

Original Article

Audiological characteristics of infants with abnormal transient evoked otoacoustic emission and normal auditory brainstem response

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Summary

Audiological characteristics were investigated in 81 ears of 53 infants with abnormal transient evoked otoacoustic emission (TEOAE) and normal auditory brainstem response (ABR). The relationship between ABR and other hearing testing methods, including 40Hz auditory event-related potential (40Hz-AERP), auditory steady state response (ASSR), distortion product otoacoustic emission (DPOAE), tympanometry, and acoustic reflex, was analyzed. Of the 81 ears, 18 ears (22.2%) were normal, while 63 ears (77.8%) were abnormal according to the tests. Testing of the 40 Hz AERP (36 ears) and ASSR (45 ears) revealed that 14 ears (38.9%) and 27 ears (60.0%) were abnormal, respectively. Testing of DPOAE in 68 ears revealed that 50 ears (73.5%) were abnormal. Testing of tympanometry in 50 ears and acoustic reflex in 47 ears revealed that 9 ears (18%) and 27 ears (57.4%) were abnormal, respectively. The present data suggests that the hearing of infants cannot be sufficiently evaluated with ABR only and that it must be evaluated with integrative audiological testing methods.

Keywords: Neonatal screening, Audiology, Evoked potentials, Auditory, Otoacoustic emissions

1. Introduction

Congenital hearing loss, a frequent birth defect, can directly slow the development of language, emotion, mentality, and social communication in infants and significantly affect school attendance and employment. These impacts of congenital hearing loss on the family and society can be huge. There is evidence that the age of discovery and identification of hearing loss and the age at which intervention is performed positively and significantly affect language development in infants (1,2). However, there is no unified standard for diagnosis and evaluation of congenital hearing loss in China. With

the increasing number of newborns and infants who fail hearing screening, correct diagnosis in the early stage of hearing loss becomes crucial. The present study analyzed hearing testing results for newborns and infants with abnormal transient evoked otoacoustic emission (TEOAE) and normal auditory brainstem response (ABR). This was done was to study the relationship between ABR and other hearing testing methods, including 40 Hz auditory event related potential (40 Hz AERP), auditory steady state response (ASSR), distortion product otoacoustic emission (DPOAE), tympanometry, and acoustic reflex, and the relationship between hearing screening and hearing diagnosis.

2. Methods

2.1. Subjects

Data were collected for all newborns and infants who underwent audiological diagnosis at the children's

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hearing diagnosis center of this hospital from December 2003 to November 2005. During this period, all subjects were screened with a TEOAE hearing test at a local newborn hearing screening center or maternal and child health care hospital. Subjects with an abnormal ear or ears in preliminary screening at the age of 2 to 7 days and in duplicate screening at the age of 30 or 42 days then underwent the ABR test at this hospital. Of 53 subjects (81 ears: 44 left ears and 37 right ears) with normal ABR, 34 were male (53 ears) and 19 were female (28 ears). The mean age was 4.1 months and ranged from 1.5 to 38 months.

2.2. ABR test

An evoked potential tester (Nicolet Spirit, Nicolet Inc., Madison, WI, USA) was used with an alternatively inverted click stimulus, pulse width of 0.1 ms, initial intensity of sound stimulus of 80 dB nHL, stimulus repetition rate of 11.9 times/s, analysis time of 10 ms, band-pass filtering of 10~3,000 Hz, and 2 or 3 replications of 1,000 sweeps. The box of electrodes consisted of four electrodes: a forehead electrode as the recording electrode, acoustic stimulation of the bilateral mastoids as the reference electrodes, and a glabella electrode as the ground electrode. The impedance values of the electrodes were below 5 Kohms. A V response threshold for the ABR wave equal to or less than 30 dB nHL served as an index of normal hearing in the range of 2 kHz to 4 kHz (3).

