An Effective Protocol for the Sleeping Baby Hearing Screen

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Summary: This study was conducted by Shawn Goodman as a master's thesis in the Brigham Young University Speech and Hearing Department under the Chairman Dr. David L. McPherson. It shows that the Sleeping Baby Hearing Screen (SBHS) and the Transient Otoacoustic Emissions (TOAE) are equally effective in identifying normal hearing in infants.

Twenty-Seven normally hearing infants ages 0 to 12 months were given the Sleeping Baby Hearing Screen (SBHS) at home and were also tested with Transient Otoacoustic Emissions (TOAE) which is the most commonly used screen for testing newborns in the hospital. One hundred percent of the children were shown to have normal hearing by the SBHS. Twenty six of the children were shown to have normal hearing by the TOAE screen. One 11 month old infant could not be tested with the TOAE because of excessive movement. Since this child was shown to have normal hearing by the SBHT this would indicate a slight advantage of the SBHS over the most commonly used infant screening test.

On the other hand the SBHS will not pick up a unilateral hearing loss, but the TOAE can be used in each ear separately. Fortunately, unilateral hearing loss does not prevent the child developing speech. Most unilateral hearing loss is discovered at age 3 or 4 when it is noted that the child cannot hear on the phone with both ears.

Sometimes an infant will not arouse but at a subsequent test will do so. This may be due to the child being too deeply asleep. The study found that children age 6 to 12 months required 70 dB to arouse. This is because normally hearing children are beginning to ignore background sounds.

Hearing loss in Infants, Review of Literature

In 1993, the National Institutes of Health (NIH) published a consensus statement on the early identification of hearing impairment. They reported that the incidence of profound sensorineural hearing loss in infants is 1 in 1000, with an additional 5 in 1000 infants having less severe losses. They also reported that hearing loss occurring in infancy and early childhood results in many difficulties, including poor development of social, emotional, cognitive, speech, language, and academic skills. These difficulties may in turn affect vocational and economic potential. Although it is generally felt that early identification of hearing impairment leading to early intervention plays a major role in minimizing these difficulties, the 1993 NIH statement reported that the average age of identification in the United States is approximately three years.

A more recent study (Harrison & Roush, 1996) reported the median age of diagnosis was less than 2 years; however, a wide range was seen in age of diagnosis. In any case, these ages are a far cry from the goal set by the Joint Committee on Infant Hearing (JCIH 1995) that all infants with hearing loss be identified by 6 months of age.

The first 4 years are called the "Critical Language Learning Years" because normal speech and language development is much more easily developed during these years. It is crucial to lower the average age of identification so that children with hearing impairment may enjoy more full and productive lives (NIH, 1993). In spite of growing recognition of the importance of early identification, there is still a need to lower the average age of identification of hearing impairment.

Methods of Identification

The JCIH (1995) and the NIH (1993) endorse two primary means of identification of hearing impairment in infants: auditory brainstem response and otoacoustic emissions. These methods are effective but there are difficulties associated with them. The main difficulties are cost and the associated availability of the tests. At the present time, universal screening programs using these methods are not available in many smaller hospitals or in outlying areas with limited funding. Further, some births may take place outside a hospital and thus not have access to a universal screening program. Even when such methods are available for newborn screening prior to discharge from the hospital, they may not be available following hospital discharge. Also because 20 to 30 % of hearing-impaired infants will acquire their hearing loss during early childhood, universal neonatal screening is not a replacement for ongoing surveillance throughout infancy and early childhood" (NIH, 1993, p. 8).

Behavioral Testing

Since the current preferred screening methods are not perfect, the NIH (1993) encouraged further research in developing and improving techniques for the identification of hearing impairment in infants and children. One area in which research was encouraged was behavioral testing. The simplest form of behavioral testing involves presenting a stimulus to an infant and then observing the infant's response. This type of testing is known as behavioral observation Audiometry (BOA). BOA has the advantage of not requiring specialized equipment and can be one of the most cost- and time-effective way of evaluating hearing in infants and children (Northern & Downs, 1991).

