Methods of hearing assessment in children

Hearing problems can have a significant impact on a child's language and general development, and therefore early detection is important. Doctors dealing with children need to understand the various types of hearing assessment and their limitations.

Neonatal hearing screening has indicated that the prevalence of deafness of >40 dB hearing perception level is around 1/1000 (Fortnum et al, 2001; Coates, 2003; Coates and Harvey, 2003) in the first 28 days; this figure will have doubled by 9 years of age (Hyde, 2005). Each year, around 840 children are born with a permanent hearing impairment, but until recently, around 50% of these children were not identified until 18 months of age, with 25% still left undiagnosed at 3 years of age (Deafness Research UK, 2010). The critical period for development of speech is during the first 6 months of life (Jacobson and Jacobson, 2004). Early detection and treatment of a hearing difficulty during this period plays an important role in limiting the consequences of deafness. Delayed detection of hearing loss can lead to serious consequences for the child's speech, development, education and quality of life (Fortnum et al, 2001).

Studies which took place before universal hearing screening was introduced in 2000 show that the median age of confirmation of hearing loss exceeded 18 months, even in some regions of the UK and USA (Fortnum et al, 2001).

This article reviews the current practice of screening and assessment of hearing in newborns and older children in the UK. Paediatricians, GPs and otolaryngologists should be aware of the current paediatric hearing assessment process.

Hearing tests in newborns and children

Plans for the introduction of universal hearing screening were first announced in the UK, with pilot programmes in 20 sites beginning in June 2000 (Kennedy, 2000; Russ, 2001) and implementation completed in 2006. All children should now be offered hearing screening in the UK. The hearing tests vary according to the age of the child (*Table 1*).

Hearing tests can be divided into electrophysiological and clinical audiological tests.

Electrophysiological tests

Oto-acoustic emission

Definition

Oto-acoustic emission is a physiological test that measures the faint sound generated by movement of the outer hair cells in the inner ear in response to an external stimulus (Hyde, 2005).

Basic physiology

The normally-functioning outer hair cells (*Figure 1*) produce vibrations when they move after exposure to sound. These vibrations pass through the middle and outer ear and can be detected in the external ear canal.

Method of measurement

A well-fitting ear piece, which has a transducer to generate sounds and a microphone which records the resulting response from the outer hair cells, should be inserted into the external ear canal (Ballantyne, 1990). The evoked oto-acoustic emission is a transient response produced when the inner ear is exposed to auditory signals (Graham et al, 2007). The signals are broadband clicks that will produce movement of the outer hair cells across the entire basilar membrane, hence they are not frequency specific. The results can be interpreted immediately by a trained observer. Infants and children must be still and quiet as the small evoked response can be easily obscured by background noise. The automated form of

Table 1. Summary of age and type of hearing test

Age of patient	Test
Neonate	Automated or diagnostic oto-acoustic emission
	Automated or diagnostic auditory brainstem evoked response
	High frequency tympanometry
6 months–2.5 years	Visual reinforcement audiometry
	Tympanometry
2.5–4 years	Play audiometry
	Tympanometry
4–6 years	Play or puretone audiometry
	Tympanometry

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this test is currently used to screen children in the UK. Results are recorded as 'clear response' or 'no clear response' and may be obtained in 1–5 minutes from both ears (Coates, 2003). A positive response is obtained when the difference between the transient evoked oto-acoustic emission and background noise level is >6 dB sound perception level (*Figure 2*).

Figure 1. The organ of Corti and the outer hair cells that are the origin of the oto-acoustic emission.

