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Research Article

Auditory Steady-State Response Thresholds in Adults With Conductive and Mild to Moderate Sensorineural Hearing Loss

Reza Hosseinabadi [1]; Sadegh Jafarzadeh [1,*]

[1]Department of Audiology, Tehran University of Medical Sciences, Tehran, IR Iran

*Corresponding Author: Sadegh Jafarzadeh, Department of Audiology, Tehran University of Medical Sciences, Tehran, IR Iran. Tel: +98-9125583372, Fax: +98-2177534133, E-mail: sjafarzade@gmail.com

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Background: The Auditory steady state response (ASSR) provides a frequency-specific and automatic assessment of hearing sensitivity and is used in infants and difficult-to-test adults.

Objectives: The aim of this study was to compare the ASSR thresholds among various types (normal, conductive, and sensorineural), degree (normal, mild, and moderate), and configuration (flat and sloping) of hearing sensitivity, and measuring the cutoff point between normal condition and hearing loss for different frequencies.

Patients and Methods: This clinical trial was performed in Iran and included patients who were referred from Ear, Nose, and Throat Department. A total of 54 adults (27 with sensorineural hearing loss, 17 with conductive hearing losses, and 10 with normal hearing) were randomly chosen to participate in our study. The type and degree of hearing loss were determined through testing by otoscopy, tympanometry, acoustic reflex, and pure tone audiometry. Then the ASSR was tested at carrier frequencies of 500, 1000, 2000, and 4000 Hz.

Results: The ASSR accurately estimates the behavioral thresholds as well as flat and sloping configurations. There was no correlation between types of hearing loss and difference of behavioral and ASSR thresholds (P = 0.69). The difference between ASSR and behavioral thresholds decreased as severity of hearing loss increased. The 40, 35, 30, and 35 dB could be considered as cutoffs between normal hearing and hearing loss for 500, 1000, 2000, and 4000 Hz, respectively.

Conclusions: The ASSR can accurately predict the degree and configuration of hearing loss and discriminate the normal hearing from mild or moderate hearing loss and mild from moderate hearing loss, except for 500 Hz. The Air-conducted ASSR could not define the type of hearing loss.

*Keywords:*Auditory Steady State Response; Behavioral Audiometry; Sensory Threshold

1. Background

The auditory evoked potentials are the essential part of hearing evaluation in infants and difficult-to-test adults. These potentials are important and useful tests in Universal hearing screening, which is a global program for identification and management of hearing loss in early ages. The Universal hearing screening emphasizes on complete hearing assessment before three months of age and beginning of rehabilitation before six months of age. It insists on the need for assessment and management of infants in early ages (1, 2). Moreover, knowing the amount, configuration, and type of hearing loss are important in prescribing the amplification such as hearing aids; hence, using a precise and accurate procedure to detect hearing loss in infants at the early ages seems necessary.

The auditory brainstem response (ABR) or brainstem auditory evoked response (BAER) has been used in clinics for many years with considerable application. The click is the usual stimuli for ABR testing but its thresholds reflect broad and uncertain frequency region (3) correlate with behavioral thresholds of 1000 to 4000 Hz. Although tone burst stimuli have better frequency specificity, the interpretation of their waves and test time depend on the experience of the examiner (4, 5), especially at lower frequencies and in cases with hearing loss. In addition, ABR has limitations on presentation of high-intensity stimuli and the determining of its waves relies on examiner's judgment; hence, it is not a completely objective test.

The auditory steady state response (ASSR) performs a frequency-specific and automatic assessment of hearing sensitivity (6); as an optional ability, it can be performed in multiple frequencies and in both ears simultaneously (7). The frequency-specific evaluation enables us to estimate the hearing sensitivity correctly in different frequency region that can be very useful in prescribing hearing aids. High-modulation ASSR thresholds are highly related to hearing loss and ASSR can provide an accurate assessment of hearing sensitivity in sleeping infants (3, 8, 9), children (10, 11), and adults (12, 13). Despite the advantages of the ASSR, some issues such as the effect of conductive hearing loss (CHL) on ASSR thresholds, ability to differentiate between normal hearing and mild hearing loss, and the effect of configuration of hearing loss on ASSR thresholds necessitate further investigation.

