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Review article

OBJECTIVE AND BEHAVIOURAL TESTS FOR AUDIOLOGIC ASSESSMENT OF CHILDREN WITH SUSPECTED HEARING LOSS

Abstract:

Audiologic assessment of infants and young children with suspected hearing loss requires selection of differential diagnostic techniques that are age-appropriate and appropriate to the child's developmental capabilities.

Objective assessment includes electrophysiologic and electroacoustic methods: otoacoustic emissions, auditory brainstem response, auditory steady-state response, tympanometry and acoustic reflex. The use of behavioural methods in audiologic assessment requires a response from the patient. Depending on the child's age, the following methods can be performed: visual reinforcement audiometry, conditioned play audiometry, pure tone audiometry, and speech audiometry.

Audiologic assessment in infants and children provides estimation of auditory sensitivity, evaluation of the integrity of auditory system andidentification of possible intervention options in case of existing hearing loss. Early detection and treatment of hearing loss in childhood is essential to ensure optimal speech and language development in the early years of life and optimal school performance for older children.

Keywords: *audiologic assessment, children, hearing loss*

Introduction

Childhood hearing loss not only affects speech and language development but also cognitive, social and emotional development (Albert, 2007).The most common type of hearing impairment in childhood is transient conductive hearing loss due to middle ear effusion (Zahnert, 2011).Most retrospective studies have shown a prevalence of permanent sensorineuralhearing loss 1.1 to 1.7 per 1000 children (Davis, Davis and Mencher, 2009).Early detection of this hearing loss is necessary for early intervention via cochlear implantation which has a positive effect on the speech and language development of children. For development of children, especially important is implantation before 12 months of age (Lorens, Obrycka and Skarzynski, 2021).

The goal of the initial diagnostic assessment of infants and young children is to confirm or rule out hearing loss, as well as to quantify the extent and configuration of hearing loss. Hearing loss can be detected through hearing screening programs or as a result of audiologic assessment because ofthe parents' concerns.

The use of age-appropriate techniques in diagnostic audiology is vital in the evaluation of infants and young children. It requires selection of differential diagnostic techniques that are within the child's developmental capabilities. Because children undergo rapid sensory, motor, and cognitive development and because some children have multiple health concerns and subsequent developmental challenges, it is important that assessment tools are appropriate for the neurodevelopmental status of the child. Physical and cognitive factors that can influence developmental status must be considered prior to the selection of an assessment strategy (Diefendorf, 2015). Audiologic assessment of children with suspected hearing loss includes objective and behavioural methods.

Objective tests for audiologic assessment

The objective audiologic assessment can be performed for children of any age as no contribution to the testing process is required by the child. Objective assessment includes electrophysiologic and electroacoustic methods: otoacoustic emissions, auditory brainstem response, auditory steady-state response, tympanometry and acoustic reflexes (Gelfand, 2016).

Otoacoustic emissions

Otoacoustic emissions (OAE) are sounds emitted from the outer hair cells of a normally functioning cochlea. OAE can be spontaneous or evoked. Evoked OAE occur in response to acoustic stimulus. The presence of OAE indicates hearing threshold of 20-40 dB HL (Elloy and Marshall, 2011). OAE are propagated through the middle ear and into the ear canal where they can be measured using a sensitive microphone (Prieve and Fitzgerald, 2015).

Distortion-product otoacoustic emissions (DPOAE) and transient-evoked otoacoustic emissions (TEOAE) are the most frequently used in clinical praxis and screening protocols. In DPOAE, two tones are presented at different levels and frequencies. The relationship between their frequencies is selected to elicit a response in the cochlea at a third frequency, where the DPOAE occurs. Different combinations of frequencies prompt responses from different frequency regions of the cochlea (McCreery, 2013). TEOAE are elicited by brief stimuli such as clicks and provide information about outer hair cell integrity across a broad range of frequencies (Mertes and Goodman, 2013). Whereas TEOAE more qualitatively assess cochlear function, DPOAE provide quantitative information about the range and operational characteristics of the cochlear amplifier, i.e. sensitivity, compression, and frequency selectivity (Janssen et al., 2006).

The presence of OAE across the speech frequency range indicates a normal function in both the middle ear and cochlea. The absence of OAE without middle ear pathology or acoustic obstruction strongly indicates sensory transmissive hearing loss (Kemp, 2002). In an absent OAE response, there is less than 6 dB of separation between the OAE response and the noise, which is measured at an acceptably low level (Smith and Wolfe, 2013). Expression of DPOAE is significantly affected not only with presence of middle ear fluid, but also in cases of negative middle ear pressure without hearing loss (Ristovska et al., 2017).

