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ORIGINAL ARTICLE

Prediction of Loudness Growth in Subjects with Sensorineural Hearing Loss Using Auditory Steady State Response

Afaf Ahmed Yousif Emara, Enaas Ahmed Kolkaila

Audiology Unit, ENT Department, Tanta University

Objective: This study was designed to investigate the relationship between auditory steady-state responses (ASSR) and loudness growth function. Moreover, we aimed to use the amplitude of ASSR test to predict the loudness growth function in order to use it for hearing aid adjustment in difficult-to-test subjects.

Materials and Methods: 15 normal hearing subjects and 15 subjects with bilateral moderate sensorineural hearing loss were examined. Contour test was recorded for loudness judgment of different sounds. ASSR also was recorded at frequencies of 500, 1,000, 2,000 and 4,000 Hz to all subjects.

Results: ASSR amplitude values and loudness judgments increase as the stimulus intensity increases for the four frequencies studied. There was a high correlation between Loudness judgment detected by the contour test and ASSR amplitude as a function of stimulation intensity in the two tested groups.

Conclusion: The results suggest that ASSR can be used as an objective test for prediction of loudness in subjects with SNHL especially in difficult-to-test individuals,

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Introduction

Sensation of loudness is a subjective response to the physical dimension of sound intensity [1]. Loudness perception involves a two-stage process: first, the stimulation evokes a loudness sensation, second; the listener assigns a judgment relative to the magnitude of the sensation [2].

Loudness measurement serves two important clinical functions in audiological practice: to distinguish the site-of-lesion in sensorineural hearing loss [3] and to determine the adjustment of hearing aids [4,5]. Moreover, subjective judgment of loudness is often applied in order to estimate the most comfortable level (MCL) or the most uncomfortable loudness level (ULL) for hearing aid adjustment [6-9].

The contour test is one of the common applied clinical methods to quantify loudness perception [6]. This test was designed in order to develop the growth of loudness perception as input levels increase from near threshold to uncomfortably loud.

To overcome the subjective testing difficulties, objective methods for estimating loudness growth using electrophysiological measures have been proposed [10]. Several studies have proved that loudness growth can be estimated using click-evoked ABRs [11-14]. The major disadvantage of procedures based on Click evoked ABR measurements is the lack of frequency specificity of this response. Other disadvantage includes testing each ear separately.

The recently developed test (ASSR) can overcome, in part, the limitations of ABR testing. Auditory steady-state response (ASSR) is an electrophysiological response evoked by one or more carrier frequencies presented simultaneously. The carrier is the specific test frequency as in pure tone audiometry [15]. There are several differences between both ABR and ASSR. First, the ASSR is more frequency specific than clicks used for ABRs [16-18]; secondly, it is faster since the two ears can be stimulated at the same time [19,20]; and thirdly, it is more objective since the response can be statistically obtained [21,22].

This work was designed to assess the relationship between ASSR amplitude at intensities down to threshold and loudness growth function in normal-hearing subjects and subjects with SNHL. Main goal of this study was to establish whether there is a relationship between loudness growth derived from the contour test and the physiological response obtained

Corresponding address:
Afaf Ahmed Emara
11 Hassan Radwan Street, Tanta, Egypt.
Telephone: +201 27405899, E-mail: Afaf_emara@hotmail.com

from the ASSR in normal hearing subjects and subjects with SNHL. Second aim was to use amplitude of the ASSR to predict loudness at different frequencies in order to be used for hearing aid adjustment in very young children.

Materials and Methods

Two groups were included in this study:

Group I: 15 adult subjects with normal hearing (Pure tone average≤ 20dBHL). They were 8 male and 7 female. Their age ranged from 19 to 40 years.

Group II: 15 patients with bilateral sensorineural hearing loss (SNHL). They were 8 males and 6 females. Their age ranged from 21 to 43 years. The average pure tone threshold ranged from 45 dBHL to 55 dBHL with flat configuration. This work was done at Audiology unit, ENT department in Tanta University Hospital in the period from November, 2008 to June, 2009. A consent was obtained from all subjects participated in this study.

All subjects underwent otological examination and full audiological history. Basic audiological evaluation included pure tone audiometry, speech audiometry and acustic immitance test.

Loudness growth measurement was performed using Contour test: We applied the Contour test using the same instructions and procedure of Cox et al. [7].