2.3. 40 Hz AER test

The instrument and electrode placement in this test was the same as in the ABR test. Acoustic stimulation (2 ms-2 ms-2 ms) was presented as a tone burst at 500 Hz with an initial intensity of 80 dB nHL, a rhythm of 40 stimulations per second, an analysis time of 100 ms, band-pass filtering of 10 Hz-100 Hz, and 2 or 3 replications of 500 sweeps. The acoustic stimulus intensity sufficient to cause a reaction was the 40 Hz AERP response threshold. A value equal to or less than 40 dB nHL served as an index of normal hearing (4).

2.4. ASSR test

ASSRs were recorded using the Intelligent Hearing Smart ASSR evoked potential system (Intelligent Hearing Inc., Miami, FL, USA). The carrier frequencies of the acoustic stimulation signals were 0.5 kHz, 1 kHz, 2 kHz, and 4 kHz. The sine wave frequencies of amplitude modulation were 77 Hz, 85 Hz, 93 Hz, and 101 Hz for the left ear, and 79 Hz, 87 Hz, 95 Hz, and 103 Hz for the right ear, with modulation depth of 100%. Many brief sound signals were sent to both ears at the same time using ER-3A standard plug-in headphones to perform calibration. The recording

electrode was placed on the forehead. Electrodes at the bilateral mastoids functioned as reference electrodes and a glabella electrode served as the ground electrode. The impedance values of the electrodes were below 3 Kohms. Band-pass filtering was 30~300 Hz and the amplifier gain was fixed at 10^5 . According to the ASSR testing results, response thresholds of 0.5 kHz, 1 kHz, 2 kHz, and 4 kHz were determined. The mean value for 4 frequencies that was equal to or less than 35 dB nHL served as an index of normal hearing of ASSR (this laboratory's standard).

2.5. DPOAE test

An ILO-96 otoacoustic emission instrument (Otodynamics Ltd., Herts, UK) was used. Test conditions were as follows: using two stimulation pure tones, f_1 and f_2 , at the same time, and $f_1 = f_2 = 70$ dB SPL, $f_2: f_1 = 1.22$. The f_2 frequencies were 696 Hz, 1,001 Hz, 1,501 Hz, 2,002 Hz, 3,003 Hz, 4,004 Hz, 5,005 Hz, and 6,006 Hz. The normal criteria for DPOAE were that the distortion product (DP) value ($2f_1 - f_2$) of each analysis frequency was in the normal range while the DP value of the frequency was at least as large as the noise value of 3 dB SPL and that passing scores were obtained for at least 4 of the 8 observed frequencies.

2.6. Tympanometry test

A GSI TympStar middle ear analyzer (Grason Stadler Inc., Madison, WI, USA) was used for testing. Sound was deemed to be detected at 226 Hz. Normal standards for the tympanometry test were that the tympanogram was an A type, tympanic cavity pressure was in the range of +100 mmH₂O, the extent of acoustic compliance was 0.3~1.6 mL, and the volume of the tympanic cavity was 0.5~1.0 mL.

2.7. Acoustic reflex test

The same instrument as used in tympanometry was used to perform acoustic reflex testing. Sound was deemed to be detected at 226 Hz. Normal standards for an acoustic reflex were as follows: a homolateral acoustic reflex was detectable and the reflex threshold was equal to or less than 90 dB SPL. Newborns and infants were tested while sleeping after they had taken 10% chloral hydrate. All testing was done in a noise-shielded room with indoor environmental noise of 18 dB (A).

3. Results

Of the 81 ears, 18 ears (22.2%) were normal in 12 subjects according to tests. Of these 12 subjects, 10 infants were male (16 ears, 30.2% of all male infant ears) and 2 were female (2 ears, 7.1% of all female infant ears). Of these normal ears, 9 were left ears

(20.5% of all left ears) and 9 were right ears (24.3% of all right ears). In contrast, 63 ears (77.8% of all ears) in 41 subjects with normal ABR were abnormal in one or more other hearing tests. Of these 41 subjects, 24 were male (37 ears, 69.8% of all male ears) and 17 were female (26 ears, 92.9% of all female ears). Of these 63 abnormal ears, 35 were left ears (79.5% of all left ears) and 28 were right ears (75.7% of all right ears). The abnormal rate in DPOAE testing was the highest among all of tests, followed by ASSR and acoustic reflex, while it was lowest in tympanometry (Table 1). Abnormal rates for female infants were significantly higher than for male infants in all of the tests (Table 2). Abnormal rates for left ears were significantly higher than for right ears in all tests except for the acoustic reflex (Table 3).

