HEARING SCREENING PROCEDURES - CURRENT STATE-OF-ART

Register No.M2kl8

An Independent Project submitted in part fulfillment for the first year **M.Sc., (Speech and Hearing)**
University of Mysore, Mysore.

All India Institute of Speech and Hearing
Manasa Gangothri
Mysore

MAY 2001

Dedicated to

Appa, Amma,

Alan Achachen, Nachi

&

Jo vava

CERTIFICATE

This is to certify that the Independent Project entitled : **"HEARING SCREENING PROCEDURES - CURRENT STATE-OF-ART"** is the bonafide work in part fulfillment for the degree of Master of Science (Speech and Hearing) of the student with Register No.M2kl 8.

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CERTIFICATE

This is to certify that this Independent Project entitled **"HEARING SCREENING PROCEDURES - CURRENT STATE-OF-ART"** has been prepared under my supervision and guidance. It is also certified that this has not been submitted earlier in any other University for the award of any Diploma or Degree.

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DECLARATION

I hereby declare that this Independent Project entitled "HEARING SCREENING PROCEDURES - CURRENT STATE-OF-ART" is the result of my own study under the guidance of Dr. Asha Yathiraj , Reader in Audiology, Department of Audiology, All India Institute of Speech and Hearing, Mysore, and has not been submitted earlier at any other University for the award of any Diploma or Degree.

Mysore
May 2001.

Reg. No .M2kl8

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INTRODUCTION

Screening for hearing loss has become an increasingly important aspect of neonatal care. The importance of screening for hearing loss cannot be overstated. Hearing loss is one of the most common major abnormalities present at birth. If undetected, it will negatively impart cognitive development communication, competency, literacy academic achievement and optimal child development. Hence, early identification of hearing loss has been given importance by audiologists, paediatricians, otoiaryngologists and early childhood specialists (Diefendorf, 1988).

One of the difficulties in any screening program is managing many infants with normal hearing while separating out the few who have a high likelihood of impairment (Diefendorf ,1988). Ideally the tests should avoid false negative and false positive responses. For this, the tests should have high sensitivity and specificity. Sensitivity is the frequency with which persons who have the disorder test positive. Specificity is the frequency with which persons who do not have the disorder test negative.

Need for hearing screening programs

Hearing screening programs have many beneficial effects. From the medical point of view, early detection offers both an opportunity for early medical treatment and a source of valuable information on me etiology of hearing problems. From the educational and audiological points, early detection provides the opportunity to apply auditory habilitation at an age that is most likely to ensure the optimum development of language (Downs and Sterritt, 1967). The present concept of mass screening in children is based on the concept of secondary prevention. The prevalence of hearing impairment is found to be high throughout the world.

Prevalence of hearing loss is high in India. According to Pandey and Advani (1995), there are about 10,000 hearing impaired out of which males are about 498 in rural and 325 in urban area and females are 435 and 355 in rural and urban regions respectively. It is clear that the prevalence of hearing loss is more in rural areas. Thus hearing screening procedures used should be less expensive, quick to use but accurate and sensitive.

Hearing screening programs should be implemented throughout the neonatal period, infancy or childhood, to detect hearing losses that occur during this period (Parving, 1999). In short the most important need of hearing screening program is to identify hearing loss early which should be followed with early habilitation.

Goal of Hearing screening

The goal is to categorize auditory function as either normal or abnormal, to identify newborns who have significant sensori-neural hearing loss. By screening hearing, audiologists can eliminate new boms with normal hearing function from further consideration, while those with a suspicion of hearing loss can be referred for clinical testing (Stach & Santilli, 1998).

Earlier, authors have concentrated more on identifying severe-profound hearing loss cases. Now the trend has changed where we try to find infants with mild hearing loss, congenital or late onset categories and fluctuating hearing loss cases. They even try to categorize children having conductive or sensori-neural hearing loss.

Methods of screening

In order to satisfy all these needs, various screening procedures were put-forward. These procedures had the same goal, but followed various different methods. Some of these methods grouped in a broad sense are:

a) Subjective, semi objective or objective
b) Verbal or nonverbal methods
c) Conditioned or unconditioned methods.

All these methods have their own demerits and merits. The selection of a particular method for screening will depend upon the age of the child, cost effectiveness and whether the quantity or quality of hearing loss has to be identified.

Location of testing

It depends on age of the child. Neonates can be tested in the nursery itself or in the ward after delivery. Infants can be tested when they come for vaccination or for paediatric checkup. The testing can be done in a quiet room where ambient noise is less. Older infants can be screened in an audiological set-up for in a convenient location, which is quiet.

State of the child during testing

The tests should not be done during feeding time, bathing time and activity state of the child should be noted before testing. Optimum testing time from the testers point of view is 45 minutes tol hour before next feeding (Downs and Sterritt, 1967).

Aim of the study:

Several hearing screening procedures have been developed over the years. Each of them are meant to test infants of a specific age and have their inherent merits and demerits. The sensitivity and specificity of these tests vary. The aim of this project is to review these hearing screening procedures and highlight the above information.

Need of Project:

This project would serve as a quick guide to an audiologist to select the most appropriate hearing screening procedure for infants and children of different ages.

Based on the sensitivity and specificity of the tests, the audiologists would know the usefulness of each tests. The choice of appropriate cut-off criteria would also be made, which will result in the least number of over referrals or under-referrals.

It would be a useful source of information for students of speech and hearing. The project would serve as a comprehensive reference.

REVIEW

The entire review on hearing screening procedures has been discussed under the following headings.

I. Subjective Techniques

a) Behavioral observation audiometry
b) Visual Reinforcement Audiometry.
c) Tangible Reinforcement Operant Conditioning Audiometry
d) Conditioned Play Audiometry.
e) Pure tone hearing screening.

II. Semi-objective Techniques

a) Crib-O-Gram
b) Auditory Response Cradle
c) Accelerometer Recording System

III. Objective Techniques

a) Oto Acoustic Emissions
b) Auditory Brainstem Response.
c) Immittance Audiometry
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IV. Speech Tests for Hearing Screening

a) The Ling's 5 sound test
b) Ling's 7 sound Test
c) The Co-operative Test
d) 4 Toy Eye Pointing Test
e) Toy Discrimination Test
f) Reed's Screening Hearing Test
g) Kendall Toy Test
h) Verbal Auditory Screening for Preschool Children

L SUBJECTIVE TECHNIQUES

Subjective techniques involve procedures where the test results are based on the testers careful observation of the childs response or the child himself or herself giving a response. It requires the cooperation of the child and the clinician needs to be alert and attentive throughout the test.

These techniques can be carried out with or without reinforcement Hence, the procedure could either be a conditioned technique or an unconditioned one.

The most common unconditioned procedure is Behavioral Observation Audiometry (BOA) and the commonly used conditioned techniques are Visual Reinforcement Audiometry (VRA), Tangible Reinforcement Operatnt Conditioned Audiometry (TROCA), Conditioned Play Audiometry (CPA) and Pure Tone Audiometry (PTA).

The test to be selected for child depends on the age of the child and his/her ability to cooperate.

a) BEHAVIORAL OBSERVATION AUDIOMETRY (BOA)

Developed by : The earliest procedure employing behavioual observation technique reported in literature is by Ewing and Ewing (1944). They named the test as "distraction test". The term 'BOA' was given by Lloyd and Young in 1969

Age : 'BOA' is said to be the only behavioural method available for infants younger than six months of age. This procedure is preferred up to two years of age (Smith, 1987; Callison, 1999). Wilsoh and Richardson (1991) added that this is the only available behavioral procedure for some profoundly retarded children or for every young infants who cannot be conditioned to respond to auditory signals.

Test Stimuli:

Experts vary in their recommendations for the choice of stimulus. Parameters like frequency, bandwidth, intensity and temporal properties such as duration and repetition rate vary (Wharrad, 1994).

Stimulus Intensity:

Eisenberg (1969) noted that the responses of infants are intensity bound. The responses can be ensured only by using high intensity stimulus. However, this may result in missing out cases with mild to moderate hearing loss (Wharrad, 1994).

Northern and Downs (1991) said that a loud sound is usually required to elicit a behavioral response in zero to four month old babies and as the age increases, intensity required for the response reduces. Wedenberg in 1956 used a 75 dB tone.

Stimulus Frequency and Bandwidth:

Eisenberg (1965), Ling, Ling and Doehring (1970) found that newborn infants are more responsive to narrowband noise than to pure tones. Mencher in 1972 noted that if the bandwidth is too narrow, the false positive rates may increase. Mendel (1968) also reported that responses of four to eight month old infants were related to stimulus bandwidth. More responses occurred to broad band noise stimuli than to a narrow band noise stimuli or a warble tone.

Similar findings regarding responses to broad band signals have been noted by Flexer and Gans (1986).

All behavioral screening programmes are recommended to use a band pass noise stimuli centred at 3 kHz (Downs and Sterritt, 1964; Simmons and Russ, 1974). This is partly because babies with congenital hearing losses show poorer hearing at 3 kHz than other frequencies as stated by Fisch in 1955. Wedenberg (1956) used a 3 kHz tone.

Temporal Aspects

Ling (1972) did a study to find the most appropriate duration to elicit maximum response. The optimum duration was taken as one to three seconds.

Rapid rise times were associated with startle response, closing of eyes and heart rate acceleration. Stimuli with slower rise times produces heart rate deceleration and orientation reaction (Kearsley, 1973).

Fowler, Smith and Tasinary (1986) did a study relating the response of newboms to change in rhythm. It was inferred from their study that infants perceive stress beats and stress beat timing of syllables as adults do. This aspect can be considered while screening newboms even though it is not mentioned in literature.

Responses:

Responses are time locked to the stimulus. The examiner watches the infant and notes any changes in the behaviour of the infant soon after the stimulus presentation (Callison, 1999).

A few of the responses expected were or an interruption in sucking action during bottle feeding (Peck, 1970) or an awakening response from light sleep (Wedenberg, 1956, and Primus 1991). These were used for very young children. Ewing and Ewing (1944) suggested using a head turn response for babies older than six months.

Friedrich in 1985 said that 'BOA' procedure can be used for neonates and older infants, but the responses to be looked for will change. For newborn infants, suprathreshold stimulation is required to elicit reflexive or arousal responses. Older infants may demonstrate "awareness" or unconditioned head response at reasonably soft stimulus levels.

A variation in procedure for 'BOA' as given by Northern and Downs (1991) is given below. They have suggested that the toys used for distraction and the seating of the child varies as a function of age.

For *0-6* ***month old infant****:* The infant can be placed in a cradle or in the arms of the parent. The baby is preferred to be in a state of light sleep with the face been seen clearly. Ears should not be covered. The baby should not be wraped around with any blanket or coat to note the body responses during testing.

Responses should be noted with each noise maker and before the presentation a "perfect stage" should be set with a quiet atmosphere for maximum response. Responses are considered valid only if it is seen within 2 seconds of the presentation of the stimulus. In this age range responses are usually seen at high intensity levels.

For ***4-7 months old child***: Localization tests can be started with the child kept on the mothers lap facing the tester. The not-too attractive passive toy can be used to distract the childs attention. Parents are instructed not to communicate with the child during the test procedure stimulus is presented through a loud speaker at a 45 degree angle and head turn responses are expected.

For *7-9* ***months old infant***: Due to better motor coordination and strength in this age group, "indirect fixation" of a sound source can be checked. In this period it is preferred to use two noise maker toys exactly the same in appearance one held in front and other to the side. Head turn responses can be elicited in a better way in this case.

For ***9-13 month old infant***: Due to their social development a two room set up is preferred wim the child with the parent in a sound treated lighted room and the clinician outside in a dark room.

For ***13-24 month old child.*** Due to the speech and language development along with the maturation of auditory system, speech stimulus like "where is your mother? Or "where is the doll?" can be asked.

The expected responses for each group of children varies and the so-called "minimum intensity of response" also varies. The auditory behaviour index for infants given by McConnell and Ward (1967) is as shown below in Table I.

Table-I: The auditory behaviour index for infants (originally given by McConnell and Ward (1967).