DPOAE are frequently recorded in the form of distortion product audiogram (DP-gram) elicited by two primary tone stimuli L1 = 65 dB sound pressure level (SPL) and L2 = 55 dB SPL. DP-grams of a child with present OAE in the right ear and absent OAE in the left ear are displayed in Figure 1.

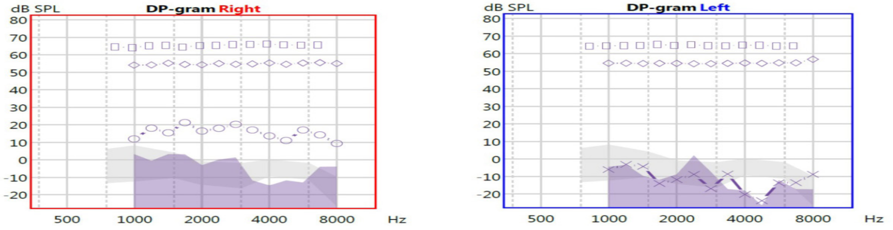


Figure 1. DP-grams of a child with present OAE in the right ear and absent OAE in the left ear

The frequency ratio is adjusted to f1/f2 = 1.22. Levels of the 2f1-f2 DPOAE are registered at frequencies from 1000 Hz to 8000 Hz at four points per octave. DPOAE is considered to be measurable if its amplitude was at least 6 dB above the noise level and minimum -5 dB SPL.

Auditory brainstem response

The auditory brainstem response (ABR) is an evoked potential measurement that allows objective testing of hearing function and an estimate of hearing thresholds in children (Bargen, 2015). The ABR can be measured from the neural pathways of the auditory system using small cup or disposable electrodes placed on the surface of the head. The electrodes are connected to a signal averaging computer that averages the synchronous neural responses occurring within the 8th nerve and brainstem that generate neuroelectric potentials that can be measured from the scalp, much like an electroencephalogram (Kramer and Brown, 2019).

Auditory evoked potentials provide an objective means of assessing the integrity of the peripheral and central auditory systems. For this reason, evoked potential audiometry has become a powerful tool in the measurement of hearing of young children and others who cannot or will not cooperate during behavioural testing. It also serves as a valuable diagnostic tool in measuring the function of auditory nervous system structures. There are four major applications of auditory evoked potential measurement: prediction of hearing sensitivity; infant hearing screening; diagnostic assessment of central auditory nervous system function, and monitoring of auditory nervous system function during surgery. The use of auditory evoked potentials for prediction of hearing sensitivity and infant hearing screening has had a major impact on our ability to identify hearing impairment in children. The ABR is used to screen newborns to identify those in need of additional testing (Stach, 2010).

The observation of an ABR is dependent on *neural synchrony*, which refers to the condition in which a relatively large number of auditory neurons discharge (fire) nearly simultaneously. To achieve neural synchrony, the ABR requires the use of brief acoustic signals with rapid onset times, *transients* (*clicks*) or *tone bursts*. A click has a broadband spectrum, whereas a tone burst has a more restricted spectrum around its centre frequency. The computer measures the neuroelectric activity that occurs during a relatively short time period (10 to 20 ms) after each stimulus. The clinical utility of the ABR is enhanced by the fact that the responses are unaffected by level of attention, sleep-state, or drugs, and can be reliably recorded across all ages, including premature infants. The ABR is characterized by a series of six to seven waves (peaks). The earliest positive wave is called *wave I*, which is a reflection of the synchronous discharge of neurons in the distal (more peripheral) portion of the auditory portion of the 8th cranial nerve as it is leaving the cochlea. The subsequent waves are generated by the synchronous neural activity in the proximal part of the 8th cranial nerve (wave II), cochlear nucleus (wave III), superior olivary complex (wave IV), lateral lemniscus, and input to the inferior colliculus (wave V). *Wave V* is the most prominent wave in the ABR waveform and is the wave most often used for clinical assessment of ABR threshold estimation because it is the only wave present near threshold(Kramer and Brown, 2019).