Procedure of loudness growth function determination (Contour Test)

Instructions to subjects:

"The purpose of this test is to determine your judgment of the loudness of different sounds. You will hear sounds which increase and decrease in volume. You must make a judgment about how loud the sounds are. Pretend you are listening to the radio at that volume. How loud would it be? After each sound, tell me which of these categories best describes the loudness. Keep in mind that an uncomfortably loud sound is louder than you ever choose on your radio no matter what mood you are in. You may find that you use response categories more often than others, or that you may not wish to use certain response categories at all, this is perfectly all right."

These instructions were written in Arabic in large type and we read them over with the subject in a tutorial fashion, using gestures and repetition as necessary.

The Categorical scale:

On the side back of the instructions, the categories were written and were also read with the subject. The categories were in Arabic form according to Elshintinawy and Kolkaila [23]: A categorical scale of eight levels were used. These levels were: 1- very soft, 2-soft, 3-comfortable, but slightly soft, 4-Comfortable, 5- Comfortable but slightly Loud, 6-loud, but O.K., 7- Very loud, 8- uncomfortably loud. A practice run at 1,000Hz was done to familiarize the subject with the test and the response. The test started one or two increments above the subject's threshold and continued in an ascending approach until the uncomfortable category was reached. The increment size was 5 dB using warble tones. The frequencies used were 500, 1,000, 2,000 and 4,000 Hz. Four runs per test frequency were done, or 3 if the subject was consistent. The mean value of levels assigned to loudness at each category across all 3-4 runs was considered as a result.

Auditory Steady State Response (ASSR): Binaural multi-frequency paradigm was done using Smart-EPs Intelligent Hearing System. This paradigm involves simultaneous presentation of stimuli. The carrier frequencies were: 500, 1,000, 2,000, and 4,000 Hz. The modulation rates were: 77, 85, 93 and 101 Hz in the right ear and 79, 87, 95, 103 Hz in the left ear. All subjects were tested in a state of total relaxation in a comfortable and quiet room. The electrode montage was: positive at Fz (high forehead), ground at lower forehead (Fpz), and two negative electrodes placed at both mastoids (M1, M2). The test was started at 80 dB SPL and lowered by 10 dB steps until threshold was obtained.

Statistical analysis

Student T- test was applied to compare between the results of the contour test in the two studied groups. It was also carried out for the amplitude of the ASSR. In order to establish a relationship between loudness judgment done by the contour test and the ASSR amplitude at the four tested frequencies, we applied a linear regression analysis test on normal hearing subjects (group I). In order to predict the loudness growth function from the amplitude and intensity of the stimulus of the ASSR, multiple linear regression analysis was applied on normal hearing subjects (group I). To determine the feasibility of application of this equation, we applied this equation on SNHL subjects (group II). Independent T- test was applied between the subjective loudness judgment detected from the contour test and the predicted loudness from the recorded ASSR amplitude using the previous equation at different intensities (50, 60, 70 and 80 dB) and total intensities.

Results

Comparing loudness growth function between the two tested groups was done. Results were presented in Tables 1 and 2. The results showed the expected increase in mean levels as loudness categories increased. There was a significant difference in loudness growth between normal hearing subjects (group I) and subjects with SNHL (group II) in all frequencies except at 1,000 Hz at category [7].

For the objective part of the study, we measured ASSR amplitude at each intensity. This procedure was done for the four tested frequencies (500, 1,000, 2,000 and 4,000 Hz). There was a statistically significant difference between ASSR amplitude in the two tested groups at all tested frequencies (p<0.001) (Table 3).

Figure-1 showed the amplitude-intensity function for the ASSR obtained from normal hearing subjects (group I) and subjects with SNHL (group II). The amplitude of the ASSR increases as the intensity increases. In normal hearing subjects (group I), the ASSR amplitudes are closer at lower intensities. While at higher intensities, the ASSR amplitudes showed increased differences between the carrier frequencies. Moreover, the differences between the amplitude of the ASSR in normal hearing subjects were larger at high frequencies, than those obtained at low frequencies. In SNHL subjects (group II) the ASSR amplitudes are closer at lower and higher intensities. Also, there was no difference between the amplitude of the ASSR at high frequencies, than those obtained at low frequencies.

Table 1. Comparison of loudness growth in all categories between normal hearing and SNHL subjects at 500 Hz and 1,000Hz.

