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Infant Hearing Screening 1984 to 1989: The Henry Ford Hospital Experience

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From 1984 to 1989 the Infant Hearing Screening (IHS) program at Henry Ford Hospital identified 1,300 infants as being "at risk" for hearing loss. The prevalence of significant sensorineural hearing loss in this sample was 1.4%. Additionally, 80 infants who passed the IHS program and reached 3 years of age were found to have normal hearing sensitivity by conventional audiometric techniques (ie, no false-negative predictions). There were three false-positive predictions. It was discovered that infants of low birthweight (ie, < 1,500 g) were three times more likely to fail IHS than those whose weight exceeded 1,500 g. A higher return rate was found for infants failing an initial hearing screening conducted in the neonatal intensive care unit in comparison to those screened as outpatients one week postdischarge. The sensitivity and specificity of behavioral observation audiometry were 43% and 92%, respectively, when brainstem auditory-evoked potentials was used as the criterion validity measure. (Henry Ford Hosp Med J 1990;38:39-43)

Childhood hearing loss has a profound impact on the development of speech and language skills (1,2) and academic achievement (3). Therefore, early identification of hearing loss and subsequent aggressive medical management and habilitation services (ie, with hearing aids) is essential for minimizing the debilitating effects of hearing problems.

The prevalence of congenital hearing impairment in full-term infants is between 1:750 to 1:1,000 in the United States (4-7), but is reported to be as high as 1:50 for preterm births (4,8). The incidence of hearing loss in the neonatal intensive care unit (NICU) could be 20 to 50 times greater than that observed in the newborn nursery (9,10). The Joint Committee on Infant Hearing was established in 1969 in an attempt to formulate criteria to identify those infants "at risk" for congenital hearing loss so that they might undergo hearing testing early in life. These high-risk criteria, expanded in 1982 (11), are presented in Table 1.

Three common audiologic procedures are used in infant hearing screening: behavioral observation audiometry (BOA), brainstem auditory-evoked potentials (BAEP), and immittance audiometry. BOA is a subjective test that is administered in a sound-treated booth. Various discrete tonal, noise, and speech stimuli are presented through a loudspeaker in an attempt to elicit reflexive responses from the infant (12). The BAEP is another semiobjective examination of the auditory system. Although the BAEP does not evaluate an individual's perceptual response to auditory signals, it does provide an estimate of hearing sensitivity. The BAEP is an electrophysiologic response consisting of 5 to 7 waveforms that emanate from the auditory nerve and brainstem auditory pathways in response to transient auditory stimulation. The auditory end organ must be intact for the BAEP to occur. The sound stimulus that elicits the response is a "click" stimulus that consists of a high-frequency noise band providing information about the 2,000 to 6,000 Hz hearing range. This test can be administered as early as 25 weeks conceptional age (8). The sound intensity level where the fifth and most stable BAEP waveform (P5) is identifiable (termed P5 threshold) is generally 20 to 30 dB lower than a person's voluntary threshold for the same stimulus. Therefore, most investigators recommend that to "pass" BAEP screening an infant must have a BAEP P5 response to each ear at a stimulus level between 30 to 40 dB normal hearing level (nHL) (13-20). The percentage of infants in the NICU failing in either ear at 30 or 40 dB nHL is reported to range from 14% to 20% (18,21-23). It has been recommended that the pass level of 30 dB nHL be utilized to identify infants who have even mild hearing loss until it has been determined that such loss neither impairs the development of speech and language nor learning (19). Immittance testing is a semiobjective test that provides information about the status of the middle ear system, cochlea, auditory nerve, and the brainstem auditory pathways that subserve middle ear muscle reflexes. This test is particularly helpful in determining whether conductive hearing loss (ie, due to middle ear effusion) is present in infants.