On the other hand, BOA has often been criticized as having a wide variance of responses, quick habituation of responses, and a vulnerability to tester bias (Northern & Downs (1991). The JCIH (1982) reported that behavioral testing is associated with a high incidence of false-positive and false-negative results. The JCIH (1995) further criticized behavioral testing, citing several studies that have evaluated behavioral techniques (Durieux-Smith, Picton, Edwards, MacMurray, & Goodman, 1985; Hosford-Dunn, Johnson, Simmons, Malachowski, & Low, 1987; Jacobson & Morehouse, 1984). Examination of these and other studies (e.g. Downs & Sterritt, 1967; Feinmesser & Tell, 1976) show close similarities in test protocol used. For example, the stimulus is usually a narrow band of noise centered around 3000 Hz. The stimulus is usually presented at a relatively high level (80 to 100 dB SPL). Additionally, the infant or child is usually tested in a quiet but alert state. Interestingly, a review of the available literature on the subject of behavioral testing does not suggest that these are the best protocol to follow. The problems associated with behavioral tests may be due in part to the fact that more effective protocols have not been proposed.

Suggested Protocol

The results of several research studies suggest that speech is the best stimuli for testing infants and young children (Eisenberg, 1969; Hoversten & Moncur, 1969; Northern & Downs, 1978, 1984; Samples

& Franklin, 1978; Thompson & Thompson, 1972). Specifically, Northern and Downs (1978) reported that behavioral responses to speech were seen at lower sound pressure levels than responses to warbled pure tones or other noisemakers. Further, the response thresholds for speech had smaller standard deviations than the other stimuli, suggesting less variability and greater reliability.

Samples and Franklin (1978) compared responses obtained using speech, warbled tone, and broadband noise stimuli. They reported that behavioral thresholds were significantly lower and less variable for speech than for warbled tone or noise band. A significantly higher number of responses were also elicited by speech stimuli than by the other stimuli, suggesting that speech may be more stable and have lower habituation rates.

In spite of the abilities of speech stimuli to elicit behavioral responses, they have not been widely employed in BOA. Perhaps the greatest deterrent to their use is the concern that since speech is composed of a wide frequency band, it will fail to identify infants or children with hearing losses in the high frequencies but normal hearing in the low frequencies (Thompson & Thompson, 1972). However, Northern and Downs (1978) reported clinical findings that "children with high frequency losses do not respond to speech at normal levels for their ages, despite the fact that the lower frequencies may be heard fairly normally" (p. 116). In addition, the lack of ability to detect high frequency and/or mild hearing losses might be overcome by using sounds of different frequencies. One way to do this would be to use some of the Ling sounds as the speech stimuli. Ling and Ling (1978) explained that these sounds include low-, mid-, and high-frequency components of speech. They further stated that the ability to hear these sounds implies the ability to hear all other speech sounds. According to Ling and Ling, these sounds should effectively test hearing up to 4000 Hz. The ability of speech stimuli to identify infants with high frequency losses has not been experimentally tested, thus they remain a viable option in BOA. This is especially true considering they have been shown to elicit more stable, stronger responses at lower levels than other stimuli.

In addition to using non-speech stimuli, most traditional BOA tests employ a high presentation level (80 to 100 dB SPL) to evoke a startle response. The problem with this approach is that using high sound pressure levels to elicit responses may fail to identify infants with lesser hearing losses (Durieux-Smith et al., 1985). It is possible that this problem may be reduced by the use of speech stimuli as opposed to pure tone or noise stimuli. This latter statement is supported by the previous discussion suggesting that behavioral thresholds for speech are lower than for other stimuli. Northern and Downs (1978) reported the behavioral thresholds of infants 0 to 6 weeks to be between 40 and 60 dB HL. By 4 to 7 months, the thresholds had dropped to 21 dB HL. Hoversten and Moncur (1969) reported that the behavioral thresholds for voice stimuli were 32 dB HL for a 3-month-old group of infants and 23 dB HL for an 8-month-old group of infants. Clearly these lower thresholds, if useable, would enable the identification of milder losses and thus result in lower false-negative rates.