Auditory steady-state response

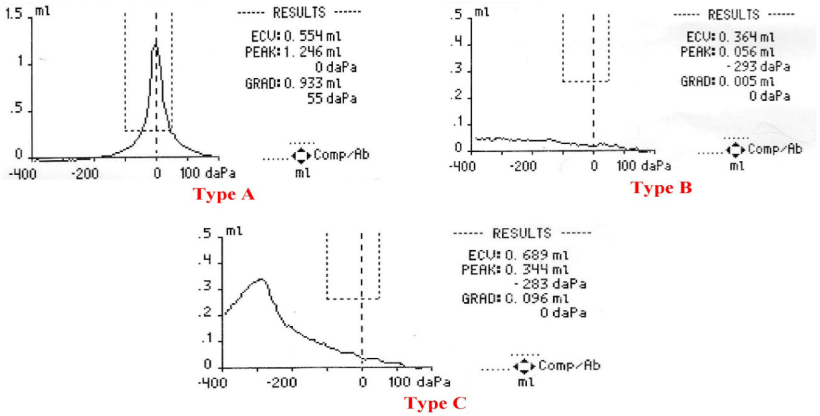
Auditory steady-state responses (ASSR) are evoked brain responses to modulated or repetitive acoustic stimuli. Investigating the underlying neural generators of ASSR is important to gain in-depth insight into the mechanisms of auditory temporal processing (Farahani, Wouters and van Wieringen, 2021). ASSR may provide a more accurate estimation of the configuration of a hearing loss than tone-burst ABR because of the nature of the signal used. This is because a modulated tone usually has a narrower spectrum than a tone-burst, thus providing a more frequency specific audiometric prediction (Stach, 2010)

The ASSR can give information about hearing in a narrow range around each test frequency, and thus provide us with approximations of a patient's thresholds at a variety of audiometric frequencies, such as 500 Hz, 1000 Hz, 2000 Hz, and 4000 Hz. Average ASSR thresholds are within about ≤ 15 dB of behavioural thresholds in normal-hearing listeners, which is also true among those with hearing loss. However, ASSR thresholds are somewhat higher among infants. Thresholds obtained by ASSR are comparable to those obtained by ABR. The ASSR reflects activity from both the brainstem and the auditory cortices, with the response being dominated by the brainstem at higher modulation rates and the cortex at lower modulation rates. An ASSR is considered present if the amplitude and/or phase of the response is reliably related to the modulated tone. This sounds complicated, but the decision is actually automated, being reached according to objective criteria programmed into the measurement instrumentation.The ASSR has several advantages as a clinical tool inaudiology. The ASSR is present from infancy through adulthood, which combined with its resistance to sleep and anaesthesia makes it a valuable tool for pediatric evaluation. The ASSR probably has potential in neonatal screening as well. However, responses are small in newborns and thresholds decrease with age during the first 12 months. Thus, more information is needed before deciding about its applicability in neonatal screening (Gelfand, 2016).

Tympanometry and acoustic reflex

Tympanometry is an objectivemeasure of acoustic admittance of the middle ear as a function of air pressure in a sealed ear canal. Normally, our ears operate most efficiently at atmospheric or ambient pressure. Clinically, it is of interest to measure middle-ear function at greater and lesser pressures compared to ambient pressure for diagnostic purposes because many conditions can affect pressure within the middle ear. Tympanograms recorded from newborn infants are often very different from those obtained from older infants, children, and adults mainly because of ear canal flaccidity in newborns. In neonate ears with confirmed middle-ear disease, 226-Hz tympanograms may not provide accurate diagnostic information. In addition, the variability of 226-Hz tympanometry in young infants because of the presence of M-shaped or notched patterns casts doubt on theclinical utility of these measures for newborns. For these reasons, 226-Hz tympanometry is not an effective test for middle-ear measurement in newborns. Evidence has accumulated that tympanometry using a higher probe tone frequency (e.g., 1,000 Hz) is more sensitive to middle-ear status, compared with 226-Hz tympanometry, in infants less than 4 to 6 months old. Some studies have reported normative data for a variety of young ages, and some have investigated test performance of specific 1,000-Hz admittance criteria in predicting OAE screening results (Hunter and Sanford, 2015).

We displayed the basic three types of tympanograms: Type A, Type B, and Type C (Figure 2).The type A tympanogram curve has a normal maximum height that occurs at a middle ear pressure closed to zero and the width of the curve is normal. It indicates normal middle ear function. Type B curve is flattened, with low static admittance. The most common cause of this pattern is decreased mobility of the tympanic membrane secondary to middle ear fluid – otitis media with effusion (OME). Type C tympanogram shows a highly negative pressure in the middle ear, correlating to a retracted tympanic membrane (Onusko, 2004).