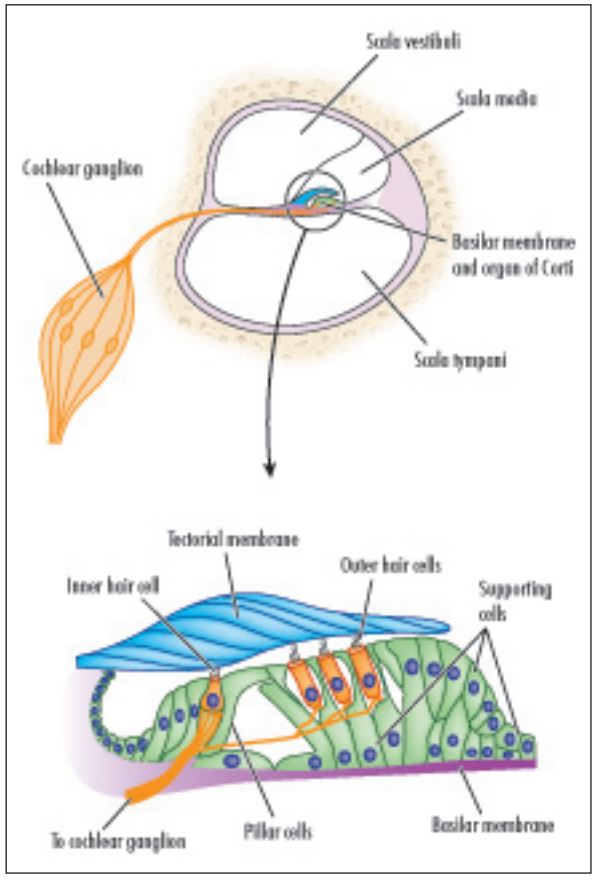
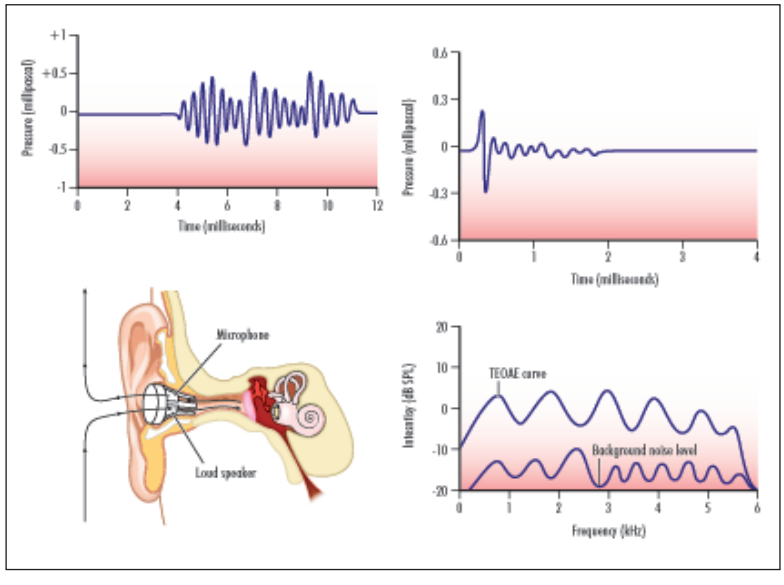


Figure 2. Transient evoked oto-acoustic emission (TEOAE). SPL = sound perception level.



Advantage

Transient evoked oto-acoustic emission is rapid (less than 5 minutes), easy to perform (Yin et al, 2009) and is an objective test that is highly sensitive and is not affected by the patient's state of arousal, providing he/she is still and quiet throughout testing.

Disadvantage

A clear response indicates a hearing level of 30 dB or better. A conductive loss may cause a 'no clear response', while a mild sensorineural or high frequency loss affecting only one or two frequencies may produce a 'clear response'. It does not determine the cause of hearing loss (Sininger, 2003).

Auditory brainstem response

Definition

Auditory brainstem response is an electrophysiological test that detects the electrical response or activity in the brainstem in response to auditory stimuli.