Age	**Noise makers (dB SPL)**	**Warbled pure tones (dBHL)**	**Speech (dBHL)**	**Expected response**	**Startle to speech (dBHL)**
0-6 weeks	50-70	75	40-60	Eye widening, eye blink, arousal from sleep, startle	65
6 weeks - 4 months	50-60	70	45	Eye widening, eye shift, eye-blink, quieting, rudimentary head turn by 4 months.	65
4-7 months	50	50	20	Head turn on lateral plane toward sound; listening attitude	65
7-9 months	30-40	45	15	Direct localization of sounds to side, indirectly below ear level.	65
9-13 months	25-35	38	10	Direct localization of sounds to side, directly below ear level, indirectly above ear level.	65
13-16 months	25-30	30	5	Direct localization of sound on side, above and below	65
16-21 months	25	25	5	Direct localization of sound on side, above and below	65
21-24 months	25	25	5	Direct localization of sound on side, above.and below	65

As there is no report on any definite screening procedures in literature BOA, a procedure is suggested based on the review of the literature and opinion of experienced audiologists.

Suggested Hearing Screening Procedure for BOA:

It is recommended that appropriate intensity be used for children of different ages, as children respond to lower intensities as they grow older.

For infants below 4 months, higher intensities are needed. The intensity could be 70 dB for noise makers, warbled tones and speech. For infants above 4 months of age, these similar signals may be presented at 50 dB. Above 1 year of age, the intensity could be further reduced to about 30 dB

The tester should observe the responses carefully at the first presentation itself. This is because on repeated presentations the response might get habituated.

After the presentation of each stimulus for 2-3 seconds a silent period should be maintained where the infants response are noted. The kind of stimulus used also should be varied in terms of their presentation order i.e. if a noise maker of high frequency is presented, the next signal presented should be of mild or low frequency one.

False negative rates:

The sensitivity and specificity of behavioral observation audiometry as a screening test has not been reported in literature. Durieux-Smith, Picton, Edwards, Goodman and MacMurray (1985) in their study concluded that false negative rate of BOA is about 40 to 86% for the diagnostic procedure.

Advantages : BOA is considered to be the only behavioral method available for infants younger than six months of age (Smith, 1987).

As mentioned by Callison (1999) the test is relatively less expensive and is non-invasive. There is no language barrier in the test

Disadvantages . Behavioral assessment of auditory behaviours of infants is based on the observation of responses BOA is a passive approach which has inherent limitations (Callison, 1999). Wilson and Thompson (1984) gave the following limitation of BOA:

- Unilateral or sloping hearing loss cannot be detected.
  As no reinforcement is provided, habituation may occur fast.
- In neonates, suprathreshold stimulus is needed to elicit a response, whereas in older infants "awareness" response maybe elicited by head turn response at low intensity levels.
  Inter-subject variability is high,

Wilson and Richardson (1991) said that the probability of obtaining the response depends on the nature of the auditory stimulus. Response habituation and variability is high. Gans (1987) has reported it to be a 'test of responsiveness'. There is a possibility that the child hears the stimulus, but does not respond. Hoverstein and Moncur (1969) have proved that high frequency stimulus are not effective with young children for conducting BOA procedure. However, most experts have recommended the use of high frequency stimuli (Downs and Sterritt, 1964; Simmons and Russ, 1974; and

Wedenberg, 1956). BOA would be the choice of test only when facilities for carrying out other tests are not available.

b) VISUAL REINFORCEMENT AUDIOMETRY (VRA)

Term coined by: The term VRA was coined by Liden and Kankkunen (1969). They modified the conditioned orientation response procedure (COR) which was given by Suzuki and Ogiba in 1961. The principles of VRA were used in various tests prior to this (Dix and Hallpike, 1947; Haug, Baccaro and Guilford, 1967).

Age : There has been a general consensus regarding the age range in which this test can be done. Experts agree that the test can be done for children in the age range of 5-6 months to *2½* years (Haug, et al. 1967; Callison, 1999; Moore, Thompson and Folsom, 1992).

Test Procedure for VRA:

Test Pre-requisite. Visual reinforcement audiometry is the simplest conditioned response procedure used in pediatric audiometry (Hayes and Northern, 1996). A two room set up is needed and the examiner will be in the control room and has foil view of the testing situation and activates the auditory stimulus and visual reinforces. In the test room, the parent and infant are located behind a table in the centre of the room. A loudspeaker is positioned at a 45 degree azimuth to the right or left of the infants headline vision. The visual reinforces, housed in a dark pexiglass enclosure, is located at the eye level. The child's attention is brought to passive toys. Head turn responses are expected to the stimulus given.

Stimulus: Liden and Kankunnen (1969) found that warbled tons are more interesting for young children and they respond better for the same. Callison (1999) suggested using either warbled tones or narrow band noise in sound field testing. However, later on due to the reduced frequency specificity of narrowband noise, warbled tones were preferred. Speech can also be used as a stimulus.

Reinforcement: Moore, Wilson and Thompson (1977) determined the rank order of visual reinforcers according to their effectiveness in eliciting the VRA head turn response in 12-18 month old infants.

(a) an animated toy
(b) a flashing light
(c) social approval reinforcement such as exaggerated handclapping and facial display of pleasure.

Visual reinforcers were classified by Lloyd (1975) as those using:

Pictures, slides, miniature scenes, toy animals, toy train and other mechanical toys.

Moore, Thompson and Thompson (1975) concluded in their study that a combined use of visual and social reinforcement would be preferable. Primus (1987) reported that the use of animated toys gives better responses when compared to un-animated toys.

Culpepper and Thomson (1994) evaluated the effects of reinforcer duration on response behaviour. The reinforcer durations used were 0.5 sec, 1.5 sec. and 4.0 sec. The response behaviour to 50 dB HL complex band pass noise was investigated. They found that the responses were better and not habituated for the visual reinforcement of. 5 sec. They recommended the use of short duration visual reinforcers.

Stimulus presentation: VRA can be carried out in two methods. The 60 dB procedure and the 30 dB procedure (Liden and Kankunnen, 1969).

In the 60 dB procedure, auditory stimulus is presented initially at 60 dB HL and it is paired with a visual stimulus which is an attractive toy kept in a pexiglass over the loudspeaker. For the first 3-4 trials the tone is presented along with lighting the pexiglass to make the toy visible. Once the child is conditioned, stimulus intensity is decreased in 20 dB steps. When no response is observed, the intensity is increased in 10 dB steps.

Threshold is determined when the child response to three out of six presentations at the lowest intensity level. In the 30 dB procedure, stimulus is presented initially at 30 dB, and if no response is seen, the stimulus is increased and the 60 dB procedure is carried out If the child responds, the visual reinforcement is presented. The procedure is repeated and intensity is reduced in 20 dB steps and when no response is observed the intensity is increased in 10 dB steps. The threshold is the lowest intensity at which a child gives two consecutive responses.

Thompson and Folsom (1984) found no significant difference between the 30 dB and 60 dB procedures. They said that the 30 dB procedure may be more time efficient for the normal hearing child, but the 60 dB procedure may provide a better starting intensity for the hearing-impaired child.

Variation in the procedure : The procedure has been used in many ways to suit the child's interest.

The peep-show technique was one of the first which was developed by Dix and Hallpike in 1947. Later Guildford and Haug in 1952 developed a Pediacometer where he used 7 dolls to represent 7 pure tones. In 1967, Haug et al. developed a technique called Puppet In the Window Illuminated (PIWI) where the reinforcement was the appearance of a interesting puppet behind a lighted window.

The Conditioned Orientation Response Audiometry (CORA) was developed by Suzuki and Ogiba in 1961 where two transparent dolls were used which could be illuminated. Based on CORA, Barr and Junker (1969), created a technique of distraction with sound from a fixed visual attention. They used a rattle, a jingle bell and a music box.

Recently, automated computer versions of VRA are available. A computer assisted system can be programmed to present a variety of digitized signals (McCormick, 1994)

Bernstein and Gravel (1990) developed a computer assisted staircase procedure called the Interwoven Staircase Procedure (ISP). Though this procedure was used for threshold estimation it can be modified for screening also.

Keith and Smith (1987) developed a play tone audiometer utilizing the animated videographics, ft was developed for threshold searching mode but can be modified for screening. This procedure is used for older children between 3-7 years.

Eilers, Wilson and Moore in 1977 utilized VRA techniques to demonstrate that 1-3 month old infants could already discriminate between certain phonemes contrasts in speech sounds. They named it Visually Reinforced Infant Speech Discrimination (VRISD).

Suggested VRA procedure for hearing screening

VRA procedure has been mainly explained and used by authors for threshold estimation. No literature is available regarding how to use it as a screening tool. Hence, it is suggested that the following procedure be used while using VRA as a screening test. The suggested VRA procedure is similar to pure tone hearing screening suggested by ASHA, 1990. As recommended the screening procedure could be carried out at 20 dB across the frequencies 1 kHz, 2 kHz and 4 kHz.

Instead of pure tones, warble tones may be utilized. The speech stimuli used is suggested to be 'name calling' and the bi-syllable 'papa'. This syllable 'papa' is suggested as it has low frequency information and it is meaningful across most of India.

As children as young as six months of age are being tested, it is suggested that an initial conditioning be done at a higher level of 35 dB to 45 dB. This conditioning should be done prior to the screening at 20 dB. While conditioning at 35-45 dB, the auditory stimulus and the visual reinforcement are presented simultaneously. Once the child is conditioned i.e. the stimulus-response relationship is established, screening maybe carried out at 20 dB, where the reinforcement will be provided only after the response has occurred. This conditioning procedure utilizing localization response is similar to that suggested by Suzuki and Ogiba (1961).

The same procedure can be used for all infants above six months of age. As the age increased, the complexity and the attractiveness of the reinforcer can be reduced.

Sensitivity and Specificity

A 90% success rate was found with VRA under earphones in children with normal hearing and hearing-impairment between ages of 12 and 30 months. In a study done by Weber (1987) found that VRA is more efficient in identifying hearing loss when compared to Auditory Bratnstem Response in infants and toddlers.

Advantages

- It is a reliable test to detect hearing-impairment in almost all infants prior to the acquisition of speech and language.
- Over referrals are usually less.
- Habituation of the infant to stimulus can be prevented as reinforcement is given.

Disadvantages

- As interpretations are subjective, careful decision has to be taken.
- As conditioning may require time, the child may lose interest in the test procedure.

(Callison, 1999 and Lloyd, 19 75).

The VRA kit is commercially available and it can be used in conjunction with an audiometer.

e) TANGIBLE REINFORCEMENT OPERANT CONDITIONING AUDIOMETR Y (TROCA)

Developed by : The procedure was developed by Lloyd, Spradlin and Reid (1968),

Age : The procedure is most effective with children between two and four years of age developmentally, but has also been shown to be effective with younger children (Diefendorf, 1988). Fulton, Gorzycki & Hull (1975) in his study found the test to be successful with children above one year. Same results were found by Wilson and Decker in 1976.

Test Method

This procedure has been explained in literature and used for threshold estimation. It can be modified for screening purpose also.

The technique requires a specially designed equipment that will dispense a tangible reinforcement to the child upon activating a switch. The various steps given by Roeser & Yellin (1987) are modified for screening purpose and given below.

The first step involves the selection of a tangible reinforces (eg. food, toy, candy, etc.). This should be viewed positively by the child without getting distracted.

A 500 Hz auditory signal is presented at 50 dB HL (for conditioning) and the reinforcement button is lit. Reinforcement is given by the tester and the task is repeated twice. Third time, the child is guided by the clinician to lit the button and receive reinforcement and gradually stops guiding the child through the task.

Once the child responds without guidance, screening can be done at a lower intensity level. As no mention, has been made in the literature, to use the test as a screening one, it is suggested that a procedure, similar to pure tone hearing screening, may be used As with pure tone screening the child may be tested through the frequencies 500 Hz, 1 kHz, 2 kHz and 4 kHz at 20 dB.

Wilson and Thompson in 1984 described a technique where visual reinforcer was used in conjunction with tangible dispenser. This task is suitable for children two to three years of age. The technique is called Visually Reinforced Operant Conditioning Audiometry. They report the procedure to be successful in very young children and also difficult to test population.

Sensitivity and Specificity

Fulton, et al, (1975) in his study had found that the procedure has good specificity for the age group of one to two years in obtaining thresholds.