Confidence interval of the difference		Std error of difference	Mean difference	p-Value	SD	Mean	Group	Category
				500 Hz				
upper	**lower**							
-20.39	-25.7	1.3	-23.05	0.00*	6.2 4.2	24.9 47.3	Normal SNHL	1
-18.17	-25.1	1.7	-21.68	0.00*	9.0 0.0	38.3 60.0	Normal SNHL	2
-15.72	-24.04	1.9	-19..89	0.00*	10.1 4.1	49.2 69.08	Normal SNHL	3
-14.68	-22.42	1.9	-18.56	0.00*	9.7 2.9	59.9 78.4	Normal SNHL	4
-10.84	-20.37	2.1	-15.6	0.00*	11.8 4.08	71.3 86.9	Normal SNHL	5
-9.23	-18.23	2.2	-2.66	0.00*	10.9 4.4	83.8 97.6	Normal SNHL	6
1.80	-7.12	2.2	-6.5	0.00*	6.8 5.1	94.7 101.2	Normal SNHL	7
7.62	-0.62	2.06	3.5	0.09	10.4 4.4	104.4 100.8	Normal SNHL	8
				1,000 Hz				
-24.80	-30.50	1.40	-27.65	0.00*	7.2 2.3	25.5 53.2	Normal SNHL	1
-18.88	-29.90	2.47	-23.89	0.00*	12.3 5.3	43.3 67.2	Normal SNHL	2
-17.43	-29.62	3.03	-23.52	0.00*	13.4 8.5	56.8 80.3	Normal SNHL	3
-10.76	-21.58	2.69	-16.17	0.00*	12.6 7.2	69.8 86.0	Normal SNHL	4
-9.03	-19.14	2.50	-14.08	0.00*	11.9 6.3	80.0 94.1	Normal SNHL	5
-5.88	-16.42	2.35	-10.65	0.00*	11.8 4.6	90.5 101.2	Normal SNHL	6
0.39	-8.45	2.17	-4.03	0.06	11.3 2.9	101.6 105.6	Normal SNHL	7
0.30	-7.14	1.86	-3.42	0.07	8.7 5.5	106.8 110.3	Normal SNHL	8

Table 2. Comparison of loudness growth in all categories between normal hearing and SNHL subjects at 2,000Hz and 4,000Hz

Confidence interval of the difference		Std error of difference	Mean difference	p-Value	SD	Mean	Group	Category
2,000 Hz								
upper	lower							
-29.76	-35.00	1.28	-32.38	0.00*	6.5 1.25	23.62 56.0	Normal SNHL	1
-24.04	-33.48	2.23	-28.76	0.00*	11.1 5.03	41.57 70.33	Normal SNHL	2
-20.92	-26.20	2.91	-26.76	0.00*	12.11 9.51	55.74 82.5	Normal SNHL	3
-15.23	-23.0	2.75	-20.77	0.00*	11.75 8.6	68.98 89.75	Normal SNHL	4
-13.47	-16.60	2.40	-18.30	0.00*	10.54 7.0	79.54 97.83	Normal SNHL	5
-8.74	-16.75	1.98	12.74	0.00*	9.08 5.12	90.09 102.83	Normal SNHL	6
-4.18	-11.43	1.80	-7.80	0.00*	8.13 4.85	100.28 108.08	Normal SNHL	7
7.62	-0.62	2.06	3.5	0.09	10.4 4.4	104.3 100.8	Normal SNHL	8
4,000 Hz								
-29.61	-38.31	2.17	-33.95	0.00*	7.90 7.71	25.44 59.40	Normal SNHL	1
-24.72	-38.49	3.43	-31.60	0.00*	12.10 12.60	41.30 72.90	Normal SNHL	2
-15.85	-30.52	3.65	-23.19	0.00*	12.12 14.02	56.11 79.30	Normal SNHL	3
-13.18	-25.99	3.19	-19.59	0.00*	11.89 11.12	67.31 86.90	Normal SNHL	4
-12.25	-22.90	2.65	-17.58	0.00*	10.29 8.80	78.43 96.00	Normal SNHL	5
-8.70	-17.79	2.52	-13.24	0.00*	10.0 5.91	88.06 101.30	Normal SNHL	6
-8.30	-16.03	1.90	-12.17	0.00*	9.10 3.50	98.33 110.50	Normal SNHL	7
1.16	-4.66	1.4	-1.75	0.23	5.15 6.06	106.0 107.3	Normal SNHL	8

The amplitude of the ASSR averaged from normal-hearing subjects (group I) and subjects with SNHL (group II) for each frequency was demonstrated on Figure-2. As expected, the amplitude of the responses increased with increasing the intensity. This figure also showed growth function curves detected by the contour test as a function of stimulation intensity for all tested frequencies in the two tested groups.