Two models have been suggested for IHS programs. In one, infant hearing screening using the BAEP is conducted in the NICU. Infants who fail the initial screening test are seen as outpatients when a second BAEP and BOA are performed. Infants who fail the repeat BAEP are evaluated with immittance audi-

Table 1
Risk Factors in the High-Risk Registry*

1. Family history of childhood hearing impairment.
2. Congenital perinatal infection (eg, cytomegalovirus, rubella, herpes, toxoplasmosis, and syphilis).
3. Anatomical malformations involving the head or neck (eg, dysmorphic appearance including syndromal and nonsyndromal abnormalities, overt or submucous cleft palate, morphologic abnormalities of the pinna).
4. Birthweight less than 1,500 g.
5. Hyperbilirubinemia at levels exceeding indications for exchange transfusion.
6. Bacterial meningitis, especially Haemophilus Influenza.
7. Severe asphyxia which may include infants with Apgar scores of 0 to 3 or who fail to have spontaneous respiration by 10 minutes and those with hypotonia persisting to 2 hours of age.

*From the American Speech-Language-Hearing Association, 1983.

Table 2
Frequency of Risk Factors*

Risk Factor	Frequency	Percent of Total
Respiratory distress syndrome† Hyaline membrane disease Meconium aspiration syndrome	715	29
Ototoxic antibiotics†	650	26
Low birthweight	357	14
Hyperbilirubinemia† (requiring phototherapy)	340	14
Hyperbilirubinemia (requiring transfusion)	165	6
Severe asphyxia	138	5
Congenital malformations	50	2
Family history of hearing loss	41	2
Congenital infections	31	1
Meningitis	18	1
Total	2,505	100

*From a sample of 1,300 infants comprising the Infant Hearing Screening program from June 1984 to July 1989. The risk factors are presented in order of observed prevalence.
†We have added these risk factors to the conventional high-risk registry.

ometry. Those with no evidence of middle ear disease are considered to have significant sensorineural hearing loss. In the second model, BAEP and BOA are conducted only after the infant has been discharged from the NICU. These two programs have not yet been compared systematically.

Results of BOA and BAEP testing have not been carefully compared. Preliminary reports suggest that there may be only fair agreement between BOA and BAEP testing. For example, Cornacchia et al (24) reported that agreement between the two tests improved only as hearing loss worsened.

The purposes of the present study were: 1) to document the prevalence of hearing loss and the frequency of risk factors in a sample of infants enrolled in an IHS program, 2) to evaluate the effectiveness of both inpatient and outpatient models of IHS, and 3) to determine the sensitivity and specificity (ability to detect hearing impairment and ability to detect normal hearing, respectively) of BOA as compared with BAEP.

Methods

Subjects

Of the 1,300 infants (760 male and 540 female) who were included in the study, 62 were from the well-baby nursery and 1,238 were from the NICU at Henry Ford Hospital. The total sample was composed of two subgroups: infants enrolled in either inpatient (N = 162) or outpatient (N = 1,138) IHS programs. The conceptional ages of the infants ranged from 28 to 64 weeks and a substantial number (1,200) were preterm. The infants referred for evaluation were considered at risk for hearing loss. The high-risk register (11) was used to screen infants into the IHS program. In addition to the seven criteria listed in Table 1, other neonatal risk factors were added, including hyperbilirubinemia treated with phototherapy, respiratory distress syndrome (RDS), and the administration of aminoglycoside drugs, all of which are generally associated with a small but significant risk of hearing loss (25). Most infants had more than one risk factor (Table 2).

Procedures

Two models of IHS programs were studied.

Inpatient infant hearing screening (10/1/88–7/31/89)—Infants at risk for hearing impairment were evaluated prior to discharge from either the NICU or well-baby nursery. Neonates were evaluated in the early afternoon usually after feeding and during natural sleep. BAEP testing was conducted in a quiet room adjacent to the NICU. Disposable pediatric silver/silver chloride pellet electrodes were placed at the left and right mastoids and frontal central (Fz) using conventional skin preparation techniques. EEG activity was filtered (100 to 3,000 Hz), amplified ($\times$ 100,000), and averaged ($\times$ 1,500 to 4,000 samples) using a commercial clinical evoked potentials system (Cadwell Quantum 84).