Few studies assessed the effect of CHL on ASSR thresholds (4, 14-16). It was reported that the present of CHL had deteriorated the ASSR thresholds in two cases (14). Moreover, simulated ASSR thresholds could result in overestimation of hearing loss (15, 16). To our knowledge, a study has evaluated actual CHL and the results showed no difference between sensorineural hearing loss (SNHL) and CHL (4). In this study, we evaluated the actual CHL and compared the results with ASSR thresholds of normal hearing and SNHL. The CHL requires somehow different management and an accurate estimation of hearing loss is important.

It was reported that ASSR had difficulties in discriminating mild hearing loss from normal hearing, especially in low frequencies (4). The mild hearing loss has negative effects on speech and language developments, academic achievements, and psychosocial development (17, 18). Therefore, differentiating the patients with mild hearing loss from normal conditions might prevent such difficulties. On the other hand, many cases of CHL have greater loss at lower frequencies, which makes it more important in CHL.

2. Objectives

The purpose of present study were as follows: comparing the difference between actual ASSR thresholds and behavioral thresholds in normal hearing conditions, SNHL, and CHL; comparing the ASSR thresholds based on the degree of hearing loss in three groups of normal hearing conditions, mild, and moderate hearing loss; determining the cutoff point between normal conditions and hearing loss; and measuring the effect of configuration of hearing loss on ASSR thresholds in the patients with SNHL.

3. Patients and Methods

3.1. Patients

This clinical trial included the patients who were referred from Ear, Nose, and Throat Department to Audiology Clinic of Tehran University of Medical Sciences, Tehran, Iran, from April to October 2013. From referred patients, 70 participants were randomly selected. All of them complain about hearing loss and 16 patients were excluded because of lack of interest to participate in a full Auditory assessment. The participants included 54 persons (17 females and 37 males) with mean age of 39.3 (12.5) years. All of the participants were tested with otoscopy, tympanometry, acoustic reflex, and audiometry. After determining the type and degree of hearing loss, they were placed in three groups: group 1, 27 patients with SNHL; group 2, 17 patients with CHL; and group 3, ten patients with normal hearing conditions. After forming the groups, the participants were tested with ASSR and their thresholds were compared with their audiogram. All of the participants were informed of tests and their role in the complete hearing assessment. They consented to participate in our study. We completely described the results for them. Performing all testes was free for patients. This study was approved by the Ethics Committee of Tehran University of Medical Sciences (91d1303430) in March 2013.

3.2. Procedure

We ask the patients age and measured the hearing sensitivity by audiometry and ASSR and middle ear condition was assessed by tympanometry and acoustic reflex. The tests performed in a sound-treated room. We performed otoscopy (Reister, Germany), audiometry (Maico, Germany), tympanometry, acoustic reflex (Maico, Germany), and then ASSR (Eclipse EP25, Intra acoustic, Denmark) was tested, during the tests, the participants were awake while resting on a bed and no anesthesia was administered.

Tympanometry was performed in sitting condition for both ears at 226 Hz, with positive to negative pressure sweep at a pump speed of 400 dapa/sec with standard probe for tympanometry. The acoustic reflex test was performed at 500 to 4000 Hz in both ipsilateral and contralateral mode at intensities of 80 to 120 dB HL (hearing level) to reach the thresholds. Pure tone audiometry was conducted at 0.25 to 8 kHz for AC (air conduction) using TDH-39 headphones and 0.25 to 4 kHz for BC (Bone conduction) stimuli with modified Hughson-Westlake procedure. The Audiometer was calibrated for each frequency according to ANSI standard. The whole test battery, including ASSR, was performed by one examiner and lasted up to two hours on the same day.

3.3. ASSR Stimuli and Recording

We used the default setting of EP25 software for measuring the ASSR. AC Stimuli presented via insert phone at the carrier frequencies of 500, 1000, 2000, and 4000 Hz in both ears simultaneously. The stimuli consisted of 100% AM (amplitude modulated) and 20% FM (frequency modulated). The carrier frequencies were modulated at 80 to 90 Hz and intensity was calibrated for insert phone at each frequency according to the ANSI (American national standards institute) standard. In addition, we checked the intensity of each frequency subjectively.