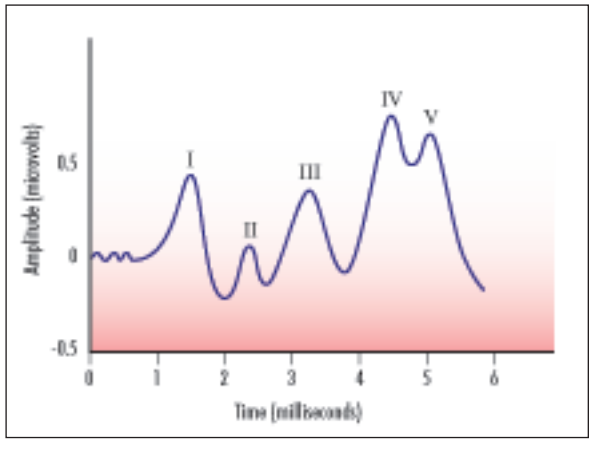
Basic physiology

The auditory pathway produces electrical stimulation when it is exposed to auditory stimuli, generating a curve with five waves originating from the following structures: wave I from the cochlea, wave II from the cochlear nerve, wave III from the superior olivary complex, wave IV from the lateral lemniscus and wave V from the inferior colliculus (*Figure 3*).

Description of the test

The test lasts for up to 1 hour in a relaxed and cooperative patient using a click stimulus, but can take 2–3 hours in a neonate, using tone bursts of two frequencies for air conduction and bone conduction, and testing both ears separately. The test starts by applying three surface electrodes: the active electrode attached as near as possible to the vertex of the skull but avoiding the fontanelle, the reference electrode attached to the mastoid process behind the test ear and the ground electrode behind the non-test ear. Broadband high frequency clicks are commonly used in

Figure 3. Normal auditory brainstem response.



this test (Ballantyne, 1990), but tone pips should be considered in order to obtain frequency-specific threshold information for fitting of hearing aids when necessary. Wave V is present down to threshold, with increasing latency and decreasing amplitude as the intensity of the click or tone pips decreases; it is in this way that the test can be used as a diagnostic tool (*Figure 4*).

Advantage
Auditory brainstem response is an objective test that can be used to estimate the hearing thresholds. It is useful in the diagnosis of auditory neuropathy or auditory dysynchrony, a rare condition in which the child has deafness with a normal oto-acoustic emission and an absent or grossly abnormal auditory brainstem response (Lalwani, 2008).

Disadvantage
Children should be asleep or sedated during the test. Training is required to be able to use the equipment and to interpret the results. It can be a very long test, with hearing-impaired infants often needing repeat appointments to ensure complete information is obtained.

Clinical audiological tests

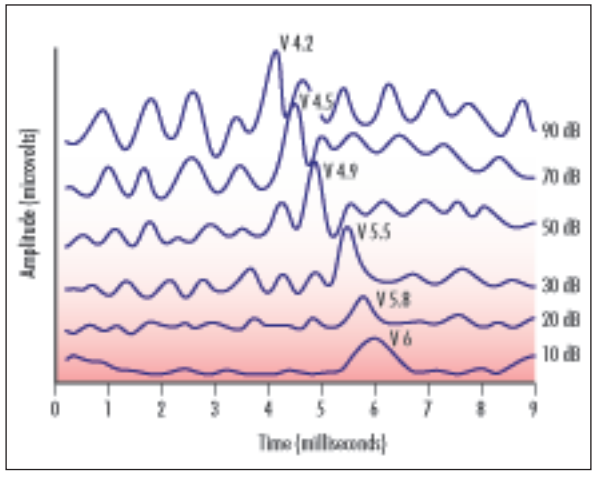
Behavioural observations (from 6 weeks' corrected age)

Definition
The behavioural observation test is based on observing the child's reaction to loud sound.

Principle of the test
Loud auditory stimuli are introduced to the baby and the response of the baby is observed (e.g. startle, frown, stilling, quietening and increase in extensor tone).

Advantage
It is easy to perform.

Figure 4. Normal, 4 KHz tone pip auditory brainstem response showing increased amplitude and decreased latency of wave V with increased sound stimulus intensity.



Disadvantage
It is very subjective. The test does not accurately measure the hearing threshold and may miss deafness with recruitment.

Distraction test (from 7 months' developmental age)

Definition
The distraction test is a clinical test of hearing, dependent on observing a response to frequency-specific auditory stimuli while distracting the attention of the child.

