



Auditory Steady State Response (ASSR) in hearing impaired children with absent Auditory Brainstem Response (ABR) waves

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Abstract:

Objectives: The aim of this work was to evaluate the residual hearing in children with sensorineural hearing loss and absent ABR waves by ASSR to select the appropriate way for intervention, either the use of a hearing aid or cochlear implant.

Patients and methods: Forty children (80 ears) were included in this study in the period from May 2019 up to April 2020. All children had complete detailed history taking, otoscopic examination, immittanceometry, hearing assessment to get an accurate frequency specific threshold with play audiometry, behavioral observation audiometry, and evoked audiometry, including ABR, TEOAEs, and ASSR.

Results: Forty hearing impaired children with ages ranged from 1 to 5 years old, 22 were males, and 18 were female. ASSR response was obtained from 53 ears, and 27 ears showed no response. The ASSR showed a better response at the low-frequency region when compared to the high-frequency regions but with no statistically significant difference.

Conclusions: The absence of click-ABR waves and behavioral free-field responses do not rule out the presence of residual hearing. ASSR was done to estimate the residual hearing mainly at low-frequency regions.

Keywords: Absent ABR waves, ASSR, Residual hearing

Introduction

Congenital hearing loss is recognized as one of the prevalent chronic conditions in children. In developed countries, neonatal hearing-screening programs allow early detection and intervention and prevent delay in speech and language acquisition, and have long-lasting, valuable results on social, emotional improvement and excellent life.¹

All children with hearing loss should have access to the resources necessary

to amplify their possibilities. The accompanying principles grant the basis for effective early hearing detection and intervention (EHDI) frameworks and have been updated and expanded since the Joint Committee on Infant Hearing (JCIH 2000) position statement.²

- All infants should have access to hearing screening utilizing electrophysiologic measures at no longer than one month old.

- All infants who do not pass the first hearing screening and the subsequent rescreening should have complete audiological and medical assessments to confirm the presence of hearing loss at no longer than three months old.
- All infants with confirmed permanent hearing loss should receive early intervention services as early as possible after diagnosis but at no later than six months old.
- Early identification and rehabilitation of hearing loss is very integral for enhancement of auditory stimuli and desirable improvement of speech and language.³

Thus, the need for proper and precise estimation of the hearing threshold at different frequencies is important for appropriate diagnosis and management.⁴

Auditory Brainstem Response (ABR) is the most broadly utilized test in clinical practice to appraise the level of hearing loss; however, the auditory brainstem response (ABR) cannot separate between severe and profound SNHL, whereas the ASSR can provide threshold estimation in frequency-specific information at intensity levels of 100 dB HL and higher. This intensity stimulation advantage uniquely qualifies the ASSR for investigation of residual hearing in younger and hard-to-test populations.⁵

Auditory steady-state responses (ASSRs) are rhythmic brain potentials generated by regularly repetitive stimuli such as clicks, amplitude-modulated (AM) noise or tones, or frequency-modulated (FM) tones.⁶

The ASSR is generated by continuous modulated tones; the continuous nature of tone modulation makes the ASSR frequency-specific in its determination of auditory sensitivity in addition to the increased levels of stimulation intensity that is applied.^{7,8}

Many advantages are reported for ASSR, such as audiogram prediction/hearing threshold estimation, hearing aid fitting, and cochlear implant mapping.⁹

Among the most important benefits of ASSRs is that they offer a way of measuring residual hearing mainly at low-frequency areas in young kids with absent ABR waves, and as a result presenting estimated thresholds to frequency-specific stimuli introduced at high stimulus levels to find the appropriate means for intervention either the continuous usage of hearing aid or shift for a cochlear implant.¹⁰

Aim of the work:

Evaluation of the residual hearing in hearing-impaired children with absent ABR waves by ASSR to select the appropriate way for intervention, either the use of a hearing aid or shift to a cochlear implant.

Subjects and Methods:

Subjects:

Forty hearing impaired children (80 ears) were included in the study; all had been recruited and examined at Audiovestibular Medicine Unit, Al-Azhar University Hospitals (Assiut), from May 2019 up to April 2020.

Inclusion criteria:

1. Age ranged from 1 year to 5 years.
2. Children with hearing loss presented by absent ABR waves with normal middle ear function all were fitted with hearing aids.