Type A

Type B

Type C

Figure 2. *Types of tympanograms*

Another part of the immittance evaluation is the *acoustic reflex threshold* (ART) test. The ART is done with the same immittance instrument, and is usually performed right after obtaining a tympanogram. The ear has an involuntary middle ear reflex in response to loud sounds that causes a contraction of the stapedius muscles. The acoustic reflex is a bilateral response. A loud tone delivered to one ear will result in contraction of the stapedius muscle in both ears. The contraction of the stapedius muscle alters the transmission of sound through the ossicular chain, hence decreases the admittance of the probe tone. The clinical utility of measuring ARTs extends beyond just the assessment of outer and middle ear pathologies. Abnormalities of the cochlea, 8th cranial nerve, lower brainstem, and/or the 7th cranial nerve may also influence the ability to record an acoustic reflex. For most reflex eliciting tones, the tone level must be at least 70 dB HL to produce a measurable reflex. The normal range for ART is generally considered to be 75–95 dB HL (Kramer and Brown, 2019).

Behavioural tests for audiologic assessment

The use of behavioural methods in audiologic assessment requires a response from the patient. Depending on the child's age, the following methods can be performed: visual reinforcement audiometry, conditioned play audiometry, pure tone audiometry, and speech audiometry (Kreisman, Smart and John, 2015).

Visual reinforcement audiometry

Visual reinforcement audiometry (VRA) uses the infant's natural tendency to turn to a sound source by reinforcing head turns with an attractive visual stimulus, typically an illuminated and/or animated toy. Around the age of 5 to 6 months, the normally developing infant begins to localize to sound on a lateral plane. Once the infant or child is brought under stimulus control, the intensity level of the auditory signal is lowered, and the infant's minimum response level sought. Auditory signals typically include frequency-modulated (warbled) tones, narrow-band noise, and speech (Johnson, 2002).

VRA is routinely used with infants to assess hearing level. This procedure is based on the association of auditory and visual stimuli. There are several recommended test procedures for VRA. One clinical VRA procedure involves presenting the initial auditory stimulus without activation of the visual reward. If the infant generates a head orientation response, the visual reward is then activated (Shaw and Nikolopoulos, 2004).

Conditioned play audiometry

Conditioned play audiometry (CPA) is a term used to describe a technique in which a game is used to obtain threshold information. CPA can be used starting at approximately 24 months of age but is better at 2 to 3 years of age. Play audiometry involves conditioning the child to respond to sound using an activity such as placing a peg in a pegboard, placing blocks in a container, stacking rings on a stick or placing puzzle pieces into a puzzle. Conditioning usually occurs after four or five guided responses or demonstrations. Often a social reinforce, such as clapping hands or praising the child is used to help to establish the conditioning. Using this technique, frequency specific and ear specific information can be obtained to both air and bone conduction stimulation. For very young children or children who have difficulty staying on task, the sequence of frequencies should be presented to optimize obtaining information necessary to predict the contour and degree of hearing loss. Furthermore, complete testing of one ear need not be done before the opposite ear is tested. That is, it may be best to get partial information from both ears rather than complete information from one ear (Sabo, 1999).

Pure tone audiometry

Pure tone audiometry is a basic hearing test. It involves determining the lowest sound pressure levels for various pure tones that the subject can hear. The lowest sound pressure level of the pure tone to which the subject responds in at least 50% of the time, that is, of the total number of presentations, is called the hearing threshold for that frequency. Pure tone audiometry determines the hearing threshold of pure tones with frequencies in the range of 250 to 8000 Hz, which are most relevant for speech sounds. Testing is performed with air and bone conduction of the tones (Kramer and Brown, 2019). Typically developing children aged ≥ 4 years may be sufficiently mature for conventional audiometry (Rosenfeld et al., 2016).

When describing hearing loss, we generally look at three aspects: type, degree, and configuration of hearing loss. There are three basic types of hearing loss: conductive, sensorineural, and mixed (Cunningham and Tucci, 2017). Degree of hearing loss refers to the severity of the hearing loss. It is calculated from the average of thresholds for 500, 1000, and 2000 Hz. There are different classifications in which the upper limit for normal hearing ranges from 15 to 25 dB HL (Schlauch and Nelson, 2015). According to the World Health Organization, degree of hearing loss is defined using the hearing threshold averaged over frequencies 500, 1000, 2000, and 4000 Hz (Stevens et al., 2011). Tonal audiograms with different types of hearing loss are displayed in Figure 3.