Principle of the test
The test requires two testers, one of whom sits in front of the child in order to engage and control the attention of the child while also observing the response of the child to the sound. The other tester will stand behind the child and produce frequency-specific sounds using a warbler and high frequency rattle at known intensities. The child is first conditioned to respond to sound at a raised level. The intensity is then reduced, and the level at which a consistent head turn can be observed is recorded for the speech frequencies 500–4000 Hz (Gliddon et al, 1999). If the child fails to respond, then the sound stimulus should be increased.

Advantage
The distraction test takes about 10–15 minutes, is easy to perform and does not require expensive resources.

Disadvantage
The test requires two trained testers in a quiet room with suitable lighting (no shadows or reflections). It lacks objectivity, cannot test the individual ears separately and fails to identify around half of all deaf children (Deafness Research UK, 2010).

Visual reinforcement audiometry (6 months–3 years)

Definition
Visual reinforcement audiometry is an audiological test that depends on rewarding children with a visual reward when they respond correctly to auditory stimuli at specific frequencies.

Principle of the test
The test requires two testers: the first will sit in front of the child and engage the child in play, while the other will sit out of sight and control the audiometer. The test can be performed on each ear separately using inserts, and unmasked bone conduction can be performed. The child is first conditioned to turn his/her head towards the side of the sound by presenting the sound stimulus at the same time as the visual reinforcement (flashing light or animated puppet). The procedure is repeated, and each time the child turns to the correct side on hearing the sound, the child will be visually rewarded.

Advantage
The success rate of visual reinforcement audiometry is very high and it is the most sensitive and efficient way of hearing assessment for this age group (Gliddon et al, 1999). Individual ear assessment can be obtained.

Disadvantage
Testers require training to perform this test accurately. Some young children are so upset by the visual reward that testing cannot continue.

Play audiometry (conditioned reflex) (2.5–3 years)

Definition
The child is conditioned to perform a simple task each time he/she hears the auditory stimulus in order to estimate thresholds at different frequencies for each ear.

Principle of the test
The test requires two testers. The first conditions the child to perform a task each time he/she hears a sound. The second tester changes the intensity and frequency of the auditory stimuli presented via the headphones and, where necessary, the bone conductor, to obtain a full audiogram.

Advantage
The test is useful for children from around 2.5 years (developmental age). From 3 years of age, it is possible to accurately determine thresholds for the speech frequencies in each ear in most children (Nielsen and Olsen, 1997).

Disadvantage
Play audiometry requires cooperation from the child and experienced testers. It is affected by developmental delay and requires a reasonable attention span.

Puretone audiometry (>4 years)

Definition
Puretone audiometry is similar to play audiometry and accurately measures the hearing thresholds.

Principle of the test
The test can be performed by one audiologist, who measures the hearing threshold at 250, 500, 1000, 2000, 4000 and 8000 Hz for air conduction and at 500, 1000, 2000, 4000 Hz for bone conduction. The child is asked to press a button or perform a simple task each time he/she hears the sound. The ears are tested separately and masking can be performed to obtain accurate individual ear thresholds.

Advantage
Puretone audiometry is a sensitive test to determine the hearing thresholds.

Disadvantage
The test requires cooperation from the child and an experienced tester. Children with a short attention span or developmental delay may perform better if play audiometry is used.

McCormick toy test (from 2 years)

This is one of two tests of speech discrimination; the test depends on recognition of words. The other test, speech audiometry, is discussed later.

Principle of the test
The toy discrimination test was introduced by McCormick in 1977. The principle is to ask the child to point to a named toy on request. The items should be familiar to a child with a developmental age of 2 years and the tester should make sure that the child knows the names of the toys before the test. The maximum possible degree of acoustic similarity should be used between pairs of monosyllabic toys. The child should sit adjacent to one of the parents and the tester should face the child and present the toys individually. The child is encouraged to name the toys, and only toys well known to the child should be used. The child is asked to point to the toy as soon as he/she hears the name. The tester should use voice intensity of 40 dB without the use of lip-reading when he/she names the toy, and the sound-level meter is used to confirm this level is achieved. The child passes the test if he/she names four out of five toys at 40 dB instruction (McCormick, 1988).