4. Discussion

Otoacoustic emission (OAE) is a type of audio energy that is generated in the cochlea, conducted through the ossicular chain and the tympanic membrane, and released into the external acoustic meatus (5,6). OAE differs from ABR and is only sensitive to the integrity of the peripheral auditory system rather than the level of hearing (7). The normal peripheral auditory system can be confirmed by OAE signals. OAE can be detected quickly and objectively in newborns and infants with a normally functioning outer, middle and inner ear (8,9), so it is thus often used to evaluate the hearing of

children and screen the hearing of newborns. When the amplitude value of OAE is reduced or missing, further audiological evaluation is required. ABR is an essential objective method to evaluate hearing especially for those infants who cannot be measured with audiometry (10). The response threshold of ABR often serves as an objective clinical standard for high-frequency hearing in infants (11). However, ABR does not fully satisfy clinical requirements. The present study analyzed all hearing tests of infants with abnormal TEOAE and normal ABR.

Of the 81 ears with normal ABR, only 18 ears (22.2%) were normal in the 5 other hearing tests. ABR energy is mainly in the high frequency range (2 ~4 kHz) because of the induction of clicks in ABR. Although a click-induced ABR is closely correlated to a behavior auditory threshold of 2~4 kHz, ABR lacks frequency specificity and cannot reflect the levels of hearing at low and medium frequencies. A 40 Hz AERP is induced by a tone burst and has some advantages, such as stable waveform, large amplitude, good reproducibility, easy identification, determined threshold, and frequency specificity. This test mainly evaluates low-frequency (0.5~1 kHz) hearing and can compensate for the insufficiency of ABR testing to measure low-frequency hearing. Of the 36 ears with normal ABR, 38.9% were abnormal in the 40 Hz AERP test. This result suggests that low-frequency hearing loss could not be detected effectively with the ABR.

Table 1. Comparison of the abnormal rate for different tests

Testing method	Total tested subjects (number of ears)	Abnormal subjects (number of ears)	Abnormal rate (%)
40 Hz AERP	22 (36)	11 (14)	38.9
ASSR	31 (45)	20 (27)	60.0
DPOAE	45 (68)	34 (50)	73.5
Tympanogram	32 (50)	8 (9)	18.0
acoustic reflex	31 (47)	18 (27)	57.4

Table 2. Comparison of abnormal rates for male and female infants according to different testing methods

Testing method	Male			Female		
	Tested subjects (number of ears)	Abnormal subjects (number of ears)	Abnormal rate (%)	Tested subjects (number of ears)	Abnormal subjects (number of ears)	Abnormal rate (%)
40 Hz AERP	13 (23)	6 (8)	34.8	9 (13)	5 (6)	46.2
ASSR	20 (29)	12 (17)	58.6	11 (16)	8 (10)	62.5
DPOAE	28 (42)	19 (27)	64.3	17 (26)	15 (23)	88.5
Tympanogram	21 (32)	4 (4)	12.5	11 (18)	4 (5)	27.8
acoustic reflex	20 (29)	12 (16)	55.2	11 (18)	6 (11)	61.1

Table 3. Comparison of abnormal rates for left and right ears according to different testing methods

Testing method	Left ear		Right ear	
	Ears tested	Abnormal ears (%)	Ears tested	Abnormal ears (%)
40 Hz AERP	20	10 (50.0)	16	4 (25.0)
ASSR	23	15 (65.2)	22	12 (54.5)
DPOAE	38	30 (78.9)	30	20 (66.7)
Tympanogram	26	5 (19.2)	24	4 (16.7)
acoustic reflex	24	13 (54.2)	23	14 (60.9)

