and female subjects with normal hearing.

In the ABR evaluation according to gender, there was no significant difference between the groups of males and females in terms of interwave latencies of waves I–III, I–V and III–V at 70 dBnHL intensity (p>0.05).

Table 10 shows the amplitude values of waves I, III, and V obtained at 70 dBnHL intensity and the amplitude values of wave V obtained at 50 and 20 dBnHL intensity through the alternate, rarefaction, and condensation polarities in male and female subjects with normal hearing.

In the ABR evaluation according to gender, there was no significant difference between the groups of males and females in terms of amplitudes of waves I, III, and V at 70 dBnHL intensity (p>0.05). Similarly, there was no statistically significant difference at 20 and 50 dBnHL intensity.

Discussion

ABR is used to determine any pathologic findings in the central auditory system, and pure-tone hearing thresholds, which cannot be determined by standard audiological methods. In ABR, wave latencies, amplitudes, morphologies and interwave latencies are evaluated. Especially wave V gives more valuable information than the other waves since it does not disappear until the threshold level. Based on findings that are obtained from ABR, cochlear and retrocochlear pathologies are being diagnosed [16].

Polarity	Gender	Alternate	Rarefaction	Condensation	p value
Waves I–III interwave latencies at 70 dBnHL	Female	2.11	2.14	2.11	0.398
	Male	2.08	2.13	2.12	
Waves III–V interwave latencies at 70 dBnHL	Female	1.84	1.88	1.85	0.508
	Male	1.87	1.88	1.87	
Waves I–V interwave latencies at 70 dBnHL	Female	3.96	4	3.96	0.633
	Male	3.98	4.03	3.98	

Table 9: Mean interwave latencies of waves I–III, I–V and III–V according to gender.

Polarity	Gender	Alternate	Rarefaction	Condensation	p value
Wave I amplitude at 70 dBnHL	Female	0.13	0.14	0.12	0.398
	Male	0.12	0.12	0.14	
Wave III amplitude at 70 dBnHL	Female	0.26	0.25	0.24	0.654
	Male	0.26	0.26	0.27	
Wave V amplitude at 70 dBnHL	Female	0.45	0.42	0.44	0.367
	Male	0.43	0.42	0.43	
Wave V amplitude at 50 dBnHL	Female	0.21	0.22	0.17	0.265
	Male	0.19	0.19	0.2	
Wave V amplitude at 20 dBnHL	Female	0.14	0.17	0.11	0.436
	Male	0.14	0.16	0.14	

Table 10: Mean amplitudes of waves I, III and V according to gender.

It is known in the literature that proper polarity selection is a controversial issue in ABR research [16]. In addition, there are not many studies related to polarity change. Existing studies show that differences occur in latencies and amplitudes based on polarity. Therefore, in our study, we tried to show changes that occur based on polarity change in individuals with normal hearing.

There was a difference between wave latencies at 70 dBnHL intensity. Wave V latency through the alternate polarity was obtained in the shortest time. For this reason, we think that the alternate polarity is advantageous in detecting wave V. Moreover, when retrocochlear pathologies are evaluated, the polarity should be compatible with standard values to which it is compared. It is seen that standardizations obtained through different polarities may give erroneous results. With the rarefaction polarity, the detection of waves I and III were advantageous. We recommend that the rarefaction polarity be used, especially in the diagnosis of cochlear pathologies.

In this study, the latencies of waves I, III, and V were evaluated at 70 dBnHL intensity. The latencies of waves I and III were obtained the earliest through the rarefaction polarity. The latency of wave V was obtained in the shortest amount of time through the alternate polarity. Therefore, it is necessary to determine the polarity-dependent changes, as latency delays are used for the differential diagnoses of cochlear and retrocochlear pathologies in the ABR evaluations [17]. It is very important to know the polarity when normative data used in clinics are created or comparisons are made according to the results of the study. If the delay in the latencies of waves is due to polarity and this condition is not taken into consideration, the cochlear pathologies can be considered as retrocochlear pathology. This phenomenon is seen especially in the latencies of wave V. This requires finding the normal values also on the basis of polarity when creating the normative data for all clinics.