Another factor influencing false-negative rates is the attention state of the infant. In BOA, infants are often tested in a quiet, alert state. One problem with this is the potential for random movement to be mistaken as a response to the acoustic stimulus (Ling, Ling, & Doehring, 1970). Another problem is the confounding influence of other environmental stimuli (Mencher, McCulloch, Derbyshire, & Dethlefs, 1977). For example, an infant could respond to the movement of a shadow or a slight movement of air. The response could easily be mistaken for a response to an auditory stimulus. A review of literature suggests an alternative to testing the infant in a quiet, alert state. Mencher et al. have suggested that “light sleep is unquestionably the optimal state for eliciting a response” (pp. 27-28). Taylor and Mencher (1972) reported that a light sleep state resulted in a greater number of covert responses as well as stronger responses than an awake state. Northern and Downs (1978) also supported the use of a light sleep state and quoted Mencher as reporting a 1 % chance of recording a random response in a sleeping baby. Consequently, a BOA test requiring the infant to be in a light sleep state should reduce variability and thus increase the validity of the test.

It has been shown that infants prefer listening to their mother’s voice over that of a female stranger (DeCasper & Fifer, 1980; Mills & Melhuish, 1974). Northern and Downs (1991) reported that the mother’s voice was particularly effective in eliciting responses in infants. In addition to the mother saying the sounds, the mother could also administer the test. There is good evidence to suggest that the mother can be as reliable as a trained professional in administering behavioral tests. Moncur (1968) compared pediatric audiologists, audiologists, and laymen in observing behavioral changes in babies. He reported that when given instruction and practice, the three groups performed about the same. Other studies also support the idea that laymen are reliable observers (Downs & Sterritt, 1964; Redell, 1970).

These findings would suggest that the most effective BOA test protocol would be speech sounds said by the mother at a relatively soft level to an infant in a light state of sleep. Structured this way, a test might overcome some of the limitations traditionally associated with BOA such as response variance, quick habituation to stimuli, tester bias, inability to detect high frequency and/or mild hearing losses, lack of sensitivity, and lack of specificity (Durieux-Smith et al., 1995; Feinmesser & Tell, 1976; Jacobson & Morehouse, 1984; JCIH, 1995).

A BOA test using speech stimuli with the infant in a light sleep state has recently been developed by William F. House, M.D. (personal communication, December 10, 1997). This test is called The Sleeping Baby Hearing Screen (SBHS). The SBHS is a self-contained, reusable home hearing screen costing $250 [to the parents]. The test is designed to be placed in physician's offices and lent to mothers to use at home. Written instructions teach the mother how to administer the test. The test is administered as follows: The mother lets the baby fall asleep in a quiet room. A sound level meter placed near the baby's ear is used to measure the loudness of the mother's voice (presented initially at 60 dB SPL that is needed to provoke an arousal response in the child. The mother says four different sounds; one at a time. The mother records the baby's responses to these sounds on a score sheet and returns to the doctor to discuss the results.

The SBHS uses speech stimuli presented at a relatively soft level to a sleeping infant. Structured this way, the SBHS may overcome some of the limitations traditionally associated with BOA such as response variance, quick habituation to stimuli, tester bias, inability to detect high frequency and/or mild hearing losses, poor sensitivity, and poor specificity (Durieux-Smith et al., 1995; Feinmesser & Tell, 1976; Jacobson & Morehouse, 1984; JCIH, 1995).

The problem of response variance should be reduced in the SBHS since it uses speech stimuli. Speech produces the most consistent responses in behavioral testing. Further, the mother's voice is used as the stimulus and it has been shown that infants prefer listening to their mother's voice over that of a female stranger (DeCasper & Fifer, 1980; Mills & Melhuish, 1974). Response variance is reduced since the test is administered while the infant is in a light sleep state. In this state, responses due to distraction or random movement are minimized.