Auditory signals were 0.100 msec rectangular unipolarity electrical pulses routed through a standard audiometric headphone (TDH-39). The headphone was loosely fit to the infant's ear by the examiner who held the infant. The stimulus repetition rate was 33.3/sec. Spontaneous activity was monitored to evaluate the amount of electrical and/or physiologic noise and the stimulus intensities were 75, 55, and 35 dB nHL. All waveforms were replicated so that an assessment of waveform stability could be made. P1, P3, and P5 latencies were measured.

The "pass" criterion employed in the screening was a replicable P5 component that could be recorded at 35 dB nHL bilaterally. If the infant passed the on-the-ward BAEP screening, the parents (or guardians) were notified that the infant passed IHS and had normal high frequency hearing sensitivity and that they would be contacted when their child was 3 years of age for a conventional frequency-specific hearing test.

If the infant "failed" the BAEP screening, the parents or guardians were requested by mail to schedule an appointment with audiology six weeks after their child was discharged from the hospital. This second evaluation, performed in the audiology clinic in a sound-attenuated environment, consisted of BOA and a second BAEP. During BOA, the infant, held by the parent or guardian, was either fed or given a pacifier. This permitted the observer seated in the test room to observe sucking response patterns as well as natural reflexive patterns during the presentation of sound-field auditory stimuli.

The criteria employed to "pass" BOA were: 1) two consistent responses (as determined by the observer in the test room and the examiner in the control room) to sound-field speech stimuli presented at sound pressure levels adequate to obtain consistent age-appropriate responses (12), 2) a reproducible response to warble tones presented at 500 and 2,000 Hz, and 3) a reproducible startle response to speech stimuli presented in the sound-field at 70 to 80 dB HL. If the infant failed BOA and passed the BAEP screening test, the child was considered a "pass." However, because BAEP testing using unfiltered click stimuli does not detect low frequency hearing loss, tympanometry was performed to test the possibility that low frequency conductive hearing loss caused the failure on BOA testing.

Infants who passed BOA and failed BAEP also underwent tympanometric testing for conductive hearing impairment. These infants were referred to a pediatric otolaryngologist for evaluation. If no correctable condition existed, the infant was usually fit with monaural or binaural amplification based on the results of BAEP.

Outpatient infant hearing screening (7/30/84–10/1/88)—The procedures for outpatient infant hearing screening were essentially identical to those described for inpatient infant hearing screening six weeks after discharge. Methods and procedures for BOA and BAEP screening are described above. Infants who passed the initial IHS evaluation at six weeks were given the opportunity to return for evaluation at six months, one year, and three years. At these subsequent evaluations, conditioned orienting reflex audiometry is conducted to obtain a behavioral estimate of auditory thresholds. Calibrated warble tone and speech stimuli are presented either through sound-field or under headphones. Minimal acceptable response levels which vary as a function of age have been reported elsewhere (12). Conventional play audiometric techniques are used to obtain voluntary monaural auditory thresholds for children at 3 years of age. In addition, screening immittance testing is conducted when there is evidence of an elevated auditory threshold or conductive hearing impairment.

Results

Outpatient IHS

Of the 1,138 who passed the initial testing, 180 are "active" patients in the outpatient IHS program. The remainder have either completed the full three-year program (n = 80 or 7%), dropped out of the IHS program (n = 872 or 77%), or died (n = 6 or < 1%). Of 872 who failed to complete the program, 529 (46% of total) did not return to the audiology clinic for their initial six-weeks IHS examination despite several attempts to contact the parent/guardian. Thus, using conventional high risk register identification techniques and testing on an outpatient basis, we were unable to evaluate almost half of those infants considered to be "at risk" for hearing impairment. A total of 166 infants (15%) returned at six weeks but not for the optional six-month or 12-month examinations, and 177 infants (15%) did not return for play audiometry at 3 years of age. Eighty infants (7%) have graduated from the outpatient IHS program (at age 3 years).