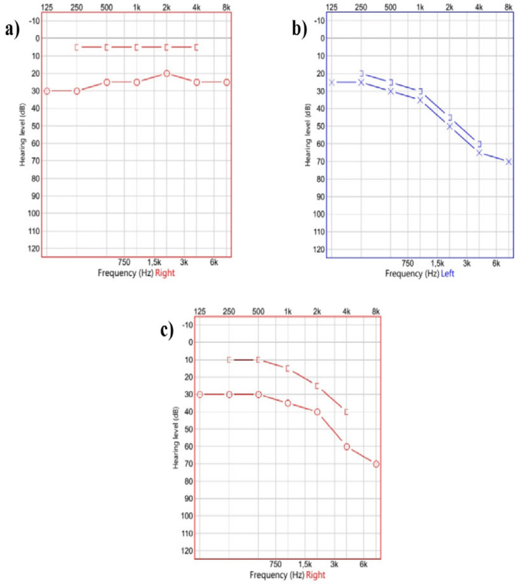


Figure 3. Tonal audiogram with a) conductive, b) sensorineural and c) mixed hearing loss

Audiometric configuration refers to the pattern of hearing loss across frequencies. In general, shape of the audiogram can be defined in the following terms: sloping, rising, flat, notch, U-shaped, and Inverted U-shape (Stach, 2010).

Speech audiometry

Speech audiometry evaluates a person's ability to hear and understand speech (Shipley and McAfee, 2016). The speech stimuli are presented in quiet or with addition of background noise. There are two types of threshold measures using speech stimuli: speech detection threshold (SDT) and speech recognition threshold (SRT). SDT is an estimate of the level at which an individual perceives speech to be present 50% of the time (McArdle and Hnath-Chisolm, 2015). SRT is the softest level at which an individual can repeat back spondaic words 50% of the time (Tye-Murray, 2020). Spondaic words or spondees are two-syllable words with equal stress on both syllables (Bess and Humes, 2008). The most common suprathreshold measure in quiet is word recognition score (WRS) and is generally measured in percent correct at a level relative to the SRT. Word recognition scores are generally expected to be 90 to 100% in normal-hearing individuals. In sensorineural hearing loss the range is from 0 to 100% depending on the etiology and degree of hearing loss. In patients with conductive hearing loss, WRS is typically between 80 and 100% (Gelfand, 2016). In this case, the performance-intensity function shows a parallel shift toward higher sound levels (Figure 4) and 100% comprehension is achieved at sufficiently high levels (Probst, Grevers and Iro, 2006).

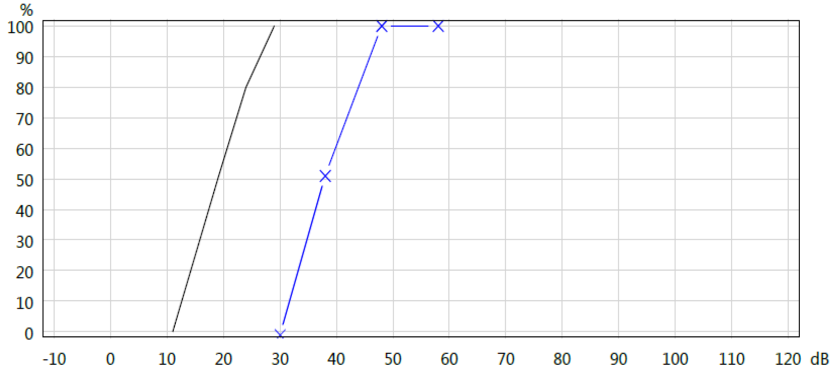


Figure 4.*Speech audiogram of a child with conductive hearing loss*

Speech materials are presented by monitored live voice or recorded speech materials are used (Lawson and Peterson, 2011). The words could be presented in an *open-set* format, which means that the patient must respond without any prior knowledge of what the possible alternatives might be, or a *closed-set* format, which means that the patient is provided with a choice of several possible response alternatives (Gelfand, 2016). It is common practice to utilize a carrier phrase such as “Say the word…” prior to presentation of the word, although this is not always performed (DeRuiter and Ramachandran, 2017).

Conclusion

Audiologic assessment in infants and children provides estimation of auditory sensitivity, evaluation of the integrity of auditory system andidentification of possible intervention options in case of existing hearing loss. Early detection and treatment of hearing loss in childhood is essential to ensure optimal speech and language development in the early years of life and optimal school performance for older children.

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