Habituation to the stimuli is reduced because there is no need for the test to be performed in one sitting. Likewise, it has been shown that infants do not habituate as quickly to speech stimuli as to other auditory stimuli. Also, if the infant habituates, testing may be stopped and resumed at a later time. The use of four different speech sounds presented at different times also helps to reduce habituation. Northern and Downs (1978) reported that "in a brief testing period, the baby's responses usually do not extinguish when a variety of sounds are presented at different time intervals" (p. 121).

The problem of tester bias should be minimized in the SBHS as it conforms to conditions recommended by Mencher et al. (1977), shown to reduce tester bias. Their research suggests that "observer bias is not a factor when arousal is the only acceptable response and is clearly defined, and the observers are limited to a yes-no decision" (p. 27). Tester bias should not be increased by using the mother as the observer. There is good evidence to suggest that the mother can be as reliable as a trained professional in administering behavioral tests. Moncur (1968) compared pediatric audiologists, audiologists, and laymen in observing behavioral changes in babies. He reported that when given instruction and practice, the three groups performed about the same. The SBHS instructs the mother and allows her to practice before performing the actual test. Thus, this condition is met and others should not be less reliable than professionals. Other studies also support the idea that laymen are reliable observers (e.g. Downs & Sterritt, 1967; Redell, 1970).

The lack of ability to detect high frequency and/or mild hearing losses may be overcome by the SBHS. The test uses four of the six Ling sounds as the speech stimuli (Ling, 1988). The sounds /a/, /i/, /m/, and /s/ are presented to the sleeping infant one at a time. The SBHS uses these sounds to detect hearing losses in the important speech -

frequency range (500 to 4000 Hz). The four sounds are initially presented at a level of 60 dB SPL. This level is softer than those routinely employed in behavioral screening (80 to 100 dB SPL). This should consequently allow the detection of milder hearing losses.

The sensitivity and specificity of behavioral tests have been cited as unacceptably low. Especially vulnerable has been the specificity, resulting in a high number of false positives and high over-referral rates. It is hoped that the SBHS will improve on the performance of currently used BOA tests. As a first step to validating the SBHS, the present study examined the test's performance in infants 0 to 12 months of age.

Method

Subjects

The subjects for this study were 30 normal-hearing infants 0 to 12 months of age and their mothers. The mothers were solicited by word of mouth from the populations of Utah and Salt Lake counties in the state of Utah. In order to help insure a normal-hearing group of subjects, each infant met two criteria to be included in the study. First, the infant was not considered "at-risk" by any of the indicators for hearing loss listed in the Joint Committee for Infant Hearing (JCIH 1995) Position Statement. Second, the infant had not been admitted to a neonatal intensive care unit (NICU). To conclusively show normal hearing, transient otoacoustic emissions (TOAEs) and tympanograms were also tested for each infant.

Instrumentation

Transient otoacoustic emissions were collected using the Quickscreen option on an Otodynamics Ltd. IL088 Otodynamic Analyzer. Tympanograms were obtained using 1000 Hz probe tone on a Virtual model 310 Digital Impedance Instrument. Ten Sleeping Baby Hearing Test packets were used for data collection. Each packet contained the following: a sound level meter with an omnidirectional electret condenser microphone (Radio Shack cat. no. 33-2055), written instructions, and response sheets