Exclusion criteria:

1. Hearing-impaired children with present ABR waves.
2. Absent ABR waves with middle ear effusion.
3. Absent ABR waves with preserved OAE or CM (in cases of ANSD).

Methodology:

All children in the study were subjected to:

1. **Complete history taking** (taken from parents): including personal history, onset, course, duration of hearing loss, medical problems, prenatal, neonatal, and postnatal events, developmental history, consanguineous marriage, and family history of hearing loss.
2. **Otological examination:** to rule out obstruction, infection, inherent abnormalities, and different lesions in the external auditory canal. The tympanic membrane was examined for perforation, discharge, otitis media, and cholesteatoma.
3. **Immittance measurements:** to ensure normal middle ear pressure.
4. **Hearing assessment** to get an accurate frequency specific threshold, either with:

➤ **Age-based threshold detection:**

i-(Play audiometry) for children older than three years old: including air conduction testing using pure tones starting at 1 K Hz then 2, 4, 8, 0.25, 0.5 K Hz in a descending order to reach the threshold.¹¹ The test was repeated twice to ensure reliable and consistent test results.¹²

ii- Behavioral observation audiometry (BOA); for children below three years with warble tones at 500, 1000, 2000, and 4000 Hz in the sound-field audiometry, have been introduced at 45° azimuth. Behavioral and reflexive responses monitored during the procedure included either attention (expanded and diminished movement, searching, localizing, listening) or reflexive (arousal, startle, or eye blinking). The test was repeated twice to ensure the result.¹³

Speech audiometry was done for hearing impaired children in the form of

speech detection threshold (SDT) or speech reception threshold (SRT) as much as possible.

➤ **Evoked audiometry**

i- Auditory Brainstem Response (ABR):

The hearing-impaired children were tested while sleeping either naturally or using sedation with chloral hydrate (0.5cc/Kg). The test was done using the *Interacoustic Eclipse 25 platform* evoked potential system. ABR was done using rarefaction click stimuli conveyed through insert phone at a level of 100 dB nHL at a repetition rate of 21.1p/s. The response was averaged and filtered between 30 and 1500 Hz, amplified 100,000 times, monitored, and recorded over 15 ms time window, and 4000 sweeps for every single run.

ii- Transient evoked otoacoustic emission (TEOAEs); to exclude auditory neuropathy spectrum disorder (ANSD).

iii-Auditory Steady State Response (ASSR):

using *Interacoustic Eclipse 25 platform* evoked potential system. The test stimuli were modulated pure tones in both ears at rates of 74, 81, 88, and 95 Hz, respectively presented via insert earphones at frequency signals of 0.5, 1, 2, and 4 KHz. Modulated tones were presented at high rates to make sure of an acceptable signal-to-noise ratio for the detection of responses during natural sleep or sedation.¹⁴ Each signal had both amplitudes, frequency modulation and was introduced independently to every ear. 100 % amplitude modulation depth and 10% of frequency modulation width of the carrier tone became used to maximize response amplitude.¹⁵

ASSRs were acquired at first at the most extreme sound degrees of 100 dB

HL or (the 500 Hz, 1000 Hz, 2000 Hz, and 4000 Hz) carrier frequencies. To obtain an ASSR threshold, the level of the stimulus was diminished in 10 dB steps before the response could no longer be recognized. It was then increased in 5 dB steps before the response is recognized. On events where no ASSR was gotten at the most extreme introduction level, the run became repeated.

Electrode montage:

The electrode montage is the same for ABR and ASSR. Dual channel recordings system contains a positive recording from Fpz, negative from ipsilateral mastoid, and a ground on the forehead. Inter-electrode impedance turned into generally less than 3000 ohms (Figure 1).

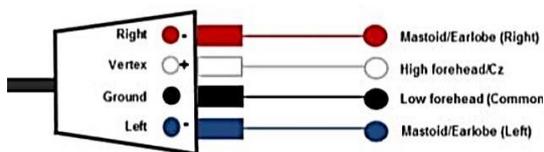


Figure (1): Electrode montage of Interacoustic Eclipse 25 platform.