Nevertheless, a 40 Hz AERP is affected by the depth of sleep and sedatives and its waveform differentiation and response threshold differ in some cases. In recent years, ear, nose, and throat (ENT) doctors have assigned importance to the ASSR to evaluate hearing in infants. When many amplitude modulation acoustic signals are sent simultaneously through the ears, the ASSR can record the response to the sound stimulus and objectively judge the values for the hearing response threshold at frequencies of 0.5 kHz, 1 kHz, 2 kHz, and 4 kHz at the same time in both ears. ASSR possesses better frequency specificity and its high frequency is closely correlated with the behavioral hearing threshold (12). In addition, it is not affected by tranquilizers and sleep (13). An abnormal ASSR mainly reflects a rise in the hearing response threshold for low frequencies (500 Hz) (14). In the present study, there were 27 abnormal ears among the 45 ears tested by ASSR, with an abnormal rate of 60.0%. The abnormal rate for ASSR testing was significantly higher than for the 40 Hz AERP. This result demonstrates that the ASSR tends to underestimate low-frequency hearing. Many reports have mentioned that there is no positive correlation between a hearing response threshold of 500 Hz and the behavioral threshold when the ASSR was used to assess the hearing of normal infants (15-17). Accordingly, ASSR results must be compared with other hearing test results when assessing the low-frequency hearing of infants.

OAE is a sensitive index used to evaluate the integrity of the peripheral auditory system and can be detected only when the external ear, middle ear, and inner ear are functioning normal or close to normal (18). Studies have shown that different sound intensity levels of sound stimuli produce different levels of sensitivity in damaged cochlea (5). The sound intensity level of the sound stimulus in TEOAE is 80 dB SPL and the test can identify hearing loss of 20~30 dB HL (19), while the sound intensity level of the sound stimulus in DPOAE is 70 dB SPL and it can identify loss of up to 35~45 dB HL (20). There is no continuity between TEOAE and DPOAE test results; that is, a normal TEOAE does not mean a normal DPOAE, and vice versa (21). Frequency specificity in DPOAE is better than in TEOAE. In this study, 50 ears (73.5% of 68 ears with abnormal TEOAE) were abnormal according to the DPOAE test.

Tympanometry testing is mainly used to measure the function of the middle ear in children (22,23). A type B or C tympanogram shows that there is fluidity in the tympanic cavity while failure to induce an acoustic reflex indicates a problem with conduction in the middle ear (24). In conductive hearing loss, such as the congenital development malformation of the middle ear, the tympanogram is type A or type As and thus normal but acoustic reflex cannot usually be induced or has a higher threshold (25). In testing with tympanometry

and the acoustic reflex, the overall abnormal rate was 75.4%. The abnormal rate in tympanometry (18.0%) was significantly lower than that in acoustic reflex (57.4%) testing. This suggests a higher proportion of middle ear disease in infants with abnormal TEOAE and normal ABR; 226 Hz tympanometry was less sensitive than acoustic reflex in testing of the middle ear disease in infants.

Analysis by gender demonstrated that the abnormal rate was significantly higher among females (92.9%) than males (69.8%). This was more prominent in results of 40 Hz AERP (male 34.8%, female 46.2%), DPOAE (male 64.3%, female 88.5%), and tympanometry (male 12.5%, female 27.8%). These results suggest a high false positive rate for screening of male infants. This finding agreed with a previous study by the authors (26). Total abnormal rates for left and right ears were 79.5% and 75.7%, respectively, and there was no significant difference between the two ears. Except for acoustic reflex test, other tests indicated higher abnormal rates for left ears than for right ears. In the 40 Hz AERP test, the abnormal rate for left ears was significantly higher than that for right ears (left 50.0%, right 25.0%).

In conclusion, these different hearing diagnostic methods possess their own characteristics and can supplement each other. However, hearing loss cannot be sufficiently determined with ABR alone in newborns and infants who fail hearing screening. ABR must be combined with other audiological tests and all testing results must be analyzed.

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