Wilson and Decker (1976) studied 32 infants between ages of seven and 20 months. The procedure was successful with 64% of the infants under 12 months of age and with 82% of those 13 to 20 months of age when used as a diagnostic procedure. No mention has been made in literature about the sensitivity or specificity as a screening tool.

Advantages

Once conditioning is done, test can be carried out fast

Disdvantages

According to Diefendorf (1988), the procedure is more time consuming than VRA procedure and requires multiple sessions to complete the training and testing.

d) CONDITIONED PLAY AUDIOMETRY (CPA)

Developed by : The earliest reports of this procedure is given by Utley (1949).

Age :This is the most common procedure used in assessment of children three years and above (Smith, 1987).

Test Method

Signals are presented to the child either through loud speakers, earphones or the above vibrator. The examiner selects a response behaviour that is consistent with the motor development of the child. The child is taught to perform a play task such as dropping a block in the bucket, placing ring on a peg. Placing a piece in a puzzle or stacking blocks. In this method the response and reinforcement are the same (Smith, 1987; Roeser and Yellin,1987; Kile, Beanchaine, 1991).

Roeser & Northern (1981) described a simple play conditioning technique named Play Audiometry Reinforcement using a Flashlight (PARF) which is carried out in the following way.

The examiner conditions the child to respond to flashlight first and then the visual stimulus is replaced with pure tone stimulus. The headphone is kept on the table and intensity is set to 90-100 dB HL and frequency 1000 Hz. After few trials headphone is kept on the child's ears and child holds the block on his cheek and a fixed intensity of about 50 dB stimulus at 1 kHz is presented. The intensity is slowly reduced.

Thome (1967) had incooperated a tactile mode in this procedure where the child holds the bone vibrator from the audiometer in one hand and block in the other hand. So that two objects are touching. A 500 Hz tone is presented at maximum level and child is conditioned to drop the block when the tactile sensation is perceived. The vibrator is kept at the mastoid and conditioning as done at 500 Hz and 2000 Hz. Later on earphones are used for the same purpose. As intensity levels for screening procedure are not mentioned in literature, it is suggested that conditioning is done at one higher level first (eg. 50 dB) and then carry out the test as done with pure tone hearing screening as mentioned in VRA and TROCA.

Reliability

According to Martin (1987) Conditioned Play Audiometry provides the most reliable threshold information when used successfully. The technique has not been used for screening purpose so reliability scores as a screening tool is not available. Information about the reliability of the procedure as a screening tool is not available.

Advantages. According to Diefendorf (1988) and Smith (1987)

When compared to BOA, the test is found to be more reliable if conducted with caution.

***Disadvantages* : According to Martin (1987); Smith (1987)**

A variety of activities are needed to maintain interest in the activity, or else, response behaviour may habituate.
The child should have normal motor skills to perform the play activity.

e) PURE TONE HEARING SCREENING

Described by : The sweep-check screening test was originally described by Newhart (1948).

Age : This procedure is usually used for cooperative children who needs relatively less amount of reinforcement. Usually pure tone hearing screening is done on pre-school children and school children (Hood and Lamb, 1974).

Test Stimuli

Pure tones are usually used for screening. The frequencies to be tested and the intensity of presentation varies for different authors.

Test frequencies and intensities

The use of the frequencies 500 Hz, 1 kHz, 2 kHz and 4 kHz has been recommended by most of the studies. Slight variations are also seen in a few of the studies.

The recommended intensities at which screening should be carried out is between 20 and 30 dB. In selecting the screening level, two factors have to be considered i.e., the effect of the background noise and the sensitivity of the test in detecting even slight hearing loss. As the level is reduced, the ambient noise will have a greater effect on the test signal. Thus school screening is not usually done below 15-20 dB HL (Roeser and Yellin, 1987).

The variations seen in different studies in terms of frequency and intensity has been given in Table II.

The frequencies and intensities at which the screening is to be carried out, varies from author-to-author. Table II indicates the variations suggested by different authors.

Table-II Frequencies and intensities recommended by various sources for pure tone hearing screening.

Source	Test frequencies	Intensity level
ASHA 1990	1 kHz, 2 kHz & 4 kHz if immittance screening is carried out or else 500 Hz also has to be included.	20dBHL at all frequencies.
ASHA(1985)	1 kHz, 2 kHz & 4 kHz if immittance screening is carried out or else 500 Hz also has to be included.	20 dB HL at all frequencies
National Conference on Identification Audiometry	1 kHz, 2 kHz & 4 kHz and 6 kHz	20dB at kHz, 2kHz & 4kHz and 6kHz 30 dB& 4kHz
State Illinois Department of Public Health	500 Hz, 1 kHz, 2 kHz & 4 kHz	25 or 35 dB
American Speech-Language Hearing Association Committee on Identification Audiometry	1 kHz, 2 kHz & 4 kHz	20 dB at 1 kHz, 2kHz 25 dB& 4kHz
Northern & Downs (1984)	1 kHz, 2 kHz and/or 4 kHz and6 kHz	25 dB
Anderson (1978)	1 kHz, 2 kHz & 4 kHz	20 dB
Downs (1964)	1 kHz, 2 kHz & 4 kHz, 6kHz, 8kHz	15 dB
ASHA(1985)	1 kHz, 2 kHz & 4 kHz	25 dB

Test Method

Individual screening procedures are preferred to group screening methods due to more accuracy (House and Glorig, 1957). The sweep check method has become more or less the standard screening procedure (Anderson, 1978).

Test Method for individual sweep test

The stimuli at pre-determined frequencies are presented at fixed intensity levels, and the child is instructed to respond by raising a hand, raising a finger or responding in some other manner. Ear phones are placed over both ears of the child and a practice tone is presented at a level above the test tone (i.e. 40 dB HL) to acquaint the child with the type of signal to be heard.

Test stimuli are presented to one ear and then to the other and the response of the child to each frequency is noted. The intensity is kept at a constant level.

The sweep check procedure can be successfully administered to both school age and preschool children in about 2 minutes per child (Hood and Lamb, 1974).

Group hearing screening procedures:

These procedures were developed primarily as a means of saving time. They were used in the past for school screening 'Pube Tone Test' given by Reger and Newby in 1947 and 'Masachusetts Test' given by Johnson in 1948).

At present, it is not used due to various problems like calibration and maintenance of multiple ear phones and funding an appropriate test environment (Roeser and Northern, 1988).

Sensitivity and specificity

Five hundred and eighty 3rd grade school children were screened for hearing loss using the standard pure tone four frequency protocol and the transient evoked otoacoustic emissions (Sabo, Winston and Maclas, 2000). Pure tone screening method was found to have a sensitivity and specificity of 87% and 80% respectively, whereas transient evoked otoacoustic emissions had poorer values. Thus, Sabo, et al. (2000) concluded that pure tone screening was a significantly better screening test for detecting hearing loss in the school population.

Mencher and McCullock (1970) compared screening using speech and pure tones. They found that hearing screening using speech had high false negative rates when compared to pure tone screening.

The false positive rates are noted to increase if the signals are presented at 10 or 15 dB HL (Roeser and Northern, 1988).

Melnick, Eagles and Levine (1964) found that the inclusion of a second screening reduced the number of over referrals by 23%.

Thus, pure tone screening is found to be a useful technique, especially for school going children.

Advantages:

No expensive and complicated equipments are needed for the test

It is non-invasive and it is the most common used screening procedure in school.

Test administration is easy and takes very les time to administer.

Disadvantages

The child should have average intellectual functioning to follow the instructions. The childs response maybe biased by the testers way of presenting (i.e. asking for a response).
The environment noise should be low and the presentation duration of the pure tone also should be optimum i.e. about 1-2 seconds or else in accurate responses maybe obtained (Roeser and Northern, 1988).

An instrument has been developed which can enable both audiometric screening and otoscopic examination and. It is a hand held instrument which can be fitted with different sizes of ear tips. The ear canal can be visualized for any cerument The instrument can present pure tones at 500 Hz, 1 kHz, 2 kHz and 4 kHz at a constant screening level of 25 dB. Each tone has a duration of 1.5 sec. and a pause of 1.5 sec between two tones. The sensitivity and specificity of the instrument was reported to be 91% and 75% respectively on initial screening and on rescreening it was slightly increased i.e. 93% and 82% respectively (Bienvenue, Michael, Chaffinch and Zeigler, 1985).

They found the sensitivity and specificity of younger age groups were poor i.e. 75% and 50% respectively, but as the age increased, the sensitivity and specificity also improved.

Advantage

The instrument is portable and there is no need to have two separate instruments for otoscopic examination and for pure tone screening.

Disadvantages

Few researchers have mentioned that the design of acoustic eartips may restrict the visualization of the ear drum for large ear canal configuration.

II SEMI OBJECTIVE TECHNIQUES

The label semi-objective has been given to the techniques as they are neither completely objective nor completely subjective. In these techniques, an overt or semi overt behaviour (like increase in heart beat) in response to auditory stimulus is detected by an instrument. Thus making the procedure partly objective. They can be also called as automated behavioral tests. They have been named as non-behavioral testes by Hayes and Northern (1996).

The various procedures used based on this technique are :

a) Crib-O-Gram
b) Auditory Response Cradle.
c) Accelerometer Recording System
d) Heart Rate Response Audiometry
e) Respiration Audiometry.

These techniques were developed doe to the disadvantages of the behavioural observation measures. The 1994 position statement concludes that behavioral observation measures cannot validly and reliably detect hearing loss of 30 dB HL in infants younger than 6 months of age.

Although many of these techniques have fallen into disuse for a variety of reasons, review of these techniques may suggest future applications based on improved technologies.

a) CRIB-O-GRAM

Developed by : The device was developed by Simmons and Russ in 1974.

Age : The instrument was developed for screening neonates. Durieux-smith, Picton, Edwards, Goodman and MacMurray (1985) suggested that the reliability of Crib-O-Gram is better for infants 38 weeks and older.

Test Stimuli

The test stimulus is a one second narrow band noise centred at 3 kHz (band width 700 Hz) which is presented at 92 dB SPL via a free-field loud speaker (Simmons and Russ, 1974). A similar procedure was used by Weber in 1988; Wharrad in 1994. Hayes and Northern (1996) used a 2000-4000 Hz band pass noise which was delivered from a transducer placed in the crib.

Test Method

The child should be in the cradle and ambient noise should be minimum. This technique uses a motion sensitive transducer placed under the crib mattress to detect any change in motor activity from the infant stronger than an eye blink (Simmons and Russ 1974). A strip chart automatically records this motor activity, before and after the test stimulus.

Hodgson (1987) said that the system measures the crib movement before stimulus presentation for 10-15 seconds and after each auditory stimulus presentation for 6 seconds. Wharrad (1994) suggested that body activity including respiratory movement, be monitored from 10 seconds before and 3.5 seconds after the stimulus onset

The auditory test stimulus is presented 20 or more times over a 7-24 hour period (Northern & Downs, 1991; Hayes & Northern, 1996).

Responses

Responses recorded are in the form of baby movement (or lack of responses). The responses are noted by the microprocessor and are analyzed until a statistically valid decision can be made (Northern & Downs, 1991). The decision will be in terms of whether the baby passed or failed the test (Hayes and Northern, 1996).

Test Method

The earlier Crib-O-Gram. as developed originally required off line analysis of the strip chart recordings by trained personnel. This has been superseded by a microprocessor controlled model which reduces the test time to 2-3 hours. The stimulus is not presented if the baby is restless and all the necessary analysis of the baby's movements is automatically processed. The statistical analysis is based on the calculation of likelihood ratios of response for stimulus, relative to pre-stimulus period. If the likelihood ratios are high enough to exceed a defined value, the baby passes the test (Wharrad, 1994).

To reduce the cost per infant, the test can be carried out in a group as loud intensities are needed and a separate microprocessor can be used for each child. Thus it saves time and cost.

Sensitivity and Specificity

McFarland, Simmon & Jones (1980), using Crib-O-Gram, found a sensitivity rate of 91% in Well Baby Nursery (WBN) and 82% in Intensive Care Nursery (ICN). The specificity for WBN was 92% and 79% for ICN.

Durieux-Smith et al, (1985) evaluated 306 infants in an NICU and reported a false positive rate of about 33%. This was done by comparing the Crib-O-Gram results with those obtained with brainstem electric response audiometry. The false positive rates was 52% for infants between 31 and 37 weeks of age and about 35% for infants between 38 and 54 weeks. They concluded mat Crib-O-Gram is preferred for infants of 38 weeks and older.