Advantage
The McCormick toy test is useful during assessment and fitting of a hearing aid. Functional hearing assessment by a teacher of the deaf is very useful in order to judge the impact of hearing loss in the classroom.

Disadvantage
It is a subjective test that requires cooperation from the child. Children need to know the names of the toys and be familiar with the vocabulary, so it can be limiting when children have English as a second language.

Speech audiometry (from 8 years)

The second speech discrimination test is speech audiometry. This test takes approximately 1 hour and is carried out under headphones using several lists of monosyllabic words, each consisting of three phonemes. Each list must be phonetically balanced with all other lists. Each list is presented at a specific intensity and the patient is given a score for each phoneme correctly heard and repeated. The test continues until the patient has achieved a score of <3%, 100% and several scores in between. These can be plotted on a graph and compared to normal curves.

Advantage
Speech audiometry can be used to estimate the average hearing loss for the speech frequencies, indicate the impact of the hearing loss on the patient and the limitations of the hearing aid. It can also be used to distinguish between conductive, cochlear and retrocochlear hearing losses.

Disadvantage
It requires a cooperative patient who has a fairly good understanding of English. Specialist equipment, a sound proofed room and an experienced audiologist are essential to carry out and interpret the test.

Tympanometry
Definition
Tympanometry measures the impedance of the tympanic membrane. It is an indirect measurement of the function of the middle ear.

Principle of the test
This test involves inserting a probe with three channels into the external ear canal. One channel is attached to a loud speaker and generates noise, while the second channel is attached to a microphone and detects the sound pressure level within the external auditory meatus at varying pressures. The third channel is used to change the pressure in the external ear canal. The sound pressure level in the external ear canal will increase as the compliance of the system decreases as a result of applying pressure to the tympanic membrane. The maximum compliance will occur when the pressure applied to the tympanic membrane is equal to the middle ear pressure. In this way, the middle ear pressure and compliance of the system can be determined. A valid tympanogram can be obtained in patients less than 4 months of age by increasing the frequency of the probe from 240 Hz to 1000 Hz (Sininger, 2003).

Advantage
This test helps to diagnose the presence of fluid in the middle ear canal, negative middle ear pressure and patency of grommets. It may also identify a perforation when the tympanic membrane is hidden by wax.

Disadvantage
Tympanometry requires specialist equipment. It does not assess hearing. It can be difficult to interpret in neonates.

Programme of hearing screening in the UK
Universal neonatal hearing screening in the UK involves performing automated oto-acoustic emissions. If 'no clear response' is detected from one or both ears on two occasions, then automated auditory brainstem response should be performed (Hagan, 2006). The tests can be performed by hearing screeners in the hospital after delivery or by trained nurses (usually health visitors) in the community.

The screening protocol is different for neonates who have spent more than 48 hours in the intensive care unit or special care baby unit. These babies should have both automated oto-acoustic emission and automated auditory brainstem response. Ideally the test should be performed just before discharge and after 34 weeks' gestational age. Babies referred by the screen should be referred to audiology and tested using threshold auditory brainstem response by the age of 3 months. If the hearing assessment reveals normal hearing, then the infant may be discharged. Further testing at 8 months will be recommended if the baby is at 'high risk' of hearing loss. The infant should also be referred to audiology if there is parental or professional concern about the hearing, irrespective of the screen result (NHS Newborn Hearing Screening Programme, 2009).

Conclusions
Health professionals dealing with children should be familiar with the various types of hearing tests and referral pathways for children when there is concern about their hearing. Early detection of hearing loss is essential to reduce the impact of the deafness. **BJHM**

Conflict of interest: none.

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KEY POINTS
- Neonatal hearing screening has an important role in the early detection of congenital deafness.
- Automated oto-acoustic emissions and automated auditory brainstem evoked response are the two main tests for neonatal hearing screening.
- Hearing loss is not always present at birth, it may be later onset, progressive or acquired.
- Hearing assessment should be appropriate for the child's developmental age – clinicians need to be aware of the different tests involved and their limitations.