Calibration

The IL088 Otodynamic Analyzer was calibrated according to manufacturer specifications prior to each test. The Virtual model 310 Digital Impedance Instrument was calibrated for a 1000 Hz probe tone according to manufacturer specifications prior to each test. The 10 Radio Shack sound level meters were calibrated prior to the beginning of data collection using a Larson Davis CA250 acoustic calibrator. The sound level meters were then checked for linearity as follows: Testing took place in a sound booth conforming to ANSI (1991) specifications for maximum permissible ambient noise for 1/3 octave bands. A Grason-Stadler (GSI-10) audiometer was used to generate a 1000 Hz puretone which was calibrated to ANSI (1996) specifications. The tone was routed through a Telephonics TDH 50 earphone connected to an NBS 9A coupler (as specified by ANSI, 1996). The microphone of each Radio Shack sound level meter was attached to the NBS 9A coupler. The sound level meter was set to “A” weighting and “slow” response. The level of the 1000 Hz tone was set to 50 dB HL on the audiometer. The tone was increased in 10 dB steps up to 90 dB HL and the sound level meter was checked for a corresponding 10 dB increase at each level. In order to insure validity, a calibrated Larson Davis 800B sound level meter was tested for linearity under the same conditions. The measurements of the Radio Shack sound level meters were compared with the measurements of the Larson Davis sound level meter. Prior to each mother being given a SBHT packet, a calibration check was performed on the Radio Shack sound level meter using the Larson Davis CA250 acoustic calibrator. All Radio Shack sound level meters remained within plus or minus 1 dB of calibration during the period of data collection.

Procedure

Prior to participation in this research study, the mother of each subject was asked to read and sign an Informed Consent Document approved by the Brigham Young University Human Subjects Research Committee. The mother of each subject then filled out a questionnaire in order to ensure the infant did not meet any of the high risk indicators established by the JCIH (1995) and that the infant had not been admitted to an NICU.

Each infant was screened for normal hearing using TOAEs. Passing criteria for the TOAE screening was a correlated reproducibility greater than or equal to 65 % or a signal-to-noise ratio greater than or equal to +3 dB in at least two frequency bands between 1000 and 4000 Hz (Otodynamics Ltd, 1997). Tympanograms were also obtained on each subject using a 1000 Hz probe tone. Tympanograms were classified according to the system introduced by Jerger (1970) as type A, B, or C.

Each mother was given a SBHS packet and shown how to use the sound level meter. The instructions to the SBHS were read and explained to her. The mother took the SBHS packet home and administered the test as follows:

1. A room in the home was chosen with an ambient noise level of 50 dBA or less as measured with the Radio Shack sound level meter. The baby was placed in this room and allowed to fall asleep. Testing was initiated within five minutes of the baby falling asleep.
2. The sound level meter was placed on or near the infant with the microphone 2 inches from the ear. The mother positioned herself approximately 2 feet from the sound level meter and said each of the four Ling sounds /a/, /i/, /m/, and /s/ at 60 dBA for 5 seconds. Ten seconds were allowed to elapse between the presentation of each sound. The mother monitored the level of her voice on the sound level meter to ensure that the correct sound level was maintained. The sounds were said one at a time and a response was looked for after each presentation.
3. Acceptable responses were (a) a definite eye-blink (type 1); (b) a slight shudder of the whole body (type 2); (c) an opening of the eyes, even briefly (type 3); (d) a slight head turn toward the sound (type 4); (e) any marked movement of arms, legs, or body (type 5); (f) a change in sucking rate (type 6); and (g) any combination of these (type 7) (Northern & Downs, 1978; Keen, 1964). These responses occurred while the mother was saying the sound or within 2 seconds

of the offset of the mother's voice. The responses were noted on the Response Sheet.

4. If there was no response to a sound, the sound was repeated a second time 10 seconds later. If there was still no response, the sound was repeated a third time 10 seconds later. If after three presentations of a sound there was no response, the intensity of the sound was increased in 10 dB steps and the same procedure followed until a response occurred or until a level of 80 dBA was reached.
5. The second trial of the SBHS was administered 24 hours later.
6. As part of this study, the entire SBHS was administered a second time, beginning 24 hours after the first test was complete. When the testing sequence was complete, the mother returned the SBHS packet and discussed the results with the researcher.