In order to establish a relationship between loudness growth function and the ASSR in normal hearing subjects, we applied a linear regression analysis between the electro-physiological responses (ASSR) and the psychophysical judgment of loudness (Contour test). There was a high relationship for the three carrier frequencies (1,000, 2,000 and 4,000Hz) (Table 4). The correlation between both variables was significant for these three frequencies. The higher correlation is for the 2 kHz carrier frequency.

L=5.99+9*Amp (at 1,000 Hz carrier frequency).

L=5.871+10.938*Amp (at 2,000 Hz carrier frequency).

L=6.174+8.454*Amp (at 4,000 Hz carrier frequency).

Furthermore, in order to be able to predict the loudness growth function from the ASSR amplitude, multiple regression analysis was applied on data of normal hearing subjects. The result of predicted loudness was expressed by an equation that includes both the intensity and the amplitude of ASSR regardless the frequency.

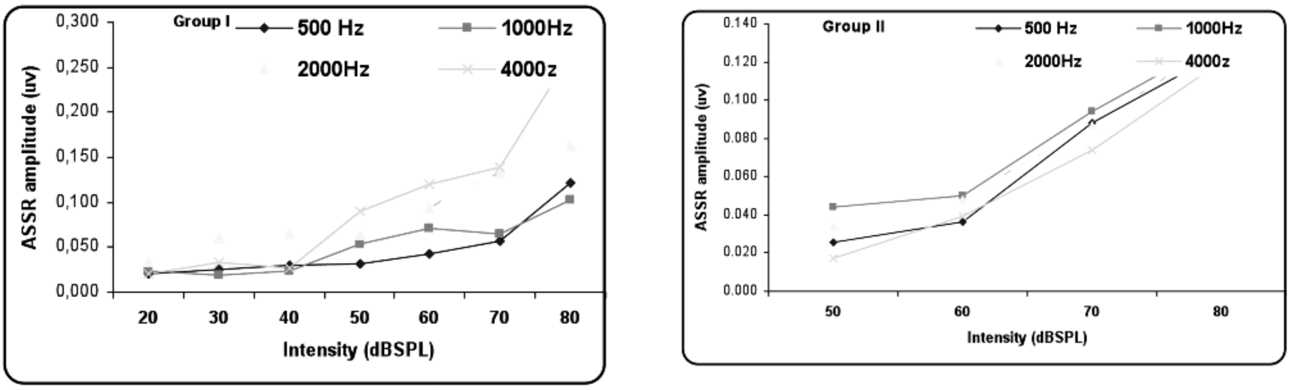

Figure 1. Amplitude intensity function for the ASSR obtained from normal hearing subjects (Group I) and subjects with SNHL (Group II)

Predicted Loudness = 3.371+ 1.05 intensity +14.01 amplitude

By applying this equation on the SNHL patients we could predict the loudness growth of those patients. Independent T- test was applied between the subjective loudness obtained from the contour test and the predicted loudness from the previous equation at the 50, 60, 70, 80 dB intensity, as well as from the recorded ASSR amplitude. There was no statistically significant difference between the subjective loudness growth and the predicted loudness (Table 5).

The ASSR amplitude increases as the intensity increases. In normal hearing subjects (group I): the ASSR amplitudes are closer at lower intensities, in contrast to higher intensities the ASSR amplitude differences between the carrier frequencies increases.

Table 3. Comparison of ASSR amplitude between normal hearing and SNHL subjects at different intensities