Ventry (1982) based on his study on 280 neonates in NICU concluded that Crib-O-Gram is unreliable, yields too many failures of infants with normal hearing sensitivity.

A validation study was carried out by Morgan &, Canalis (1991) with 1195 infants. Here a periodic pulsed noise (centered at 3 kHz) was presented. A screening run comprised of 30 trials. They found the false positive error to be 13.8%, but had high sensitivity and specificity.

Advantages

Low cost per infant screened.

There is no need for an experienced examiner to conduct or interpret the results of the screening (Morgan et al.1991).

The technique was found to be very sensitive and specific for infants (McFarland etal, 1980; and Morgan & Canalis, 1991).

Disdvantages

The procedure is insensitive to mild to moderate hearing loss.
The false positive error rates are high among NICU population (Morgan & Canalis, 1991).

b) AUDITORY RESPONSE CRADLE

Developed by : The device was designed and developed by Bennett in 1975.

Age : The test can be used for screening infants.

Test pre-requisite

Babies are placed in the cradle which houses the electronic components including a microprocessor (Bennett, 1975). There is a pressure sensitive mattress, transducer embedded in a head rest, a plastic belt which has a transducer and is placed around tine upper abdomen of the baby.

Stimulus

As Bennett has described, the stimulus used is a high pass noise of 85 dB SPL with a bandwidth from 2600 to 4500 Hz. The stimulus is presented through closed coupled ear probe fitted with tips similar to those used for acoustic impedance testing. The stimulus is presented for 5 seconds and the resulting motor and respiratory responses are detected and stored by the microprocessor (Northern & Downs, 1991; Wharrad, 1994; Hayes & Northern, 1996).

The automated program presents stimulus trials as well as an equal number of no sound control trials.

Responses

The trunk and limb movements are monitored by the mattress, head jerk component of the startle reflex is monitored by a transducer, embedded in the head rest. It is pivoted on low friction bearings to detect head turn reactions. The respiratory patterns are sensed by a transducer which is fitted in a plastic belt placed around the upper abdomen of the body (Wharrad, 1994).

In the automated program, the probability is calculated mat the infants motor responses are valid and not unrelated spontaneous movements. When the probability rate exceeds 97%, the baby is considered to have normal hearing and is passed average time taken for the test is 2-10 minutes.

Various researchers like Bhattacharya, Bennett and Tucker in 1984 have done studies using this instrument and have reported that infants with severe hearing loss as well as infants with middle ear disease have been identified with mis instrument

Advantages

Time taken for the test is only 2-10 minutes.
Even respiratory alterations can be detected using the instrument

Many infants with severe hearing loss and with middle ear dysfunction have been identified using this instrument (Bennett, 1979,1980; Bennett and Lawrence, 1980).

Disadvantages

As a high pass noise of 85 dB SPL is used, only moderate to profound cases can be detected.

The test can be conducted in a nursery in a group to save time and cost per infant, but it needs individual recording systems for each child.

c) ACCELEROMETER RECORDING SYSTEM

Developed by : Altman, Shenhav and Schandintschky developed this instrument in 1975 for graphically recording responses of neonates to auditory stimulation.

Age : The instrument is considered to be a valid test method for mass screening of newborns for early detection of profound hearing loss (Altman et al. 1975).

Test Stimuli

The stimuli is a pre-recorded thermal band noise amplified by audio-amplifier into a loudspeaker. Sound stimulus was a 1/3 octave noise band with central frequency of 3150 Hz. Sound level was 90 dB at ear of infant. Duration of signal was 500 msec. Three stimuli or more were presented with an interval of at least 5 second.

Test prerequisite

An infant cradle fitted with a wooden pillow. The cradle is placed on a floating floor structure, ft consists of a concrete slab supported by a tyre tube. It is covered by a polyurethane sheet. The complete structure and cradle were placed on a table.

Testing procedure

Infants are wrapped in diapers, leaving only head and upper limbs for observation. Pre-testing state could be classified as (i) "awake and quiet" when their eyes were open and they remained quiet after transfer (ii) "deeply a sleep' when not aroused by transfer, and (in) in "slight sleep" when they were temporarily aroused by transfer. Fretful or crying infants are not tested.

Responses

Whole or partial body movement and eye blink responses are recorded.

The "wooden-pillow' enhances pick-up of vibrations from weak response movements such as eye blink. Eye blink may be accompanied by contractions of neck muscles, which elude observation.

Response Recording

An accelerometer is attached to top of wooden pillow. Vibrations are picked up by this and a preamplifier amplifies the voltage of the response signal from the accelerometer. The response signal is passed through a narrow band filter adjusted to 0.1 -20 kHz. -

This voltage is finally recorded by a pen recorder. The maker of the recorder notes the sound stimulus on the paper and is connected with an automatic timer which releases and controls the duration of stimulus. The paper speed of the recorder is 25 mm/sec.

Validity

The method has poor validity as the responses were observed by human in mass screening. It is considered to be reliable when used for individual screening.

Altman et al, (1975) reported the following advantages -

- It is short, simple and reliable procedure.
- As an accelerometer was used as a transducer, it generates voltage proportional to the acceleration of vibrations set up in the wooden pillow. Thus sensitivity is more with minimal interference by undesirable side effects.
- As the filter is adjusted to lowest pass band, a very good signal-to-noise ratio is seen. The influence of speech and other random noises in the testing room and especially that of the sound pulse of the stimulus was completely eliminated from the recordings. Solid-borne noise was excluded by placement of cradle on the "floating floor structure".

Disadvantages

- Although the instrument is very sensitive to vibrations, breathing and heart beats do not show in the recordings, as their accelerations is very low (Altman, et al. 1975).

Two other semi objective techniques which were used earlier are:

1. Respiratory audiometry and
2. Heart rate response audiometry.

These procedures were developed and used on neonates first by Canestrini (1913) and Bartoshuk (1962) respectively. They are not currently used for hearing screening due to the development of more accurate and simple objective procedures.

III OBJECTIVE TECHNIQUES

These procedures are scientifically precise and independent of errors of hearing judgment Objective methods of hearing screening are preferred due to their advantages over the subjective and semi-objective techniques.

The common objective methods used currently are :

a) Otoacoustic emissions
b) Auditory brainstem response
c) Immittance audiometry
d) Reflectometry

Even though these procedures are accurate and are independent of the human judgement errors, the results have to be co-related with the subjective methods which can be easily administered. This needs to be done to confirm the results obtained.

a) OTOACOUSTIC EMISSION (OAEs)

Otoacoustic Emissions (OAEs) are the most recent objective method for auditory response measurement. They are low level "leakage" of acoustic energy associated with normal hearing process which can be detected with specialized equipment in the external auditory canal (Bonfils & Uziel, 1989).

The presence of OAE in human auditory canal were first verified by Kemp (1978). He developed a computerized system which used a sound source and a miniaturized microphone mounted in a probe tip and sealed in the ear canal to measure OAEs.

OAE's are measurable in neonatal ears, though there are consistent differences between neonatal and adult OAEs. Partly due to anatomical differences, OAE amplitudes from neonates are greater by 10 dB or more and lypically have a higher resonant frequency for both the stimulus and response spectra than adults. Adult responses have notches while neonates typically have smooth, flat response spectra (Burns, Archart & Campbell, 1992; Kemp, Ryan and Bray, 1990).

Two broad classes of OAEs are

1) Spontaneous Otoacoustic Emissions (SOAE)
2) Evoked Otoacoustic Emissions (EOAE)

1) Spontaneous Otoacoustic Emission (SOAE)

SOAEs are low intensity sounds measured in the external ear canal when there is no external sound stimulation (Ruggero, Rich, Freyman, 1983;

Culpepper, 1997; Hayes and Northern, 1996). They are present in about 60% of persons with normal hearing (Martin, Probst and Lonsbury-Martin, 1990). Although the presence of SOAE is a good indicator of normal, healthy cochlea (Bonfils and UzieL, 1989), it has limited value for use for neonatal hearing screening as it cannot be detected in all the ears with normal hearing (Culpepper, 1997).

In general, the majority of SOAE's from infants and newboms are somewhat higher in frequencies (3000-4000 Hz) man those from adults (Burns et al, 1992; Ruggero et al, 1983).

With regard to amplitude, the majority of SOAE's recorded had a mean of 10 dB SPL in infants (Burns et al, 1992). They reported a systematic decrease in SOAE amplitude for infants who were tested between 1 month and 24 months of age. By 24 months, the average SOAE amplitude decreased to 0 dB SPL from 8.5 dB SPL at 1 month.

The second category of OAE's i.e. the EOAE's involves low intensity evoked otoacoustic emissions, elicited by low to moderate levels of acoustic stimulation presented through an ear canal microphone. These have been used extensively for screening newborns and iniants.

2) Evoked Otoacoustic Emissions (EOAE's)

One widespread clinical application of evoked otoacoustic emissions is the detection of peripheral auditory dysfunction in neonatal hearing screening programs (Culpepper, 1997).

The EOAE's include -

(i) Transient Evoked Otoacoustic Emissions (TEOAE's)

(ii) Distortion Product Otoacoustic Emissions (DPOA's) and

(iii) Stimulus Frequency Otoacoustic Emissions (SFOAE's)

Glattke, Pafitis, Cummiskey and Her er in 1995 found TEOAE's to be more sensitive in identifying hearing loss as low as 20-30 dB HL using a stimulus level of 80 dB peak. DPOAE's are able to detect hearing losses of above 35 dBHL.

(i) **Transient evoked otoacoustic emissions (TEOAE)**

Reported by - Kemp in 1978, first reported TEOAE's The effectiveness of TEOAE's for infant screening was practically demonstrated by Johnsen and Elberling in 1982. Johnsen, Bagi and Elberling (1983) were the first to report TEOAE responses in neonates which were comparable to adults.

Age — A pass rate greater than 90% can be expected for infants less than 24 hours old if multiple attempts are made to screen children (Glattke and Robinette, 1997). Kok, van Zanten, Brocaar & Wallenberg (1993) in their study reported the success rate to be approximately 75% when infants were less than 36 hours old. The success rate rose to about 95% for infants greater than 108 hours old Thus, it can be said that the test is more reliable for infants above 108 hours of age.

Stimulus

TEOAE's involve click stimuli presentation at moderate intensities (45 dB above perceptual threshold) (Giattke and Robinette, 1997). The stimulus used by ILO88 equipment used a broad band 80 msec. Duration of electric pulse presented at 80 dB SPL. The frequency response is between 1500 and 5000 Hz with a sweep time of 12.5 msec.

A modified TEOAE method, used a narrow band signal. The screening device was ILO 1088 Echosensor which reduced the testing time (Maxon, Vohr, White, 1996).

In a comparison study done between the ILO88 and ELO1088, equipments Maxon et al, (1996) concluded that there was a good agreement between the two devices. The BLO1088 automated screener demonstrated good potential as a quick, accurate hearing screening device for newborns. It reduces screener training and also the need for off-line interpretation of the results when employed in a universal program.

Responses

Amplitude

The amplitude of responses recorded from neonates exceed that from adults by 10 dB or more and the 95th percentile for TEOAE response amplitude has been estimated to be 26 dB SPL (Kemp and Ryan, 1993). Kok, van Zanten and Brocaar (1992) reported that the magnitude of the TEOAE that the magnitude of the TEOAE grows idiosyncratically with age during the first few days of life of normal newborns. TEOAE's were judged to be present if the emission had a 3 dB signal-to-noise ratio present in four bands centered at 1.5, 2.3 and 4 kHz with 70% reproducibility (Dort, Toboloski, Brown, 2000).

Various studies were done on low birth weight children (van Zanten, Kok, Brocaar & Sauer 1995). They reported that the magnitude of TEOAE grows by approximately 10 dB between post conceptional age of 47 weeks. Kok et ai. in 1992 noted that responses of low-birth weight infants approached the levels found in healthy newboms when they were tested between 37 and 77 weeks after conception.