Equipment:

1. Two-channel Audiometer: Interacoustics **AC 40** with local manufactured double walled single room sound treated booth.
2. Acoustic immittancemetry: Interacoustics **AT 235** with 226 Hz probe tone.
3. Evoked Potential system Interacoustic **Eclipse25 platform** used to perform ABR, OAEs, and ASSR.

Ethical code:

Verbal permission was gotten from the parents of hearing-impaired children before contributing to the studies, and all data kept confidentially.

Data analysis:

The gathered data had been coded, tabulated, and statistically analyzed using a statistical package for social sciences software (SPSS), version 18.0. Simple descriptive statistics were performed to calculate numerical parametric data, like the mean, SD, and minimum/maximum of the range. The degree of significance at *P* value significantly less than 0.05.

Results:

The present work consisted of 40 hearing impaired children with absent ABR waves; their ages ranged from 1 year to 5 years old. 22 were males (55%) and 18 were female (45%). There were multiple risk factors of hearing loss in the study group; a few of the children had multiple risk factors as shown in table 1.

Table (1): Demographic data of the study group

	No. (40)	%
Age (years)		
Mean \pm SD (Range)	2.31 \pm 1.24 (0.5-5.0)	
Sex:		
Male	22	55.0
Female	18	45.0
Risk factors:		
Eclampsia	1	2.5
Low birth weight	1	2.5
Preterm	1	2.5
Twins	2	5.0
Jaundice	5	12.5
Fever	6	15.0
Consanguineous marriage	31	77.5
Family history of HL	17	42.5

On audiological evaluation, two children gave play audiometry, 20

children had behavioral responses to free field examination, and 18 children had no response as shown in table 2. Finally, 24 children had a good aided response, and 16 had a poor response. According to the speech banana audiogram, the aided response was classified into:

- The group with good aided response, i.e., fitted or approaching to speech banana curve.
- The group with poor aided response, i.e., far away from the speech banana curve.

Table (2): Behavioral response, play audiometry, and aided response results

Response Test	No. 40			
	Good response	%	Poor response	%
Behavioral response	20	50	18	45
Play audiometry	2	5	-----	-----
Aided response	24	60	16	40

ASSR response was obtained from 53 ears, and 27 ears showed no response. There was no statistical difference between them, as shown in table 3.

Table (3): The ASSR results of the studied children

ASSR results	Right (n= 40)		Left (n= 40)		P-value
	No.	%	No.	%	
Present ASSR	27	67.5	26	65.0	0.813
Absent ASSR	13	32.5	14	35.0	

The average thresholds of ASSR at a different frequency (500, 1000, 2000, and 4000) showed that the lower frequencies (500 and 1000) had better thresholds. But still, there was no

statistically significant difference at different frequencies in both ears, as shown in table 4.

Table (4): The Average thresholds of ASSR at different frequencies

ASSR	Right	Left	P-value
	Mean \pm SD	Mean \pm SD	
500	83.33 \pm 12.00	87.14 \pm 11.89	0.159
1000	91.18 \pm 11.11	85.00 \pm 13.54	0.417
2000	91.60 \pm 10.38	89.25 \pm 12.38	0.614
4000	92.59 \pm 8.92	92.71 \pm 11.23	0.553

The ASSR was obtained at both low and high-frequency regions; there is better response at low-frequency region when compared to high-frequency regions but with no statistically significant difference, as shown in table 5.