Confidence interval of the difference		Std error of difference	Mean difference	p-Value	SD	Mean	Group	Category
upper	lower							
				80 dB				
0.11	0.08	0.008	0.09	0.00*	0.04	0.14	Normal	500
					0.02	0.05	SNHL	
0.08	0.05	0.008	0.07	0.00*	0.03	0.13	Normal	1,000
					0.03	0.07	SNHL	
0.09	0.06	0.006	0.08	0.00*	0.03	0.16	Normal	2,000
					0.01	0.08	SNHL	
0.1	0.08	0.01	0.1	0.00*	0.04	0.16	Normal	4,000
					0.03	0.06	SNHL	
				70 dB				
0.04	0.01	0.007	0.08	0.007*	0.04	0.07	Normal	500
					0.02	0.05	SNHL	
0.05	0.03	0.005	0.04	0.00*	0.03	0.09	Normal	1,000
					0.02	0.06	SNHL	
0.06	0.03	0.006	0.04	0.00*	0.03	0.11	Normal	2,000
					0.02	0.07	SNHL	
0.07	0.04	0.01	0.06	0.00*	0.04	0.12	Normal	4,000
					0.03	0.07	SNHL	
				60 dB				
0.04	0.02	0.005	0.03	0.00*	0.01	0.06	Normal	500
					0.02	0.03	SNHL	
0.03	0.005	0.007	0.01	0.05*	0.03	0.06	Normal	1,000
					0.02	0.04	SNHL	
0.05	0.02	0.009	0.04	0.00*	0.03	0.07	Normal	2,000
					0.03	0.04	SNHL	
0.07	0.03	0.01	0.05	0.00*	0.04	0.08	Normal	4,000
					0.02	0.03	SNHL	

Table 4. Linear regression between the electro-physiological responses (ASSR) and the psychophysical method for loudness judgment

4,000 Hz	2,000 Hz	1,000Hz	
6.174	5.871	5.990	Y "intercept"
8.454	10.938	9.000	Slope
L=6.174+8.454*Amp.	L=5.871+10.938*Amp.	L=5.99+9*Amp.	Equation
0.551	0.616	0.546	R
0.871	0.823	0.875	Std. Error of the estimate

Predictors: (Constant), Amplitude of the ASSR
Dependent Variable :Loudness

Table 5. Comparison between the subjective loudness detected by the contour test and the objective loudness predicted from ASSR:

Confidence interval of the difference		SE of difference	Mean difference	p-Value	SD	Mean	Group	Category
upper	lower							
0.057	-1.17	0.31	-0.56	0.08	55.37 (2.42)	54.82 (2.39)	Mean (SD)	50 dB
3.25	-1.83	1.29	0.71	0.58	67.78 (2.03)	68.49 (13.9)	Mean (SD)	60 dB
3.1	-1.79	1.25	0.68	0.59	78.64 (2.01)	79.3 (13.57)	Mean (SD)	70 dB
1.55	-2.92	1.13	-0.69	0.55	90.12 (3.82)	89.44 (11.82)	Mean (SD)	80 dB
0.36	-3.83	1.068	-1.73	0.105	75.12 (14.76)	73.39 (18.17)	Mean (SD)	Total

In normal hearing subjects: the differences between the amplitude of the ASSR were larger at high frequencies, than those obtained at low frequencies. In SNHL subjects (group II) the ASSR amplitudes are closer at lower and higher intensities. Also, there was no difference between the amplitude of the ASSR at high frequencies, than those obtained at low frequencies.

Solid line represents the normal hearing subjects (group I) and the dotted line represents the SNHL subjects (group II)

In order to establish the relationship between loudness and the ASSR we carried on a regression analysis. In this table we show the linear regression between the physiological responses and the psychophysical judgements. The correlation between both variables was significant for these three frequencies.

Discussion

The contour test yields data describing the sound loudness ranging from very soft to uncomfortably loud. There was a significant difference in loudness growth between normal hearing subjects and subjects with SNHL at all frequencies. The results suggest that the more the hearing loss was, the more rapid the loudness growth. This result agrees with those of results belong to Zhou et al., [24].

Within each stimulus, the results showed the expected increase in the mean levels as loudness categories increased. The standard deviations revealed that the variability between-subjects was fairly similar for a given loudness category across warble tone test frequencies. The contour test appeared to offer a viable approach to clinical measurement of loudness perception. It has good patient acceptance and combines fairly rapid administration with acceptable reliability. However, it is important to keep in mind that the application of loudness perception for warble tones to hearing aid prescription is complicated by the need to account for the effects of loudness summation across bandwidth [7].