It was noted by Kok, van Zanten, Brocaar & Wallenburg in (1993) that the median response amplitude for neonates was approximately 16 dB SPL for those who were 24 hours old. This level rose to 20 dB and 22 dB SPL for babies 48 and 72 hours old respectively. This was higher when compared to adults (12 dB). Similar findings were given by Johnsen, Bagi, Parbo and Elberling, 1988; Norton and Widen, 1990; Smurzynski, 1994; Thornton, Kimm, Kennedy and Cafarelli-Dees, 1994.

Widen and Norton in 1993 found the overall amplitude of TEOAE to be greater at one month than at 1 to 2 days of age. This increase in amplitude may be attributed to post natal changes in the middle ear transmission characteristics. The changes may occur as a result of exposure to the environmental conditions outside the womb. They also found that the changes from one month to seven or nine months were minimal.

Sensitivity and Specificity

In a study done by Dort, Tobolski and Brown (2000) sensitivity of TEOAE was found to be 85.7% and specificity was 49.1%. Sabo, Winston and Maclas (2000) compared pure tone and TEOAE screening in a grade school population. The sensitivity and specificity of TEOAE reported by them in their study was 65% and 91% respectively. The scores were poorer when compared to pure tone screening. TEOAE is found to have high false-positive rates in screening infants in a nursery (Salamy, Eldredge and Sweetow, 1996).

Advantages

TEOAE's are found to be more sensitive in identifying hearing loss as low as 20-30 dB HL using a stimulus level of 80 dB peak (Gattke, Pafitis, Cummiskey, Herer, 1995).

TEOAE's was found to be most suitable method for screening peripheral auditory function in infants and can be most successfully performed at the age of 3 to 4 days (Engdahl, Arensen and Mair, 1990).

Maxon, Vohr & White (1996) found TEOAE to be having a significant potential as a newborn screening tool when used in a carefully designed hospital based early identification programme.

(ii) Distortion product otoacoustic emissions (DPOAE)

Age : They have been used in neonatal hearing screening, but not to a large extent (Widen, 1997).

Test Stimuli

The DPOAE's are an inter-modulation-distortion response produced by the ear in response to two simultaneous, pure tone stimuli referred to as the primary tones. The lower frequency pure tone is referred to as the f_1

primary and its level as L_1. The higher frequency pure tone is refereed to as f_2 primary and its level as L_2 (Bonfils & Uziel, 1989).

The most frequently measured acoustic intermodulation distortion product is at the frequency $2f_1 - f_2$ This should be two standard deviations above the noise floor and the two primary tone stimuli should be within 3 dB SPL of their expected values.

The suggested stimulus parameters by Logan Regional Hospital are a frequency separation ratio of 1.22 and primary-tone stimuli at intensity levels of 65 dB SPL and 50 dB SPL for f_1 and f_2 respectively. They said that recording at two points per octave may increase in the test time, but assists in reducing false positive rates.

Brown, Sheppard and Russel (1994) used low amplitude primaries (L_1=55, L_2=40) whereas Dort, Tobolski and Brown (2000) used L_t = 60 dB and L_2 = 45dB.

Response

The adult newborn differences are still in conclusive. Lafreniere, Jung, Smurzynski, Leonard, Kim, Sasek (1991) concluded that DPOAE "audiograms" were quantitatively similar to adults. They found that the average DPOAE level of newborns was slightly higher (2.0 to 6.6 dB) than that of adults in the frequency region betweenl and 2.4 kHz. It was lower (0.4 - 3.5 dB) than that of adults in the frequency region of 4.8 to 8 kHz.

Amplitude

Lasky, Peariman and Hecox (1992) noted that their neonatal DPOAEs were comparable in amplitude to their adults, but the neonates did not show the characteristic dip in the distortion product (DP) gram between 1 and 3 kHz. The amplitude of neonatal DPOAE's in that region was significantly greater than adults.

Bonfils, Avan, Francois, Trotoux, Narcy (1992) reported that DPOAE amplitudes were 6 dB higher in neonates than in adults. When a lower amplitude primaries are used mean DPOAE amplitude, was found to be 10 dB higher in neonates than adults (Brown, Sheppard and Russel, 1994).

Noise

When compared to TEOAEs, DPOAEs recordings usually show higher noise levels in infants than adults (Lasky, Peariman, Hecox, 1992; Brown, Sheppard, Russel, 1994; Culpepper, 1997).

Bonfils et al. (1992) reported high noise levels precluded DPOAE testing below 1200 Hz. Smurzynski et al. (1994) reported in his study that noise prevented the collection of DPOAE data in the 1000 Hz range for many infants. Dort et al, (2000) noted that DPOAEs are judged to be present if the DPOAE level was more than 6 dB above the associated noise floor.

For screening in noisy situations good probe fit should be achieved. Not all DP equipments provides feedback regarding adequacy of probe fit. Most DP units have artifact reject systems which exclude noisy data from averaging. Thus, the equipment can be used in noisy settings, but data collection is slower. Because PPOAEs measure one frequency at a time, they are more susceptible than TEOAEs to a response at that frequency being obscured by noise.

Spectrum

Neonates typically show more of high frequency energy than adults. This maybe because the higher noise level may obscure low frequency emissions.

Sensitivity and Specificity

Dort et at, (2000) noted the sensitivity and specificity of DPOAE to be 71.4% and 61.4% respectively.

Advantages:

The mean time taken to test two ears was found to be the least (10 min.) when compared to AABR and TEOAE (Dort, et al. 2000).
When compared to AABR and TEOAE, the cost of universal hearing screening program using DPOAE per infant is $12.89 in USA
When compared to TEOAE, this test gives more frequency specific information but limited to higher frequency (Maurizi, Ottaviani and Paludetti, 1995).

Disadvantages:

At present, the test is less accurate when compared to other tests like AABR (Dort et al. 2000).

- Norms are not established for neonatal population to give a cut off point in order to discriminate between mild hearing loss and normal hearing (Culpepper, 1997).
- They give frequency specific information and are not good in detecting hearing loss at 500 Hz (Culpepper, 1997).
- Central auditory processing disorders cannot be detected.

Stimulus frequency otoacoustic emissions are not likely to be widely used for neonatal hearing screening as they provide similar information to that provided by TEOAE. They require more time to record and more complex calculations to separate stimulus from response (Culpepper, 1997).

OAEs are the most recent objective techniques used for neonatal hearing screening and many studies are being done to establish a pass/fail criteria for infant hearing screening.

b) AUDITORY BRAINSTEM RESPONSE (ABR)

Auditory brainstem response (ABR) or brainstem auditory evoked response (BAER) has been used effectively as a screening test for neonates.

Earlier, the same ABR instrument was meant for both diagnostic and screening purpose. Later Automated ABR was developed just for screening purpose. Based on this ABR can be classified as

(i) Conventional ABR and

(ii) Automated ABR

i) Conventional ABR

Description by : Jewett and Williston (1971) gave the first description of- human ABR. Schulman-Galambos and Galambos (1975) first is reported the use of ABR in intensive care nursery. Neonatal screening by ABR was first proposed by Galambos (1978).

Age : The test is recommended for neonates before discharge from the hospital. Finitzo-Hieber (1982) recommended mat premature infants should be tested near discharge time. The infant should be at least 37 weeks of gestational age and should be in an open crib. Premature infants are advised to be tested every three months in the first year of life. The test is usually administered on neonates who are at risk. The Joint Committee on Infant Hearing (1994) in USA has advised that newborns who manifest. One or more items on the risk criteria should be screened using ABR prior to discharge. They have also recommended that infants below 6 months should be screened using **ABR**

Test Stimulus

There is no consensus among the experts regarding the most appropriate stimulus to be used in screening ABR The stimulus vary in terms of their presentation level, repetition rate the filter settings used and number averaged.

Stimulus Intensity

Intensity recommended by Galambos when he first suggested ABR for screening was 30 dB nHL. Later, other experts have suggested variations in the presentation level. The recommended intensity cut-off varies from expert to expert While some have recommended the use of just one level (Schulman-Galambos and Galambos, 1979; Jacobson et al. 1981; Galambos et al. 1982; Mjoen et al. 1982), others have suggested using a combination of two intensity levels (Roberts et al 1982; Shannon et al.1984; Fria, 1985).

The lowest cut-off suggested has been 25 dB nHL (Shannon et al. 1984). The combination of intensities most often recommended are 30 dB nHL and 60 dB nHL (Fria et al1985; Jacobson and Morehouse, 1984; Callison, 1999). The various intensity levels used for ABR screening since 1979 are listed in a Table III.

Table HI. Cut-off criteria for intensity during ABR screening

Author	Year	Cut off criterias
Schulman-Galambos and Galambos	1979	30 dB nHL
Jacobson, Seitz, Mencher and Parrott	1981	30 dB nHL
Galambos, Hicks, Wilson	1982	30 dBnHL
Mjoen, Langslet, Tangsrud and Sundby	1982	40 dB nHL
Roberts, Davis, Phon, Reichert, Sturtevant and Marshall	1982	40 dB nHL and 40 dB nHLand 70 dBnHL
Alberti, Hyde, Corbin, Riko, and Abramovich	1983	40dB nHL
Durieux-smith, Edwards, Hyde, Jacobson, Kileny, Picton and Sanders	1983	30 dB nHL
Stein, Ozdamar, Kraus, Paton	1983	40 dBnHL
Dennis, Sheldon, Toubas and McCaffee	1984	30 dB nHL
Shannon, Felix, Krumholz, Goldstein, Harris	1984	25 dB nHL, 25 dB nHL, 65 dB nHL
Fria, Kurmin, Ashoff and Sinclair-Griffith	1984	30 dB nHL, 60-70 dB nHL
Jacobson and Morehouse	1984	30 dB nHL, 60 dB nHL
Fria	1985	30dB nHL& 60 dB nHL
Weber	1988	30dB nHL& 45 dB nHL
Callison	1999	30dB nHL and 60 dB nHL

Fria (1985) reported that when the cut-off score was taken as 30-40 dB nHL, the number of over referrals increased to 70%. When a 60 dB stimulus is used, it results only in 10% over referral rate, but may show substantial under referral rate. Hence, Fria (1985), suggested using a combination of these two levels for a compromisably reasonable over-referral rate of 50% (Fria, 1985).

Stimulus rate

A click rate of 37/sec was used by Galambos (1978) when he first suggested it for neonatal screening. To reduce the false positive rates, the repetition rate was lowered to 21/sec by Dennis, Sheldon, Toubas and McCaffee (1984), Stein, Ozdamas, Kraus and Paton in 1983 and Cox (1984). Jacobson, Seitz, Mencher and Parrott in 1981 suggested an even lower repetition rate of 10/sec.

Weber (1988) recommended a higher rate of 30-40/sec. Wilson and Richardson (1991) reported that no standard repetition rate for screening of newborns has been established, but a repetition rate of 30/sec is used usually. It represents a compromise between the need for waveform clarity and a reasonable test time according to the author.

Filter Settings

Neonatal hearing screening when done for the first time by Galambos in 1978 made use of a filter setting to pass a band from 150 Hz to 3000 Hz. Not many variations have been suggested for the filter settings.

Fria (1985) suggested to use a 100 to 3000 Hz band pass filter for neonate ABR screening. However, Stapells (1989) recommended that the EEG pass band be lowered to 30 Hz.

Number Averaged

Initially when ABR was used for the first time by Galambos (1978) for neonatal screening, he recommended that the number of clicks averaged should be 2042. Later Alberti et al. (1983) recommended an increase to 4000.

Response

Most of the ABR screening procedures depend on the identification of wave V as the pass/fail criterion. If two click presentation levels are used and if wave V is present for a 30 dB nHL stimulus, the infant passes the tests. Establishment of a replicable ABR at 60 dB nHL increases the probability of accurate interpretation of the presence or absence of a replicable ABR at 30dB nHL. If no ABR is identifiable at 30 dB nHL or at 60 dB nHL, the infant fails the **ABR** screen and follow up procedures are initiated (Callison, 1999).

Marshall, Reichert and Kerley (1980) classified infants of 24-43 weeks and a birth weight of 530-2338 gms as pass or fail, depending on the presence or absence of wave V at a latency of 7-11 milli second in response to clicks of 60 dB above the normal adult threshold. They suggested that the smaller, younger babies failed the **ABR** screening because of the physiologic immaturity.

Sensitivity and Specificity

Fria (1985) had stated that failure rate ranges from 11-19%. False positive rates are about 30-50%. Watson, McClelland and Adams (1996) found that if appropriate pass/fail criteria are adopted, ABR has good sensitivity and specificity.