To our knowledge, no infant predicted to have normal high frequency hearing sensitivity has been found later to have a high frequency hearing loss (false negative). Twenty-four (2%) of 1,138 infants were identified as having either unilateral (n = 5 or 21%) or bilateral (n = 19 or 79%) hearing impairments. Four of these have had normal hearing sensitivity on reevaluation and their hearing losses are thought to have been conductive in origin and transient in nature. Ten of these infants are now wearing hearing aids and one has died. The others (n = 8) have not returned to our clinic for treatment.

The results in three infants (of 958) are considered false positives, ie, predicted high frequency hearing loss on IHS was later found to be normal. Initial electrophysiological testing showed unilateral or bilateral lowest BAEP P5 responses at 55 dB nHL and these infants were fit either monaurally or binaurally with mild gain, ear-level hearing aids. Subsequent unaided reevaluation using behavioral audiometric techniques or BAEP demonstrated bilaterally normal high frequency hearing sensitivity and use of the hearing aids was discontinued. These false-positive responses may have occurred because of transient conductive hearing losses.

Inpatient IHS

As of July 1989, 162 infants have enrolled in the inpatient IHS program. Only 25% of those failing the screening did not return for the six-week follow-up examination. The return rate for those infants referred from inpatient screening was 75% contrasted to the 54% return rate for outpatient IHS.

Of the total number enrolled in the inpatient IHS program, 130 infants (80%) passed and 32 (20%) failed BAEP screening. The infants who passed will be evaluated at age 3 years to determine whether or not there have been any false-negative errors. Improved efficiency of the IHS team was evaluated by comparing the infant failure rate in two successive three-month intervals. In the first period, during which 67 infants were evaluated in the NICU, 50 (75%) failed screening and 17 (25%) passed. In the second period, during which 56 infants were evaluated, 48 (86%) passed and eight (14%) failed BAEP screening. The results suggest that as the examiners gained technical experience the number of infants passing the testing also increased.

Low birthweight infants

Some observers suggest that low birthweight infants not undergo IHS because: 1) they are usually born preterm and have a premature nervous system (26,27), and 2) they have a greater likelihood of middle ear disease that would cause them to fail BAEP screening (27-30). Of the 162 infants that we evaluated as inpatients, 29 (18%) weighed less than 1,500 g. Of these infants, 16 (55%) passed BAEP screening and 13 (45%) failed. Of the 133 infants who weighed more than 1,500 g, 115 (86%) passed BAEP screening and 18 (14%) failed.

Sensitivity of BOA testing to the detection of hearing loss

BOA, used by some clinicians as the sole method for screening infant hearing, has important disadvantages. BOA cannot determine degrees of hearing impairment. Responses to sound by newborns are rudimentary and cannot be obtained at threshold levels. BOA stimuli are presented through loudspeakers in the sound-field, therefore permitting the evaluation of the better

hearing ear. In contrast, BAEP permits hearing tests for each ear separately using broadband high frequency signals. One purpose of the present investigation was to evaluate the sensitivity of BOA in identifying infants with hearing loss. The BAEP is the preferred method of infant hearing screening (31) and was used to check the validity of BOA.

A total of 124 infants, aged 6 weeks, underwent both BOA and BAEP testing during the period 1984 to 1989. Test results were evaluated to determine the sensitivity of the BOA examination in identifying hearing loss. The examinations were conducted for infants who had either failed inpatient screening or been discharged from the NICU before inpatient BAEP screening could be conducted. Data obtained from 97 infants were adequate for evaluation and 76 (78%) showed normal responses on both tests. An additional nine infants (8%) showed normal responses on BOA testing but abnormal responses in one or both ears on BAEP testing. Six of these infants had evidence of middle ear disease using tympanometry, unilateral in five and bilateral in one. Tympanometry could not be performed on the other three infants. BOA indicated the presence of hearing loss for seven infants (7%) which was not confirmed either by BAEP testing or tympanometry. Results of BOA and BAEP testing agreed in six cases (6%) when both tests indicated hearing loss.