Results

Subjects

A total of 31 infants and their mothers were recruited for this study. One (1 /31) infant was excluded from the study because she was considered "at risk" by the JCIH (1995) Position Statement. Three (3/31) infants were included in the study, but were excluded from data analysis because their parents failed to follow test protocol. In all three cases, one or more trials of the SBHS were administered by the father rather than the mother.

The remaining 27/31 infants were included in the data analysis. Thirteen (13/27) of the infants were male and 14/27 were female. The ages ranged from 1 to 12 months, with a mean of 5.26 months and a standard deviation of 3.39 months.

Transient Otoacoustic Emissions

Recordings of TOAEs were obtained from both ears of 26/27 infants. One (1/27) infant (both ears) could not be tested due to excessive movement of the infant. All of the remaining infants (26) passed the

TOAE screening in the right ear. Twenty-four (24/26) of the infants passed the TOAE screening in the left ear.

Tympanograms

Tympanograms were obtained from 27/27 infants in the right ear and 24/27 infants in the left ear. Classification of tympanograms (Jerger, 1970) obtained from the right ears showed 24/27 were type A, 2/27 were type C (> -100 daPa), and 1/27 was unidentifiable. Classification of tympanograms obtained from the left ears showed 20/27 were type A, 2/27 were type B, and 2/27 were type C.

Sleeping Baby Hearing Test

Intensity

The median and mode of the intensities at which responses were seen to the four Ling sounds were 60 dBA across all trials.

Discussion

Three (3/31) infants were excluded from data analysis because their parents failed to follow test protocol. In all three cases, one or more trials of the SBHT were administered by the father rather than the mother. This would suggest that this part of the test protocol be made more explicit in the instructions. The data obtained when fathers administered the test was not analyzed statistically; however, anecdotally it appears that greater intensities were required to elicit a response when fathers administered the test compared to mothers.

Only one infant could not be tested for TOAEs. This was due to excessive movement in the infant. This infant was 11 months old. It was observed, in general, that the older the infant, the harder it was to test TOAEs. Two (2/26) infants failed the TOAE screening in the left ear. Both infants had type B tympanograms in their left ears. The infants were referred to their doctors and scheduled for follow-up TOAEs and tympanograms after the fluid in the middle ear had dissipated. The infants had type A tympanograms and passed TOAE screening following medical intervention.

One infant had a tympanogram that could not be identified according to Jerger’s (1970) classification system. The infant was referred to her doctor and scheduled for a follow-up TOAE and tympanogram. The infant had type C tympanogram and passed TOAE screening following medical intervention. Four other infants had type C tympanograms, and all four passed the TOAE screening. This is consistent with the results of a study by Trine, Hirsch, and Margolis (1993) which showed that although negative middle ear pressure resulted in a decrease of TOAE amplitude and reproducibility, TOAEs with a reproducibility greater than or equal to 50 % were still obtainable in the majority (86 %) of ears tested.

The vast majority of responses were seen at an intensity of 60 dBA, regardless of the Ling sound used. Any of the response types should be counted as a pass.

As the infant became older, a louder intensity was required to evoke a response. This is consistent with the comments of many mothers with older infants, who reported having a difficult time obtaining responses from their infants. They reported that it was difficult to observe them falling asleep, making it difficult to start the test immediately after the infant fell asleep. These observations suggest that the older infants may have been in a deeper sleep state, requiring louder intensities to evoke an arousal response. Because of the difficulty in observing the sleep of older infants and because visual reinforcement audiometry is able to test infants older than 6 months of age, it is recommended that the SBHT be used to test infants 6 months of age or younger.

It is recommended that passing criteria for the SBHS be at least one response to all four of the Ling sounds presented at an intensity of 60 dBA. Responses may occur on either the first trial or second trial. Any of the seven response types may be counted as a pass. This study only tested normal hearing subjects. The ability of the SBHT to correctly identify hearing impairment in hearing impaired subjects remains to be determined. The SBHT should also be validated on a large sample in order to determine its sensitivity and specificity.

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