Mason and Herrmann (1998) did a study on 10,372 infants born during a 5 years period. Successful screening in the nursery was achieved for 96% of infants- The failure rate was 4%.

A breakdown of ABR screening results for a hypothetical population of 1000 high risk new boms was given by Fria (1985). It was found that the sensitivity and specificity was 98% and 90% respectively when the cut-off score was taken as 30 dB. The sensitivity and specificity reduced to 97% and 95% when a 45 dB cut-off score was taken and for a 60 dB cut-off score sensitivity reduced to 96%, while specificity increased slightly (98%). The false positive rates were very high in the first case (95-99%) while it reduced as the cut-off score was increased i.e., 50 for the second group and 20 for the third group (Fria, 1985).

Dennis et al. (1984) in a study on 200 infants from NICU got 88.5% pass and 11.5% fail rates. Out of the 23 infants who failed, only 10 infants (5%) had sensori-neural hearing loss and seven out of the 10 failed initial screening at 70 dB nHL. In many studies approximately 80-90% of infants pass the ABR screen at 30-40 dB nHL (Galambos, 1984).

The failure rate in intensive care units are observed to be high when infants are first tested. On repeat evaluation, they usually pass the test (Galambos, Hicks and Wilson, 1984). Cevette (1984); and Finitzo-Hieber (1982); attributed this to middle ear disorder which later resolved before the second test Roberts, Davis, Phon, Reichert, Sturtevant and Marshall (1982) attributed this to maturation of ABR response during the first month of life.

Advantages

It is relatively immune to minor middle ear disorder as mentioned by Cone-Wesson and Ramirez, (1997) and can be obtained via air or bone-conduction stimulation.

Disadvantages

The raw acoustic click routinely used in neonatal screening contains frequencies predominantly in the 2000Hz - 4000 Hz range and hearing sensitivity for other frequencies is not evaluated.

Morgan and Canalis (1991) said that the time required for infant preparation in terms of electrode placement and other preparations are more. The cost per infant also is high. The interpretation of the responses are subjective.

Occasionally electrical interference may occur with other equipment and thus it might be difficult to use this in an intensive care unit (Stach and Santilli, 1998).

ii) Automated ABR Screening (AABR)

Natus Medical incorporation was the first company to offer a commercially available AABR hearing screener, the ALGO (Stach and Santilli, 1998; Erenberg, 1999; Weber, 1988). The approach is designed to be easy to administer as pass/fail decision is automatic.

AABRs are suitable for infant hearing screening.

The ALGO device is designed to present click stimuli at a fixed intensity level record ABR tracings and compare the recorded tracing to a template that represents expected results in neonates (Stach and Santilli, 1998 and Erenberg, 1999). The ALGO system has many fail safe mechanisms that halt testing in the presence of excessive environmental or physiological noise. When all the conditions are favourable, the device proceeds with testing until it reaches a decision regarding the presence of an ABR. It then alerts the screener as to whether the infant has passed or needs to be referred for additional testing (Stach and Santilli, 1998).

ALGO-1

It is a battery operated microprocessor dedicated solely to newborn ABR screening (Kileny, 1988; Weber, 1988).

Stimulus

Click stimuli are presented automatically at 3 5 dB nHL and at a rate of 37/sec. (Weber, 1988).

Test method

Click stimuli are presented automatically whenever the electrode impedance, ambient noise level and movement artifacts are all within acceptable limits. As the stimuli are being presented to the baby, the ALGO-1 plus is comparing the accumulated response in memory with an internal nine-point template of a neonatal ABR. When the likelihood of a response reaches a predetermined criterion level, the test stimuli automatically cease and a display panel indicates mat the baby has passed the hearing test. If the likelihood of response is not sufficiently high at the end of 15,000 sweeps, testing is automatically halted and the display panel indicates that the baby should be referred for further testing (Kileny, 1988). Average time taken to screen using ALGO-1 is 8 minutes (Erenberg, 1999).

Advantages

- Training to use the instrument takes less time . The instrument is portable (Erenberg, 1999).
- No audiologists needs to be present throughout the testing.
- The cost is less compared to other ABR test units (Weber and Jacobson, 1994).
- It is fully automatic and very conservative (Weber, 1988).
- It will not begin a test run if ambient noise, electrical interference or movement artifact exceed predetermined levels (Weber, 1988).

Disadvantage

The recording requirements being stringent may preclude testing in some environments.

Sensitivity and Specificity

Erenberg (1999) reported the sensitivity to be 93% and specificity, 78%. The overall efficiency is 83%.

In a validity test done by van Staaten et al, (1996), they reported a sensitivity of 100% following the first and second ALGO-1 screening. Specificity after the first screening was 94% and 100% following the second screening. It has excellent sensitivity and low failure rates (Stach and Sanitille, 1998).

The ALGO-1 AABR screener was found to be an effective and safe method for detecting hearing loss in infants in N1CU.

100% sensitivity was reported by Hall et al. (1987X Jacboson, Jacobson and Spahr (1990) and Hermann, Thornton and Joseph (1995). Specificity ranged from 78% to 98%.

ALGO-2

ALGO2 differs fromALGO-l m terms of the algorithm used. InALGO-2, a binomial sampling is employed. It statistically determines the presence of noise and response at 99% confidence. Further, the two differs in terms of the patient preparation and time taken for testing with the ALGO 2 taking lesser time. The procedure also differs in the patient preparation procedure and time taken for test administration.

ALGO-2 is a screener designed for use only with infants. Consequently, it can only be used for screening newborns. It is a microprocessor controlled device which uses a dual artifact reject system to control both environmental or ambient noise and muscle artifact Ambient noise sensor detect background noise under the ear coupler and each data sweeps is accepted only if SNR exceeds 10 dB.

Test stimulus

As it is intended to be a completely automated system, the ALGO-2 is designed to have very little flexibility. It is possible to screen at either 35 dB or at 40 dB and 70 dB. Both ears can be screened simultaneously or individually.

Test method

ALGO-2 matches the ABR to a template derived from the wave forms of normally hearing neonates to 35 dB nHL click stimuli. The algorithm employs binomial sampling and a statistical test to determine that data collected sufficiently discriminates between the presence of a response and noise versus pure noise at above 99% level of confidence (According to National Center for Hearing Asessment and Management 2000).

Advantages

The National Center for Hearing Assessment and Management (2000) UTAH State University has given the following advantages of ALGO-2.

- Time taken for screening is about 15-40 minutes which includes preparation of infant upto recording of results.
- Referral rates are low with an average of about 4%.
- ALGO-2 screens babies in noisy settings but it may slow down data collection. This is because an artifact reject systems automatically interrupts data collection when ambient noise is above 50 dB SPL at 2000 Hz and automatically resumes when conditions meet criteria again.
- Due to the algorithm used (nonparametric binomial probability approach), electrode impedance can be assessed at a significantly higher frequency.
- Skin preparation is not required thus saving time and patient distress.
- Earphones are designed to allow visualization of the auricles, thus assuring proper placement on the ears (Stach and Santilli,1998).

Disadvantages.

- The National Center for Heading Assessment and Management (2000) have mentioned that children with mild sensory loss may be missed.
- No frequency specific information is obtained with ALGO-2
- It can be used for only screening new borns and it cannot be used for diagnostic purpose
- Infants with 25-30 dB toss, high frequency loss, reverse slope loss or precipitous losses may be missed.

Referral rates

The children who have normal hearing, but are referred for further diagnostic evaluation ranges from 1% toI0% with an average of about 4%. This report was given by National Center for Hearing Assessment and Management (2000). The device has high sensitivity and specificity.

AABR's are the most recent objective screening devices and research needs to be carried out using it, to determine its usefulness with different population.

c) ACOUSTICIMMTTTANCE MEASURES

Described by : Keith (1973, 1975) was one of the first to investigate immittance audiometry in neonates. Brookes (1969) has explained the efficacy of tympanometry and associated acoustic immittance measure for screening middle ear disorders.

Age: even; though it can be used with any age group, the test is not preferred for infants below seven months of age The best age group suited for this test as said by Margolis in 1978 & Paradise, Smith & Bluestone in 1976 is six months to 24 months where middle ear effusion has high incidence and prevalence.

A combination of tympanometry and acoustic reflex measurements can be used for screening. American Speech and Hearing Association (ASHA) in. 1979 recommended a combination of tympanometry & acoustic reflex measures which resulted in 'pass', 'at risk' or 'fail' outcomes. The Nashville Task Force recommendations included similar criteria as ASHA (1979) and differed only in terms of referral criteria. The revised ASHA guidelines in 1990 and 1997 do not include measures of tympanometric peak pressure and acoustic reflex.

Probetone in tympanometry

A low frequency probetone of 220 Hz was always preferred to a high frequency probetone. (Callison, 1999; Sprague, Wiley & Goldstein, 1985; Margolis & Shan, 1985).

Margolis & Shan (1985) advocated the use of 220 Hz, as the outer ear volume and susceptance is exaggerated at 660 Hz and it becomes less sensitive for the detection of middle ear effusion.

Responses

In tympanometry, the various parameters like static compliance, ear canal volume& tympanogram width are recommended to be used as a criterion for middle ear screening (ASHA, 1997).

Static compliance

ASHA (1990) and Margniis & Heller (1987) gave the mean static compliance in preschool children as 0.5mmho. ASHA (1997) suggested that normal compliance should be above 0.2mmhG for infants

Keith (1975) reported a range of 0.25 to l.65cc in neonates between 2 and 1/2 to 20 hours of age as lots of variations are reported in this age group. Jerger,, Jerger & Mauldin (1974) in a study of children less than six years of age, found a median compliance of 0.5 5cc.

From all these studies reported, a cut-off criteria of 0.2 mmho can be given for infants above seven months upto six years of age. This cut-off is suggested so that no child with a deviant static compliance is missed out.

Equivalent ear canal volume

It is an estimate of volume between the probe tip & the tympanic membrane. The normal range in young children is 0.4 to 0.9cm^3 (Shanks, Stelmachowicz, Beauchaine & Schulte, 1992). Margolis & Heller (1987) gave the range as 0.4 to 1.0 cm^3 as the cut-off score for impedance screening.

Not much of variations are found in most of the studies. A cut-off criterion of 1.0 cm^3 can be taken as the cut-off score in infants.

Middle ear pressure

The tympanometric pressure varies widely in children with normal middle ear systems, with as many as 25%of children having values of -250 daPa during some seasons Lidholdt, 1980). Due to the amount of normal pressure variation, current screening guidelines suggest that tympanometric peak pressure need not he used as a criterion for screening.(ASHA, 1990; ASHA,1997).

Tympanogram width

An abnormally wide tympanometric width of greater than 150 daPa is considered abnormal (Margolis & Heller, 1987). ASHA (1997) has given the cut-offpoint of 150 daPa.

A negative predictive value of 61% was reported by Karzon (1991) based on a study done on children 3—5 years of age.

A cut-off criteria of 150 daPa can he used for middle ear screening.

ASHA (1990) and ASHA (1997) has recommended to check the pattern of tympanogram, the ear canal volume, static compliance and tympanometric width for middle ear screening.

Acoustic Reflex Measurements

Callison (1999) reported that the acoustic reflexes in neonates have been reported to be significantly different when compared to normal adults. He added on that with the use of high frequency probe tones, acoustic reflexes can be compared to normal adults at 4 months of age.

Probe tone

Most of the studies have recommended the use of high frequency probe tone usually 660 Hz, for acoustic reflex measurement (McCandless & *Allred,* 1978).

Stimulus Frequency

Earlier when used for screening, Bennett (1984) recommended to use a 1400 Hz pure tone, McCandless and AUred (1978) suggested a stimulus frequency of 500 Hz and 1 kHz.

Berlin and Hood (1987) have recommended the use of broad band noise.

As the false positive rates are very high, acoustic reflex measures were excluded from the 1990 and 1997 ASHA guidelines for middle ear screening.

A few studies have suggested that acoustic reflex measures may increase the sensitivity and specificity for identification of middle ear disorders, particularly when combined with selected tympanometric measures (Silman, Silverman & Arick, 1992).

Thus further research needs to be done to decide whether the acoustic reflex needs to be taken as a middle ear screening criterion.