We used vertical and noncephalic three-electrode array for recording ASSR. The cups surface electrodes were placed at Fz as non-inverting, at low forehead as ground, and at C7 as inverting. Impedance was kept under 5000 Ωand maximum interelectrode impedance was 2000 Ω. The response was detected by an automatic algorithm for each level in a maximum of six-minute period.

3.4. Measure

In audiometry, the patients sat in front of the examiner in a sound-treated room and responded to the pure tone stimulus by pressing a button. The ASSR initial level was 50 dB HL for people with normal-hearing condition and 70 dB HL for patients with hearing loss. If there was no response, the initial level would be increased by 20 dB. The ASSR measurements were performed by descending procedure with 10-dB steps. Near the threshold, the 5-dB steps were used. The minimum and maximum presentation levels were 10 and 100 dB HL, respectively. The six-minute averaging time was used to declare no response for each level. The whole test lasted for 20 to 73 minutes. The threshold was defined as the minimum intensity of detected responses. For each participant, all of the tests were performed in a single visit. Instead of estimated thresholds, the actual ASSR thresholds were compared to audiometric results. The actual ASSR threshold did not include the correction factors for the estimation of behavioral thresholds; therefore, it showed the intact electrophysiologic thresholds.

3.5. Data Analysis

The analysis performed using SPSS 14.0 (SPSS Inc, Chicago, IL, USA). The differences between actual ASSR thresholds and behavioral thresholds were determined for each frequency and theses differences were compared among patients with SNHL, CHL, and normal hearing conditions through two-way ANOVA. We also compared the mean of ASSR thresholds in normal hearing conditions (behavioral thresholds, 0-20 dB HL), mild hearing loss (21-40 dB HL), and moderate hearing loss (41-70 dB HL) and used different cutoff value for differentiation of normal hearing loss from hearing loss with ROC curve. In addition, the effect of configuration of hearing loss on ASSR thresholds in SNHL group was investigated with two-way ANOVA. The audiogram was considered flat if the threshold variations between frequencies of 500 to 4000 Hz were up to 20 dB; the audiogram with higher threshold variation in these frequencies were considered sloping.

4. Results

The mean age and sex of 54 participants is shown in Table 1. All of them were 19 to 60 years old and there was no difference in mean age between patients with SNHL and CHL. The mean behavioral and ASSR thresholds are shown in Table 2. Moreover, 47% of persons with CHL had type B tympanogram and 53% had type C tympanogram. The mean behavioral thresholds for SNHL and CHL were similar. The comparison of behavioral and ASSR results for left and right ear showed no difference. Therefore, in absence of ear effect, we add left and right ear data together for further analysis.

Table 1. The Basic Characteristics of Patients in Study Groups [a]

Group	Number	Gender		Age, y	Minimum	Maximum
		Female	Male			
Sensorineuralhearing loss	27	5 (18.5)	22 (81.5)	41.3 ± 11.4	22	60
Conductivehearing loss	17	7 (41.2)	10 (58.8)	41.2 ± 13.0	21	60
Normalhearing	10	5 (50)	5 (50)	31.1 ± 12.4	19	56
Total	54	17 (31.4)	37 (68.6)	39.3 ± 12.5	19	60

[a] Data are presented as Mean ± SD or No. (%).

Table 2. The Behavioral and Auditory Steady State Response Thresholds of Study Groups [a, b]

Group	Behavioral Thresholds, Hz				ASSR Thresholds, Hz			
	500	1000	2000	4000	500	1000	2000	4000
Sensorineural hearing loss	26.4 ± 26.4	26.3 ± 28.4	28.1 ± 31.0	44.8 ± 32.1	41.1 ± 16.8	39.2 ± 23.1	39.1 ± 25.3	52.6 ± 29.2
Conductive hearing loss	29.6 ± 10.5	28.1 ± 11.1	30.1 ± 13.7	40.1 ± 19.0	45.3 ± 13.6	41.2 ± 11.0	40.9 ± 13.7	49.6 ± 18.8
Normal hearing	13.7 ± 6.4	12.9 ± 6.8	12.9 ± 8.1	13.7 ± 8.0	33.6 ± 2.3	33.3 ± 3.2	29.0 ± 3.7	33.7 ± 3.7

[a] Data are presented as mean ± SD.
[b] Abbreviation: ASSR, auditory steady state response.