The results of this study showed that the amplitude of the ASSR response increased with increasing levels of intensity for all carrier frequencies studied. In general, ASSR amplitude was larger for higher intensity levels if compared to lower intensity levels. These results are similar to the results of other researchers who reported using the 40-Hz response [25-29]. Furthermore, the results

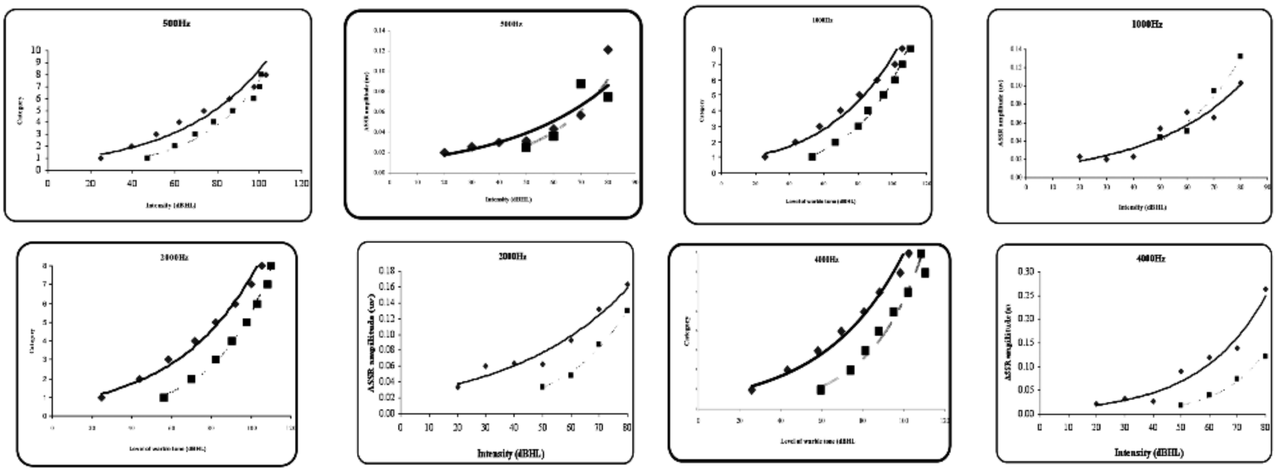

Figure 2. Loudness judgment detected by the contour test and ASSR amplitude as a function of stimulation intensity for tested frequencies in the two tested groups

of our work also agree with those of the multiple ASSR technique [30- 33].

In normal hearing subjects, the ASSR amplitudes increased more rapidly at intensities above 70 dB SPL at all carrier frequencies. This result agreed with those of Lins et al. [34]. In sensorineural hearing loss subjects, the ASSR amplitude increased rapidly in intensities above 60 dBSPL at all carrier frequencies. For normal hearing listeners, the OHCs enhance discrimination in the cochlea at low stimulus intensity. So, only the fibers tuned to the characteristic frequencies near the carrier frequency would be activated. At higher stimulus intensities, the spread of activation in the cochlea would be wider, thereby activating more inner hair cells. This could explain the difference in slope in the response obtained. Consequently, the relation between ASSR amplitude and loudness would be more linear in subjects with SNHL. The amplitude of the ASSRs could reflect the activity of the OHCs and be an objective measure of loudness recruitment [11].

An important issue of the present study was to examine the relationship between the loudness growth function and the amplitude of the ASSR at different intensity levels. A significant relationship between the intensity-amplitude function of the ASSR and the subjective measurement of loudness was found for the sample of normal-hearing subjects and subjects with SNHL. This result agreed with those of Castro et al. [35].

A potential application of the current study could be prediction of loudness from the amplitude of the ASSR at a particular intensity level. Comparing the results of loudness judgment obtained from the contour test with the predicted loudness from the ASSR amplitude showed no statistically significant difference in SNHL. However, this prediction might provide an objective measurement that could be used to adjust compression functions or maximum amplification levels of hearing aids. This will facilitate the objective characterization of loudness growth function in babies, infants and uncooperative children or adults.

In summary, these data suggest that loudness growth can be reasonably well predicted from the ASSR amplitude. An electrophysiological measure of loudness growth could help audiologists in estimating discomfort levels and determining hearing aid features. Objective measurement of loudness could be included in the prescription of gain in order to fit hearing aids within the first few month of age. The procedure described is no longer time-consuming since it does not necessitate any additional examinations. In difficult-to-test individuals, such as young infants, subjective and objective measures such as functional gain and real-ear probe measurements, are not always possible. For those subjects who do not provide reliable responses to behavioural audiometry, the appropriate selection and fitting of hearing aids require the establishment of accurate hearing thresholds by other means. ASSR can be used in the characterization of hearing loss to estimate the auditory threshold. In addition, the ASSR can provide information at threshold and also at suprathreshold levels. In the future,ASSR parameters can be used to verify and select the adjustment of hearing aids.

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