Using the results of BAEP testing as the "gold-standard," BOA has a sensitivity of 43% and a specificity of 92%. BOA testing on this sample produced a false-positive rate of 8% and a false-negative rate of 57%, but these results should be viewed with caution. The BAEP is most sensitive to the status of the high frequency portion of the peripheral hearing mechanism.

Discussion

The prevalence of sensorineural hearing loss in these infants, excluding those with transient hearing loss, was 1.4%. Other investigators have reported prevalence figures ranging from 2% to 10% in similar populations (15,16,20). With the exception of the study by Roberts et al (32), between 14% and 20% of infants evaluated in the NICU have been found to fail BAEP testing (21-23,33). In the present study 20% of infants evaluated in the NICU failed BAEP testing. Of the group who failed BAEP, 56% passed repeat testing six weeks after their discharge. These infants may have failed initial screening because of transient conductive hearing losses. The prevalence of middle ear effusion is as high as 25% to 34% of the newborn population (34,35).

In the present study the sensitivity and specificity of BOA in the detection of hearing loss were 43% and 82%, respectively. Thus, BOA is only a fair predictor of hearing loss when BAEP results are used as the criterion validity measure. Moreover, BAEP provides separate ear measurements with auditory signals presented under headphones, while BOA furnishes hearing estimates of the better hearing ear only because test signals are presented through loudspeakers. A number of infants had normal responses to BOA testing, yet failed monaural BAEP screening. Furthermore, BOA is dependent upon the arousal level and neurologic maturity of the infant as well as the skill of the examiner in identifying subtle responses to auditory stimuli.

However, BOA does provide information regarding the response to both low and high frequency auditory signals, whereas BAEP tests high frequency hearing sensitivity only. We recommend that BAEP testing be used in conjunction with BOA.

In the present investigation 45% of the low birthweight infants failed infant hearing screening compared to 14% of babies weighing more than 1,500 g. Accordingly, we concur with the recommendation to defer IHS until the infant weighs at least 1,500 g.

To our knowledge, our study is the first attempt to determine the prevalence of high-risk factors in a large sample of infants. We employed the seven high-risk criteria recommended in the 1982 position statement of the Joint Committee on Infant Hearing (11) along with three additional factors also associated with neonatal hearing loss (25). In our study, the two risk factors with the highest prevalence rate (RDS, 29%; ototoxic antibiotics, 26%) are not included in the criteria identified by the Joint Committee on Infant Hearing. The risk factors of RDS or ototoxic antibiotics were present in 38% of the infants who failed IHS.

Since October 1988, 7.4% (12 of 162) of our infant population are born to mothers who admit to "crack" cocaine or cocaine use. One of these 12 infants was found to have electrophysiological evidence of hearing loss on BAEP testing. Cocaine, when administered in acute, psychoactive doses to rats, imposes significant delays in the interpeak latencies (ie, increases neural transmission time) of the BAEP (36). Moreover, Shih et al (37) demonstrated that cocaine imposed significant changes in the absolute and interpeak latencies of the BAEP of infants born to cocaine-abusing mothers. Whether the latency prolongations represent a delay in central nervous system maturation as a result of maternal cocaine abuse or permanent effects on brainstem auditory pathways is not yet known. We continue to study infants of cocaine-using mothers and will evaluate their auditory perceptual processes after they reach an age at which they can perform behavioral auditory tasks.

Follow-up of infants enrolled in the IHS program has been simplified by the use of a data base program developed by one of the authors (RGT). This program manages data including risk factors and the performance of infants on various screening measures and provides reminders when infants should be recalled for evaluation.

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