4.1. The Effect of Hearing Loss Type

We did not have any missing value and all data had normal distribution. We checked ANOVA assumptions such as normality, independency (there was only one observant and the realization of one possibility of data in one group did not influence the possibility of others), and homoscedasticity (the variance of data in groups were same). Two-way ANOVA was performed to evaluate the effect of hearing loss type on ASSR thresholds and showed no correlation between types of hearing loss (CHL or SNHL) and difference of behavioral and ASSR thresholds ($F = 0.82$, $P = 0.69$, and the power of 0.83). Table 3 shows the mean difference between behavioral and ASSR thresholds for three groups. The difference among behavioral and ASSR thresholds was similar in patients with SNHL or CHL and there was no significant difference between two types of hearing loss (P values of 0.80, 0.56, 0.64, and 0.98 respectively for 500, 1000, 2000, and 4000 Hz).

Normal hearing group differed from other two groups in frequency of 1000, 2000, and 4000 Hz and significant differences existed between normal hearing and SNHL groups (P values of 0.18, 0.00, 0.06, and 0.00 for 500, 1000, 2000, and 4000 Hz, respectively) as well as between normal hearing and CHL groups (P values of 0.35, 0.00, 0.03, and 0.00 respectively for 500, 1000, 2000, and 4000 Hz, respectively). The 500 Hz had no significant difference among three groups. The difference between behavioral and ASSR thresholds decreased as the frequencies increased in both SNHL and CHL groups. This issue was not observed in those with normal hearing condition.

The association between ASSR and behavioral thresholds was measured with Pearson's correlation coefficients for SNHL and CHL. The Correlation coefficients were 0.89, 0.95, 0.95, and 0.97 in SNHL group and 0.68, 0.75, 0.85, and 0.85 in CHL group for 500, 1000, 2000, and 4000 Hz, respectively. Although all correlations were significant ($P < 0.01$), the correlation was stronger in higher in comparison to lower frequencies and in SNHL group in comparison to CHL group.

4.2. Degree of Hearing Loss

Hearing loss type had no significant effect on ASSR threshold; hence, all of cases were used for this analysis. Table 4 shows ASSR thresholds, behavioral thresholds, and the difference for normal hearing and mild, moderate, and severe hearing loss categories. The cases had similar behavioral threshold loss in different frequencies or greater loss in higher frequencies. There were only four ears with severe hearing loss, which were excluded from analysis. The difference between ASSR thresholds in groups of normal hearings and mild and moderate hearing loss was significant, except for 500 Hz. Therefore, the ASSR could differentiate normal hearing conditions from hearing loss or differentiate mild from moderate hearing loss, except for 500 Hz. The difference between ASSR and behavioral thresholds decreased as frequency increased or as severity of hearing loss increased.

Table 3. The Difference Between Behavioral and Auditory Steady State Response Thresholds Among Study Groups [a]

Group	Frequencies, Hz			
	500	1000	2000	4000
Sensorineuralhearing loss	16.2 ± 8.5	13.1 ± 8.6	11.3 ± 8.3	7.1 ± 8.3
Conductivehearing loss	16.8 ± 10.2	12.0 ± 7.7	10.4 ± 7.5	7.1 ± 9.7
Normal hearing	20.0 ± 6.3	20.4 ± 6.8	16.8 ± 9.2	20.0 ± 8.7

[a] Data are presented as Mean ± SD.