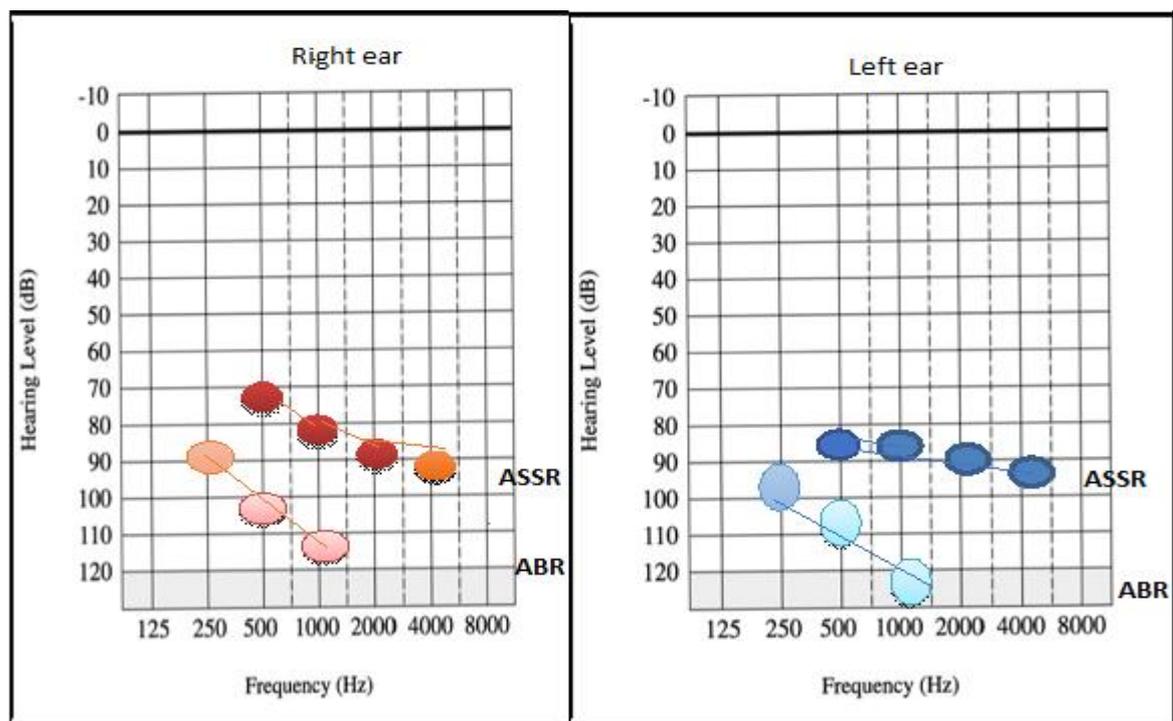
Comparison of the average ASSR responses at right and left ears with the aided responses showed a high statistically significant difference, as shown in table 6.

Table (5) Comparison of ASSR response in the right and left ears at low and high-frequency regions

	Right (n= 40)		Left (n= 40)		P-value
	No.	%	No.	%	
Low frequency (500, 1000 Hz):					
Response	30	75.0	27	67.5	0.496
No response	10	25.0	13	32.5	
High frequency (2000, 4000 Hz):					
Response	15	37.5	18	45.0	0.485
No response	25	62.5	22	55.0	

Table (6) comparison between the number of children with the response of hearing aid in the group with presence of ASSR and group with absent ASSR

Aided Response	Average ASSR (Rt)				P-value	Average ASSR (Lt)				P-value
	Present		Absent			Present		Absent		
	No.	%	No.	%		No.	%	No.	%	
Good response	26	96.3	0	0.0	0.000*	26	100.0	0	0.0	0.000*
Poor response	1	3.7	13	100.0		0	0.0	14	100.0	

**Figure (2):** Average threshold of different frequencies by ASSR Versus threshold obtained by ABR and behavioral response. [The area in between showed the amount of hearing that could be measured by ASSR].

Discussion :

The study was conducted on 40 children with absent ABR waves; their age ranged from 1 to 5 years, 22 of them were males, and 18 were female. Most of the children had risk factors for sensorineural hearing loss. According to (JCIH 2019)³ these risk factors considered as a cause for hearing loss; these include a family history of hearing loss, NICU admission for more than 48 hours, hyperbilirubinemia, low birth weight, aminoglycoside administration (ototoxicity), asphyxia, craniofacial anomalies also bacterial and/or viral meningitis or encephalitis (especially herpes viruses, varicella, Haemophilus influenza, and pneumococcal meningitis) (Table 1).

In this study, 20 children (50%) had a response to sound stimuli in free field examination through behavioral observation audiometry (BOA), while 18 children (45%) had no response. **Stueve & Rourke 2003**¹⁶ reported that behavioral observation audiometry (BOA) is a critical test that provides useful insight into the child's auditory responsiveness and gives an idea about the presence of residual hearing, prediction of audiometric curve specially slopping curve and to exclude cases of ANSD in case of contradiction between behavioral response and ABR test results. **Stueve & Rourke** reported that the absent response either by absent ABR waves and behavioral free field stimulation does not rule out the clear presence of residual hearing, mainly low-frequency region using ASSR. In the current study, all hearing impaired children were fitted with binaural hearing aids, and the aided response was classified into:

- Good aided response, i.e., fitted or approaching to speech banana curve.