Rosenhammer et al. [18] and Terkilsen et al. [19] found no difference between latencies in normal individuals in their study carried out using the rarefaction and condensation polarities. Ornitz and Wolter [20] reported findings similar to the findings obtained in our study. Again, Schoonhoven [21] and Sininger and Masuda [22] did not observe large latency differences between the polarities in their study.

Latencies of waves I and III disappear as the level of intensity is reduced. Therefore, the results are evaluated through the latencies of wave V. The results of this study reveal that in studies that are done to detect the different latency values depending on the polarity, the polarities must be the same. At 20 and 50 dBnHL intensity, the latencies of wave V were obtained early through the alternate polarity method.

At 50 and 20 dBnHL intensity, high amplitude values were obtained for wave V through the rarefaction polarity. One of the biggest problems in the ABR test is that as the wave approaches the threshold level, its recognizability decreases. For this reason, it is necessary to use the rarefaction polarity in the ABR tests where hearing thresholds are tried to be determined.

In our study, no significant differences were observed in the interwave latency values of waves I–III, I–V and III–V depending on the polarity. The interwave latency values of waves I–III based on polarity were approximately 2.10 ± 0.15 ms for the alternate, rarefaction and condensation polarities. The interwave latency values of waves I–V were approximately 4.00 ± 0.20 ms for the alternate, rarefaction and condensation polarities. The interwave latency values of waves III–V were approximately 1.85 ± 0.15 ms for all the polarities. The interwave latency values that were obtained based on the three polarities can be used as normative data in clinics. In our study, at 70 dBnHL intensity, the latency of wave V was obtained earlier through the alternate polarity method. These values can be used in clinics by considering them as normative data.

The early acquisition of waves suggests that polarity is effective in neural firing. Besides that, amplitudes are also important in terms of recognition of waves. If the polarity is good at doing neural firing, it ensures that the amplitudes are high. In particular, it is necessary to pay attention to cases where the wave recognition is low and to know which polarity enables the neural firing.

In our study, the amplitudes of waves I and III obtained through the rarefaction polarity were at highest level at 70 dBnHL intensity. At 20 and 50 dBnHL intensity, higher amplitude values were obtained for wave V through the rarefaction polarity. When assessing the hearing thresholds in the ABR test, the use of rarefaction polarity is extremely important for the recognition of the wave.

Another one of the parameters assessed in the stimulus-evoked ABR test is the morphology. Borg and Löfqvist [23] reported that polarity did not affect latencies and amplitudes of waves, but significantly affected polarity-dependent wave morphologies. It has been reported that clearer ABR waves are created with the rarefaction polarity, and early component amplitudes decrease slightly with the condensation polarity [23-26]. In our study, at 70 dBnHL intensity, the amplitudes of waves I and III were low through the condensation polarity, and the amplitude of wave V was high. At 20 and 50 dBnHL intensity, the amplitudes were low through the condensation polarity. In the past studies, the condensation polarity has been observed to yield low amplitudes, which was the same in our study, as well. According to these results, the alternate and rarefaction polarities were shown to be more advantageous in hearing threshold assessments.

No consensus has been reached in the studies on the latency periods of ABR waves based on polarity. For example, in some studies, waves I and V through the rarefaction polarity had shorter latency times, while in another study, the latency of wave III through the condensation polarity could be obtained earlier [27]. Our study is very important in terms of composition of the results of different studies that have been proposed based on polarity. Besides, as a result of our study, we think that using different polarities based on different intensity levels will affect the results positively.

Conclusion

In the ABR test, high-amplitude waves are obtained at low intensity levels through the rarefaction polarity. For this reason, the use of rarefaction polarity in the studies of hearing threshold detection will lead to more accurate results. Polarity-based changes are observed in the latencies of wave I, III, and V in the ABR assessment. Therefore, polarity should be taken into consideration when normative data are used in clinics. In the differential diagnosis of cochlear and retrocochlear pathologies, it is necessary to know the interwave latency values of waves I–III, I–V and III–V on the basis of polarity to achieve the correct diagnosis. In the ABR test, the polarity changes and the cochlear microphonic values should be used to evaluate auditory neuropathy in cases where there is no wave, the wave morphology is distorted, or latency changes are absent when intensity is reduced.

Conflict of Interest

No conflict of interest reported.

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