Table 4. Auditory Steady State Response thresholds, Behavioral Thresholds and the Difference for Three Categories of Normal Hearing, Mild and Moderate Hearing Loss [a, b]

Thresholds	Frequencies, Hz			
	500	1000	2000	4000
ASSR				
Normal	32.6 ± 5.5	31.2 ± 5.1	27.8 ± 4.2	33.2 ± 9.8
Mild	41.9 ± 11.1	36.5 ± 9.6	34.3 ± 6.5	48.7 ± 16.2
Moderate	50.5 ± 14.6	47.2 ± 10.3	58.6 ± 8.9	70.5 ± 14.9
Behavioral				
Normal	14.8 ± 5.2	12.6 ± 5.6	12.6 ± 6.4	18.6 ± 10.7
Mild	24.0 ± 8.6	24.1 ± 9.0	24.1 ± 8.0	42.0 ± 18.7
Moderate	39.5 ± 13.1	38.6 ± 14.3	48.1 ± 10.7	64.5 ± 10.3
The difference				
Normal	17.6 ± 7.5	18.7 ± 7.3	15.4 ± 7.2	14.7 ± 8.3
Mild	17.8 ± 9.4	11.8 ± 7.5	10.0 ± 7.7	7.0 ± 8.1
Moderate	13.3 ± 10.6	8.6 ± 7.1	10.4 ± 9.6	6.0 ± 8.0

[a] Abbreviation: ASSR, auditory steady state response.
[b] Data are presented as Mean ± SD.

Table 5. The Difference Between Behavioral and Auditory Steady State Response Thresholds for Flat and Sloping Configurations [a]

Configurations	Frequencies, Hz			
	500	1000	2000	4000
Flat	15.6 ± 7.5	13.1 ± 7.8	9.7 ± 7.4	6.8 ± 7.6
Sloping	17.7 ± 9.1	13.0 ± 9.7	13.4 ± 9.5	7.7 ± 6.7

[a] Data are presented as Mean ± SD.

Table 6. The Sensitivity and Specificity of Different Cutoff Points

Cutoff Value, dB	Frequencies, Hz							
	500		1000		2000		4000	
	Sensitivity	Specificity	Sensitivity	Specificity	Sensitivity	Specificity	Sensitivity	Specificity
< 20	100	0	100	2	100	2	100	0
< 25	97	0	97	2	100	4	100	0
< 30	97	23	94	24	97	40	96	23
< 35	94	41	92	56	79	81	91	59
< 40	66	75	68	93	64	97	78	91
< 45	55	88	50	100	48	100	66	100
< 50	47	94	34	100	43	100	60	100
< 55	33	100						

4.3. Effect of Hearing Loss Configuration

The difference between behavioral and ASSR thresholds in SNHL group was compared between flat and sloping configurations. All of the sloping configurations had greater loss at higher frequencies. Two-ways ANOVA (configuration-frequencies) showed no difference between two types of configurations (f = 0.49, P = 0.83). Moreover, comparing the mean of behavioral and ASSR thresholds difference indicated no significant difference between flat and sloping configurations (P values of 0.45, 0.95, 0.18, and 0.69 for 500, 1000, 2000, and 4000 Hz, respectively.) Table 5 shows the difference between behavioral and ASSR thresholds in two configurations.

4.4. Ability to Differentiate Between Normal Hearing Conditions and Hearing Loss

Table 6 shows the sensitivity and specificity of different cutoff points for differentiation between normal hearing condition and hearing loss. The sensitivity decreased and specificity increased with higher cutoff points and the sensitivity and specificity had different combinations of different frequencies. The 500 Hz reached the specificity of 100% at < 55 cutoff point that would suggest a normal hearing person might have ASSR thresholds of up to 55 dB in this frequency. The cutoff point with the best sensitivity and specificity was used for determining the normal condition. According to this Data, we suggested cutoff points of 40, 35, 30, and 35 dB for 500, 1000, 2000, and 4000 Hz, respectively.

5. Discussion

The ASSR is an automatic assessment of hearing sensitivity that minimizes the effect of examiner's judgment in testing. The test uses the modulated stimulus such as amplitude-modulated (AM) and frequency-modulated (FM) stimulus that allows the test to have a frequency-specific assessment of hearing sensitivity. Using high modulation rate also enables us to have a better evaluation in relaxed situation of testing. The strength of present study was comparison of the actual ASSR thresholds in patients with CHL and SNHL with normal hearing conditions and using the frequency-specific stimuli for hearing assessment. On the other hand, our limitation was inaccessibility for recording bone conduction ASSR.