- Poor aided response, i.e., far away from speech banana curve.

Twenty children had a good aided response, 20 children had a poor response, 6 of them had poorly adjusted HA, on proper readjustment or use of a new powerful hearing aid, 4 of them developed good response. Two children had poor responses despite good residual hearing and powerful well-adjusted HA, they were referred to a neuro-pediatrician to exclude central causes, and they were diagnosed with cerebral palsy and mental retardation. Fourteen children had poor response despite the well-adjusted hearing aids, and they had absent ASSR response, which can explain the poor aided response Table (2).

In the current study, 53 ears had an ASSR response while 27 ears had no ASSR response. There was no significant difference between right and left ears (Tables 3).

Similar results were obtained in adults and children with bilateral severe to profound sensorineural hearing loss by **Bosman 2003**¹⁷ and **Swanepoel & Hugo 2004**¹⁸, respectively. But the result disagrees with **Hassan et al., 2014**¹⁹ that reported the percentage of present ASSR was (40.6%) nearly corresponding to behavioral results. Similar to the study of **Swanepoel & Ebrahim 2009**²⁰ who reported that the compatibility of ASSR with behavioral response has hold promise in the assessment of threshold of hearing across different age groups in spite of the significant differences between studies. The variability may be accounted for to a large extent by the amount of hearing loss since ASSR thresholds approximate behavioral thresholds better as the severity of the sensorineural hearing loss increases.

Rodrigues et al., 2010²¹ reported that another component contributed to the accelerated differences between free

field thresholds and ASSR became connected to the boundaries of loudspeaker used in the free field audiometry (85 dB) lacking children in the profound degree.

In the present study, analysis of the results of ASSR demonstrated that the lower frequencies (0.5, 1 K Hz) had better threshold detection while the high frequencies (2, 4 K Hz) showed the lesser threshold detection (table 4, 5). One of the reasons for such distinction in response detection across frequencies may be related to the exceptional stimulation intensity across frequencies given by means of the system platform. It is the highest at 1 kHz and 0.5 kHz, and the absence of the response at 4 K Hz in hearing impaired children might be related to the severity of the hearing to loss at this frequency; also a lot of these children had sloping hearing loss. These results agreed with **Hassan et al., 2014**¹⁹ and **Ahn et al., 2007**²² who found that the biggest percentage of absent ASSR was at 4 K Hz when they studied children with severe to profound sensorineural hearing loss. In a study by **Swanepoel & Hugo 2004**¹⁸ he reported that 15 children with severe to profound sensorineural hearing loss owing to the biggest responses of ASSR at 2 K Hz followed by 1 K Hz, 4 K Hz then lastly 0.5 KHz.

Notably, the ASSR thresholds obtained were significantly higher than the behavioral threshold. **Stapells & Van Maanen 2005**⁹ and **Bosman 2003**¹⁷ emphasized that in hearing impaired children with absent ABR waves, the distinction in thresholds between the behavioral responses and ASSR depend upon the techniques used for ASSR and may attribute to the shortage of standardization among systems.

To summarize, the current presence of ASSR thresholds at higher intensities and low frequencies, which may be no

longer achievable with ABR nor with behavioral measures in hearing impaired children, makes this technique uniquely suitable to the evaluation of children with absent ABR waves. Such goal consequences obtained with the use of the ASSR can provide essential data that the ear might have a residual hearing that could offer good aided reaction or the absence of residual hearing and then shift to a cochlear implant.

ASSR may be applied in choosing and adjustment of hearing aids for infants and young children who cannot provide dependable behavioral thresholds. ASSR and ABR every contribute importantly and rather uniquely to the pediatric audiological test battery. The relationship between the two techniques is not competitive but, instead complementary.

Conclusion and Recommendation:

- 1- The absent response during the behavioral free-field examination and ABR testing does not exclude the presence of residual hearing.
- 2- ASSR can be achieved to provide reliable data about the presence of useful hearing, mainly at low-frequency region, and consequently select the correct way for intervention, either the use of a hearing aid or cochlear implant (CI).
- 3- Addition of ASSR as one of the crucial tests in the protocol for assessment of hearing in children who are potential candidate of CI.

Conflict of interest: The authors declare no competing interests.

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