Referral Criteria

In ASHA (1979) protocol, some cases were recommended for medical referral on the basis of initial immittance findings. Nashville guidelines recommended rescreenittg all individuls with abnormal tyropanometac results 4 to 6 weeks after the initial test was failed. Revised guidelines of ASHA (1990) never recommend immediate medial referral on the basis of initial immittance findings alone. When tympanometric results are abnormal, rescreening is done after 4 to 6 weeks. If results are again abnormal an audioiogical/medical referral is made. The referral criteria remained unchanged for ASHA (1997) guidelines.

Sensitivity and Specificity

Nozza, Bluestone, Kardatzke & Bachman (1994) compared the ability of aural acoustic immittance measures and otoscope in the identification of middle ear effusion. They concluded that of the individual admittance variables, tympanometric width had the best performance. Otoscopy had good sensitivity and fair specificity. On combining both the procedures, an increase in specifificity without a change in sensitivity was found. They used a cut-off score of 0.2 ml for static compliance and found the sensitivity as 46% and specificity as 92%. When the cut-off score was taken as .03 mi, sensitivity improved to 70%, but specificity was dropped to 85%.

Robinson & Allen (1984) attempted to demonstrate potential racial difference in tympanometric results with 253 children from day care centres. Their purpose of study was to provide data on middle ear dysfunction, as inferred from tympanometry, across and within black and white middle cases pre school children between 30 and 48 months of age. Results showed that black children have significantly less middle ear dysfunction. At the same time both races showed a high risk for failure of tympanometry at younger age.

Margolis & Heller (1987) followed 210 infants during the initial 2 yeais of life with routine pneumatic otoscopy and immittance. In this study, tympanornetry proved to have high specificity (86%) and low sensitivity (58%). On the other hand moderately high sensitivity and tow specificity have been reported by Lous (1982), Paradise & Smith(1978),Roeser and Northern(I988).

Paradise, Smith & Blustone (1976) reported the immittance sensitivity with otoscopy as the criterion measure. They gave it as 94% and 97% respectively while specificity was 42% and 61% respectively.

A validity study of impedance tympanoscope versus impedance audiometer Z7 was done by Molter & Tos (1992). The fully automated screening impedance tympanoscope was compared with a clinical impedance audiometer. The study done on SI normal children found that using the automatic screener, there was a significantly higher prevalence of type B tympanogram They attributed the difference to the different ways in which a type B tyumpanogram was defined. The high prevalence of B type was seen at the expense of type C tympanomtry. The prevalence of B type is 60% in the age range of 1-2 years. They reported poor test-retest-reliabithy in tympanoscope even though the pressure is measured with 30 seconds.

Birch, Elbrond & Kristiansen (1986) did a comparative study between the different parameters using impedance audiometer ZO73A and tympanoscope ZS339. In terms of middle ear pressure, the tympanscope measured reduced values static compliance measures had a good compliance in 68% of ears. They concluded that when middle ear pressure is measured by impedance audiometer ZO73A, the result obtained is lower than actual. In terms of compliance, the tympanscope, ZS330 gave lower values than actual for low compliance, and higher values than actual for high compliance.

Advantages

The procedure is safe, noninvasive and can be executed easily
It often takes only 30 to 60 seconds to complete tympanograms on both ears of infants, If combined with behaviour a screening, impedance tests with infants could result in a high correct identification rate for hearing problems of all types of middle ear disorders (Birch et al, 1986).

Disadvantages

- It has been seen hat head turn, swallowing or even an eye blink may affect the results and they are least controllable in small children.
- Roeser and Northern in 1988 noted that debris and cerumen in the ear has to be removed for valid results.
- Mild to moderate loss cases in Neonatal Intensive Care Unit may be missed out as they have high incidence of middle ear fluid and neurological problems

The main limitation of immittance measurements in young children is that the test battery cannot be completed while the child is vocalizing, speaking, crying, yelling or a combination of these noises. The clinician must devise a technique to momentarily distract the screaming child.

Northern and Downs (1991) found that it is most effective to employ a distractive technique to redirect the youngers attention from the test. While testing infants between 2 and l2 months of age Few of the distractive techniques that can be used with children under 3 years of age are animated toys, cotton swab, pendulum, mirror, toys which produce sounds, watch, shoe, action toys, was of cotton OR kleener or tape. Thus the external disttactive stimuli can be visual, tactile, auditory or a combination of these.

If the diversions fail, a passive restraint of the child's body, head or hands can be applied to complete the test

Even after the administration of distractive toys, if the immittance cannot be measured, an acoustic otoscope/acoustic reflectometry can be used to check for the presence of middle ear effusion.

Acoustic Reflectometry (Acoustic Otoscope)

Described by : It was described by Teele and Teele in 1984.

Age : Children of any age can be tested using this instrument. No age range has been specified in literature. In most of the studies children ranging from two months upto 14 years have been selected (Northern and Downs, 1991).

Test stimuli

The stimuli consists of 100 millisecond multi frequency sweep between 2 kHz and 4.5 kHz at 80 dB SPL (Norther, 1988).

Test method

The examiner aims the speculum in to the childs ear canal and presses the activator button. Once the stimulus is delivered the pick up microphone measures the amplitude of the reflected probe tone from the plane of the tympanic membrane.

The instrument works on quarter wave leagth theory so that the reflected wave completely cancels the principle wave in the external ear canal at a distance of one-quarter wave length from the tympanic membrane. Thus, the reflected sound is inversely proportional to the total sound. For example, a greater reflection produces a reduced amplitude suggestive (Northern, 1988).

Once the button is pressed the instrument is repositioned until highest level of reflectometry is noted on the LED vertical display (Northern, 1988).

The verbal display reading can range from 0-9. A reading of 0-2 indicates normal middle ear, 3-4 represents possible middle ear effusion and above 5 represents middle ear effusion (Sohn and Davis, 1991).

Sensitivity and Specificity

Teele and Teele in 1984 did a study on 260 children who were examined with acoustic otoscope sensitivity scores were 94.99% and specificity 78-83%.

The sensitivity was found to be least when compared to otologtc examination puce tone screening and immittance screening (Buhrer, Wall & Schuster, 1985).

Holmes, Jones, Muir &. Kemeker (1989) said that the instrument has high positive sensitivity, but low specificity rates.

Lampe, Weir, Spier and Rhodes (1985) compared the results with tympanocentesis and myringotomy in 75 patients between 6 montths and 13 years off age. *They found* that with five as the cut-off point, 87% was the sensitivity and 70% specificity.

Kenworthy, Bess &. Wright (19X6) discussed evaluating infants below 12 months of age using reflectometer using smaller experimental tips of 6.25, 4.5 and 3.0cm.based on their initial evaluation from 36 ears, agreement between otoscopic examinations and reflectometry results are approximately 60%.

Advantages

Buhrer (1985) and Northern (1988) said that,

It is a simple, noninvasive screening instrument to identify middle ear fluid in children.

No hermatic seal is required at the ear canal.

The test can be conducted with in co-operative children who are crying or can be used even when the ear canal is obscured partially with wax.

Training needed to operate the instrument is minimum.

Disadvantages

General pathologies of the ear other than middle ear effusion cannot be identified using this technique (Northern, 1988)

The instrument is commercially available and costs about Rs. 13,000 in India.

Thus it can be seen that acoustic reflectometer can be used in young children and the physiological state of the child does not affect the measurement. The sensitivity and specificity rate is also found to be relatively high when compared to immittance.

III. SPEECH TESTS IN HEARING SCREENING

Speech tests specifically meant for screening are very few. Most of the tests are designed for finding the speech reception threshold. Since these tests are simple, they can be used for hearing screening also. In the following sections, some of these tests are described.

a) The Ling's Five sound test

Developed by : The test was developed by Ling (1978)

Age : The test can be used with young children.

Test stimuli

The test makes use of three vowels /u/, /a/ and *l\l* and two consonants /sh/ and /s/. According to Ling, these sounds cover the frequency range of all phonemes and the vowels and contain sufficient harmonics to convey suprasegmental information (Ling, 1978).

The test is mainly used for a daily hearing and check, but it can be modified for hearing screening.

Response

The child has to repeat the sounds after the tester.

b) The Ling 7 sounds test

Developed by : the Ling's 5 sound test was modified in 1996 to incooperate seven sounds. These sounds cover the entire range of frequencies used in English speech. They can be used for hearing screening.

Age : Detection tasks can be used for children as young as 18 months 'Identification' and 'consonant babble' tasks can be used with older children.

Stimulus : the seven sounds to be detected are /rn/, /ah/, /ee/, /oo/, /or/, sh/ and /s/. The stimulus are recommended to be presented at supra threshold level for hearing aid checking. It is suggested that if the test is to be used for hearing screening, the signal may be presented at about 40dB HL. The usefulness of this would however have to be established.

For children who find the seven sound test too easy, Ling, 1996 suggested using a "consonant babble task". The stimulus used are in such a way that vowels and consonants are used to broaden the range of spectral cues and to form a stimuli which varies in only one formant. A few of the syllables are /bah/, /tee/ /ork/, /uhs/, /shoo/, /may/, /no/, /lah/, /choy/, /dow/.

Response :

For the detection task, children may respond by a gross physical response like placing rings on to a tower, placing large colourful blocks into a box, saying 'yes', building towers, tapping the table, pressing buttons etc.,

In the identification task younger children may respond by a picture pointing task and older children by repeating after the tester. Repetition response is required by the 'consonant babble' task also.

c) **The Cooperative Test**

Developed by : The test was developed by McCormick in 1994.

Age : The test can be used with children from 1 ½ years to 2 ½ years (McCormick, 1994).

Test stimulus

Test stimulus includes simple instructions such as 'Give this to teddy' 'take the duck' etc., Even though the test was given to find the minimum listening level, it is suggested that it can be modified for screening purpose by keeping the presentation level constant at about 35-40 dB HL after demonstration. Demonstration trials can be carried out at high intensities and screening can be done at lower intensity. The usefulness of this screening procedures would have to be checked, before it is implemented.

Test Method

Demonstration trials can be carried out with visual clues and at loud intensities. Once the child is familiar with the task, visual clues will be removed and instructions will be given at low intensities.

Sensitivity and Specificity

McCormick has mentioned that to increase the sensitivity of the test it is desirable to choose items with the same number of syllables and with acoustic similarities. Sensitivity and specificity of this test has not be mentioned in literature.

Advantages

Children find the activity interesting.

Disadvantages

- More cooperation is required and tester should have more skill in conducting the test (McCormick, 1994).

d) Four - Toy Eye Pointing Test

Described by : The test was described by McCormick in 1988.

Age range : This test can be used for children between 18 months and 30 months.

Stimulus

Two pairs of items are selected from McCormicks Toy Discrimination Test eg. Cup/duck and child is asked the question 'Where is the spoon?" or "Look at the cup". Items selected should be from the child's vocabulary. No set pattern is followed and no visual clues are given to the child (McCormick, 1994). The tester should use a loud conversational level of voice initially and at this stage the child is permitted to watch the tester's face. Then the test can be done at normal conversational level i.e. 40 **dB HL.**

Response

Child has to respond to the question by looking at the toy. Ther esponse should be recorded when the eyes have fixed on one item. A few test trials can be given at higher intensity, but while screening at 40 dBA the intensity is kept constant (McCormick, 1994).

Advantages

The response does not require a pointing task. So minimum cooperation is needed from the child.

Disadvantages

The tester may give premature praise as the child's eyes glance across the toys.

As only four items are used at a time there as a 25 per cent probability of a chance response (McCormick, 1994).

e) The Toy Discrimination Test

Developed by : The test was developed by McCormick in 1977.

Age : The test can be used with children whose mental age is above two years (McCormick, 1977).

Test Stimuli

Stimulus used are paired items of monosyllables with maximum degree of acoustic similarity (McCormick, 1994). Test consists of 14 toys presented in 7 pairs. They are presented initially in free field situation, then using bone vibrators and finally earphones can be used.

Trial presentations will be given at higher levels (50-55 dBA) and once the child is familiar, screening will be done at a lower level i.e. 35-40 dB HL. McConnell and Ward (1967) has noted that children between 21 and 24 months respond to speech stimulus at 5 dB HL. For speech recognition, higher intensity levels will be needed. So it can be done at 35-40 dB A. McCormick (1994) said that children with normal hearing can identify at 40 dB A i.e. at normal conversational level.