5.1. The Effect of Hearing Loss Type

Few studies have evaluated the effect of CHL (4, 14) or simulated CHL (15, 16) on ASSR thresholds. In a case study of two patients with severe to profound hearing loss, middle ear abnormality caused severe deterioration of ASSR thresholds (14). The middle ear abnormalities were identified with tympanometry but in this case report, the degree of CHL was not calculated with behavioral or ASSR testing and it was not clear whether CHL would cause more threshold shift than SNHL would. The other study showed that the ASSR can accurately estimate the degree and configuration of CHL and type of hearing loss did not affect the ASSR thresholds (4).

In the study of ten persons with normal hearing with

15- to 60-dB simulated CHL (15), the hearing loss was simulated by different substances such as placing wool into the head phones and the threshold shift was controlled with behavioral testing. Behavioral and ASSR Air-bone gap were strongly correlated, but the ASSR had overestimated the gap about 10, 13, 2, and 9 in frequencies of 500, 1000, 2000, and 4000 Hz, respectively. Another study of simulated CHL also showed strong correlation and overestimation of the ASSR (16).

We did not find a significant difference between ASSR thresholds of CHL and SNHL. It was reported that ASSR had strong correlation with behavioral thresholds (4) and showed an overestimation in the simulated CHL. Further studies are required to draw a conclusion in effect of CHL. The air-conducted ASSR cannot differentiate CHL and SNHL. Nonetheless, the type of hearing loss affects the hearing aid prescription. It shows the necessity of using the SAL (sensorineural acuity level) technique (19) or bone conduction ASSR in threshold estimation in infants (20) and adults (20).

5.2. Degree of Hearing Loss

It was reported that separation of normal hearing from mild hearing loss was difficult at 500 Hz. This could be the result of poor neural synchronization and higher ASSR threshold of 500 Hz in normal hearing condition (4). Moreover, the difference between ASSR and behavioral thresholds decreased as severity of hearing loss increased and this could be related to recruitment (4). In our study, the ASSR could separate normal hearing from mild or moderate hearing loss, and mild from moderate hearing loss, except for 500 Hz. Separating the mild hearing loss from normal hearing have special importance in early ages in early ages. Mild hearing loss must be identified and managed because it can affect the speech and language developments, academic achievements, and psychosocial development (17, 18). Some cases of CHL mostly affect low frequencies and this could be a problem for using ASSR as a screening tool.

5.3. Effect of Hearing Loss Configuration

The flat and sloping configurations are the most common configurations of hearing loss and therefore, we selected them for assessment. In our study, the strong correlation and similar mean of behavioral and ASSR thresholds in different frequencies indicated that ASSR could provide a good estimate of the hearing loss configuration. The configuration of SNHL did not affect the ASSR thresholds and ASSR could accurately reflect the flat and sloping configuration of hearing loss. These results were consistent with other studies (4, 21, 22). In general, the two groups had a similar result and the configuration of hearing loss did not affect the ASSR thresholds, but the difference between behavioral and ASSR thresholds was greater in 500 Hz in both configurations. This can be related to less neural synchrony in this frequency. The apical portions of the cochlea are responsible for detecting 500 Hz in low levels.

5.4. Ability to Differentiate Between Normal Hearing and Hearing Loss

The cutoff points with the best sensitivity and specificity were determined at 40, 35, 30, and 35 dB for 500, 1000, 2000, and 4000 Hz, respectively. This was slightly higher than another study (4). In this study, the best cutoff values were suggested at 30 dB for 500 to 4000 Hz. This difference might be related to a different setting and modulation of stimulus. This high cutoff might be problematic for detecting hearing loss, especially for CHL with a greater degree of hearing loss in lower frequencies. The cutoff point for infant and children are about 10 dB higher than that for adults (3). These cutoff points are 50, 45, 40, and 40 for 500, 1000, 2000, and 4000 Hz respectively, which might be a problem for identification of patients with hearing loss, especially in the lower frequencies.

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Authors' Contributions

The Author performs all part of design and performing the study. Study concept and design, analysis and interpretation of data, statistical analysis, drafting of the manuscript, and study supervision: Sadegh Jafarzadeh. Administrative, technical, and material support: Reza Hosseinabadi. Acquisition of data, critical revision of the manuscript for important intellectual content: Reza Hosseinabadi and Sadegh Jafarzadeh.

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