Test Method

This is a finger pointing task in response to the stimulus. An automated version is also available which has a button control for presentation and recording of responses. Selection of speaker and choice of warble tones, with frequency selection and level controls in ten five, two and one dB steps is also present (Palmer, Sheppard and Marshall, 1991).

Sensitivity and Specificity

The McCormick test was compared with other standardized tests like tympanometry and audiometry. Sensitivity was found to be 100% and specificity was 94% (Harries and Williamson, 2000). But this result cannot be generalized as the study was done on only 14 children.

Advantages

McCormick (1994); Harries and Williamson (2000) noted that the failure rates are less in this test and mild unilateral conductive hearing loss can be detected when used as a diagnostic test. Harries and Williamson in 2000 also said that when carefully administered in screening, using headphones, unilateral hearing loss can be identified.

Disadvantages

- The test needs cooperation from the child
- The test cannot be used with children with speech and language delay (Harries and Williamson, 2000).

f). Reed Screening Hearing Test

Developed by : The test developed by Reed in 1959.

Age : The test can be used with young children who can comprehend simple commands and is familiar with pictures of common animals and objects i.e. approximately 2 years of age.

Stimulus

The test consists of a set of cards, each one containing four pictures. The pictures each depict a single object which have different consonants but vowel is kept constant. Monosyllabic words are used. Eg. house, cow, owl, mouse. There are eight cards in all (Markides, 1987). Stimulus is given at normal conversational speech first and then whispered speech.

Test Method

The child is required to point to the picture that is named eg. 'Show me the cow'. A practice trial with the tester in front of the child is done to ensure that the correct names are associated with the pictures and also to make sure that the child understands the test. Then the test is repeated with the tester six four cards are used and if the child fails to select the correct picture for more than 2 consecutive trails, the child should be referred for a full audiometric examination. If the child is successful the test should be repeated with a whispered voice and should be referred if it fails on more than one or two pictures.

Sensitivity and Specificity

No literature is available regarding the sensitivity and specificity of the test.

Advantages

No expensive equipments needed to conduct the test.

Disadvantages

As speech is used as the stimulus, child should know the language spoken (Reed, 1959).

- The exact presentation level cannot be controlled as no instrumentation is used. This can be overcome if an audiometer is used.

g) **The Kendall Toy Test (KT Test)**

Developed by : Kendall (1953)

Age : K.T. Test was intended for very young children of three to five years old who have moderate vocabulary (Markides, 1987).

Stimulus

This is pointing task for the child for instructions like "show me the ....". The test material consists of three lists, each list containing 10 monosyllabic words which are represented by small toy replicas. Test is conducted in a free field situation (Markides, 1987).

Level of presentation can be monitored using a sound level meter situated near the child's ear. The vocabulary of the child is tested. Five additional test items are taken to conduct test trials and to lessen the possibility of chance response.

The test needs to be conducted at higher intensities, probably 30-35 dB, as they need to be identified.

Response

The child has to carry out the given command with the help of auditory clues.

Sensitivity and Specificity

Has not been mentioned in literature.

Advantages

- The level of presentation can be monitored.

  As test trials are given, the possibility of chance responses are reduced (Markides, 1987).

Disadvantages

Unilateral hearing loss cannot be detected. In children who are cooperative the signals may be presented through an audiometer with the output given through headphones. This will enable the detection of unilateral hearing loss. (Kendall, 1953).

h) Verbal Auditory Screening Test for Preschool Children (VASC)

Developed by : The VASC was developed by Griffing, Simonton and Hedgecock(1967).

Age : It is used with preschoolers in the age range of 4 to 5 years.

Test Stimuli

The test utilizes a board with pictures representing 12 spondaic words. The words are recorded by a male voice. The initial word in each list is presented at 51 dB, with each subsequent word presented at a 4 dB attenuation rate. The last three words are presented at 15 dB (Griffing, et al., 1967).

The test examines hearing from 100 to 7500 Hz. VASC-2 which is an experimental model contained bird whistle at 51, 47, 23 and 15 dB levels and lion roar at 51 and 31 dB. (Ritchie and Merklein, 1972).

Test Procedure

Test procedure is closed-set picture identifying task. The child is required to point to the appropriate picture in the board, place in front of him. The examiner records the child's responses as "correct", "incorrect", or "no response" by making an appropriate notation on a check-off sheet.

False Positives and False negatives

In a study done by Mencher and McCulloch (1970) the false positive rate was found to be low and false negative rate was comparatively high. They obtained this by comparing the results of VASC to an audiometric screening carried out using pure tones at 20 dB.

Ritchie and Merklein (1972) noted the false positive rates at 4.1% whereas Griffing, et al., (1967) found to be 7.8%.

Advantages

Griffing, et al., (1967) indicated that 89.7% of preschool children can be accurately detected having hearing loss by verbal screening.

Disadvantages

The test may miss children with mild hearing loss (30-40 4b) as mentioned by Mencher and McCulloch (1970). Even though the tests called verbal auditory screening test, non-verbal sounds like bird whisle and lion roar were used in the second version (VASC-2) (Ritchie and Merklein, 1972).

SUMMARY

From the review on hearing screening procedures, it is evident that the screening procedure differs for each age group. The sensitivity and specificity also varies from test to test.

Table - IV gives a summary of the various screening procedures that have been recommended for infants and children.

Though details regarding the procedures for tests such as Behaviour Observation Audiometry, Visual reinforcement audiometry and Tangible reinforcement operant conditioning audiometry have been provided in literature, no specific criteria have been given to use them as a screening tool. Hence, suggestions have been given to utilize the above tests as screening tools. Using the cut-off intensity suggested by several of the Authors (Northern and Downs, 1991 and Wedenberg, 1956) for BOA, there is high chance of missing out children having lesser degrees of hearing loss. Using the cut-off criteria of the present study, they would be lesser chance of this occurring. This is because the suggested cut-off intensity has been reduced as the age of the infant increases. The validity of these suggestions would have to be determined prior to them being put in to practice.

It has been noted that there has been extensive usage of otoacoustic emissions and brainstem evoked response audiometry in the current years. However, the use of otoacoustic emissions has tended to predominate the scenario. This can be attributed to the high sensitivity and specificity of the test, simplicity in carrying out the procedure and time effectiveness. There has been considerable disagreement between the current studies regarding the pass/fail criteria for the test.

Even though ABR's are the most widely recommended screening tool, further research needs to be done on the AABR versions to confirm their validity.

Knowledge regarding the different hearing screening procedures is essential for all audiologists. The project would enable the audiologist to choose the most appropriate procedure for a particular are group.

Non-Verbal Procedures

I. Subjective Techniques

Method	Author	Age range	Sensitivity	Specificity	False negatives	False Positive	Stimulus	Cut-off criteria
Behavioural observation audiometry	Recommendation of present study	0 to 1-2 years	- -	- -	40-86% -	- -	Warbled tones, noise, speech	Below 4 months - 70 dB 4 months - 1 years - 50 dB Above 1 year - 30 dB
Visual reinforcement audiometry	Recommendation of present study	6 months -2V2 years					Puretones, band pass noise, speech	20 dB
Tangible reinforcement operant conditioning audiometry	Recommendation of present study	2-4 years	-	-	-	-	Pure tones	20 dB
Conditioned play audiometry	Utley (1949)	Up to 4 years	-	-	-	-	Pure tones	20 dB
Pure tone audiometry	ASHA (1990)	Upto5 years	-	-	-	-	Pure tones	20dB for 1 kHz, 2 kHz, & 4 kHz
	Northern & Downs (1984)		-	-	-	-	Pure tones	25 dB
Audioscope	Bienvenue et al, (1985)	Above 3 years	15-95%	50-73%	-	-	Pure tones	25 dB

II. Semi-objective techniques

Method	Author	Age range	Sensitivity	Specificity	False negatives	False Positive	Stimulus	Cut-off criteria
Crib-O-gram	Hayes & Northern (1996)	Infants above 38 weeks	91%	82%	-	13.8%	Band pass noise centered at 3 kHZ	92 dB SPL noise with 700 Hz band width
Auditory response cradle	Bennett (1975)	Infants			-	-	Band pass noise	85 dB SPL noise 2.6 to 4.5 kHz
Accelerometer recording system	Altman et al,(1975)	Newborns				-	1/3rd octave noise band	90 dB SPL at center frequency 3150 Hz

III. Objective technique

Method	Author	Age range	Sensitivity	Specificity	False negatives	False Positive	Stimulus	Cut-off criteria
OAE	Kemp (1978)			-			-	
1 ransient cvukcu otoacoustic emissions	National consortium on newborn hearing screening (1995)	> 108 hrs		-	-	-	Clicks	At moderate intensity level, 50% or more reproducibility in 1600 Hz band width and 70% or more in 2.4, 3.2 and 4 kHz bandwidths. Emissions recorded should be 3 dB above noise floor.
	Sabo et al,(2000)		65%	91%		▪	▪	-
	Dort et al,(2000)	-	85.7%	49.1%	-	-		
Distortion product otoacoustic emissions	National consortium on newborn hearing screening (1995)	> 72 hrs		-			Two primary frequencies f i andf2	Visually the distortion product should be 3 dB above the noise floor in each of the designated frequency regions. The intensity of primary frequencies are L1=60dB, L_2=45dB
	Dort et al (2000)		71.4%	61.4%		-	-	

cont-

Method	Author	Age range	Sensitivity	Specificity	False negatives	False Positive	Stimulus	Cut-off criteria
Auditory brainstem response	Galambos (1972)	>37 weeks	-	-	-	30-50%	Clicks	40 dB nHL
Conventional **ABR**	Mason (1988)	Neonates	82%	93%				40 dB nHL
	ASHA (1990)							40 dB nHL
	Dennis et al, (1984)							30 dB nHL
	Shannon et al. (1984)							25 dB nHL and 65 dB nHL
	Fria (1985)							30 dB nHL and 60 dB nHL
	Callison (1999)							30 dB nHL and 60 dB nHL
ABR	Kileny (1988)	Neonates	100%	94%	-	-	Clicks	30 dB nHL
	Van Staaten et *al* (1996)		93%	78%			Clicks	35 dB nHL
| Immittance	ASHA (1997) and ASHA (1990)	Infants above 7 months	-	-			Probe tone of 220 Hz for tympanometry and 660 Hz for acoustic reflex measurement	Static compli < 0.2mm ho equivalent ear canal vol. > 1.0 cm^3. Tympanometric width > 150 dapa. Tympanogram 'A'
| Reflectometry	Lampe etal1985)	88%	83%		-			Reflectometer value of 5

Cont'

Verbal Frocedures

Method	Author	Age range	Sensitivity	Specificity	False negatives	False Positive	Stimulus	Cut-off criteria
Ling 5 sound test	Ling (1978)	Young children			-	-	3 vowels /a/ *I'll* *l\xl* and 2 consonants /s/ /sh/	35 - 40 dB
Ling 7 sound test	Ling (1996)	Young children	-			-	*/m/*, /ah/, *ltd*, *loot*, /or/, /sh/ and *Is/* for "detection task"	
The co-operative test	McCormick (1994)	*1 ½-2 ½* years			-	-	Instructions like "Give this to Teddy". It is a "giving game"	35-40 dB
4 Toy Eye pointing test	0McCormick (1988)	*1 ½-2 ½* years				-	2 pairs of items from McCormicks discrimination test	35-40 dB
Toy discrimination test	McCormick (1977)	2 years	-		-		Monosyllables with maximum degree of acoustic similarity	35-40 dB HL
	Harries and Williamson (2000)		100%	90%		-		
Reeds screening hearing test	Reed (1959)	Approximately 2 years		-		-	Picture card of objects with same vowel and different consonant	Whispered speech

cont.

Method	Author	Age range	Sensitivity	Specificity	False negatives	False Positive	Stimulus	Cut-off criteria
Kendall toy test	Kendall (1953)	3-5 years	-	-	-	-	10 mono syllabic words	Normal conversation level
Verbal auditory screening for pre school children	Griffing et al, (1967)	4-5 years	-	-	-		12 spondee words	15 dB
	Ritchie & Merklein (1972)					4.1-7.8%		

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