Chapter 6: Testing and screening of hearing

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When testing the hearing of young children different methods may be used from those employed for an older child or adult, but the information that is being sought is similar. The aim is to identify as accurately as possible the threshold of hearing at a range of frequencies in both ears and to identify the nature and cause of any hearing impairment that may be present. As the main effect of hearing loss in young children is on their verbal communication skills, the tests of threshold are supplemented as early as possible by tests of speech discrimination. Screening tests, whatever their nature, are designed to identify two groups of children, those with normal hearing and those who fail the screen and need definitive testing as above. If a hearing loss is identified by testing, the child will then need further investigation and following this may undergo corrective surgery or may enter a rehabilitative programme. These topics are covered elsewhere, but it is important to recognize that testing is only one aspect of the assessment of the child with a hearing problem.

Development of response to sound

The behavioural response to sound matures with the child's development in the same way as other skills. Before a tester can start to assess the hearing of children, it is essential to have a good working knowledge of how these responses develop in a normal child. It is also necessary to understand the normal development of the child in other fields, as the hearing responses and communication skills have to be related to the child's overall level of maturation.

Neonatal responses

In the period after birth a baby responds to loud sounds by a form of startling reflex. This reaction includes the aural-palpebral reflex, which is the most consistent response to sound, a change in heart rate and pattern of respiration, a backward head jerk and an increase in general body activity (the Moro reflex). These responses are not elicited by quiet sounds and the intensity of the auditory stimulus producing a reaction depends very much on the psychophysiological state of the child. For this reason it is not possible, at this stage, to assess accurately a child's hearing threshold by behavioural techniques.

Responses of the infant aged under 4 months

As the infant matures he/she begins to notice sounds and to respond by stilling and listening. By 4 months of age an infant stills and smiles to a parent's voice, even when the source is not in visual range, and obviously vocalizes in response to voice in a communicative way. The response is mainly seen to louder sounds and there is no consistent response to quieter sounds that could reliably be used for threshold estimations.

Responses at age 4-6 months

At this age the infant is beginning to turn its head to the source of a sound with increasing consistency. Not only is the response more reliable, but it also occurs to sounds
of lower intensity, so that estimates of the threshold of hearing using behavioural techniques are sometimes possible. However, because the localization of sound is still developing at this age, the response often varies from the prompt localization of a sound in an older child.

The turn to an auditory stimulus is often delayed and a longer presentation of the stimulus is necessary prior to a response, without raising the intensity of the sound. The sound may also need to be presented closer to the child than the usual 1 m distance. A child of this age may learn to localize sound to the first side tested but then only turn to this direction, wherever the source of sound. This could lead to a suspicion of a unilateral hearing loss if the child's developmental age is not taken into account. The child may also turn to the correct side but with a half turn that does not visualize the sound source, or may assume the sound to generate from the first object or person identified on turning, again not recognizing the actual source of sound. These are the normal responses for many children of this age. Children of this developmental age respond best to the more traditional testing sounds and do not turn to warble tones at the same quiet levels, which could lead to a suspicion of hearing impairment if only the latter are used.

**Responses at age 7-9 months**

At this age a child can localize accurately quiet sounds on a horizontal plane, although many children still have some problems in identifying a source of sound below and, in particular, above their heads on testing. A child will turn readily to a parent's voice across the room and search for the source of interesting sounds. The child should also be babbling tunefully and during this time may begin more noticeably to copy sounds.

**Responses at 10-12 months**

At this age a child can localize quiet sound on any plane when not otherwise occupied. Verbal comprehension is developing for single words, such as his/her name, 'no' and well-known objects. The range of vocalizations increases and by their first birthday a few children are attempting to say and repeat one or two words.

**Responses at 13-24 months**

A child of this age localizes sounds readily but begins to anticipate and search for the sound source during testing, so that more active distraction may be necessary. Understanding of words increases so that by 18 months many children will respond readily to questions such as 'Where's your nose?' or 'Where's the cat?' By the age of 2 years children will often pick out toys when requested, and simple speech tests can be introduced into the assessment. The child's vocabulary increases over the second year of life and many children are joining two words together by 18-21 months. Even before speech is heard the vocalizations should show good intonation patterns with speech like rhythms.

**Responses over the age of 2 years**

As the child gets older, he/she becomes increasingly able to inhibit the earlier, ready response to sound. Such a child will usually turn to a particular stimulus on the first presentation only, and will subsequently appear to ignore the sound. There is a developing
ability to recognize background sounds without visual confirmation, so that many sounds do not seem to be registered at a conscious level. At the same time there develops an ability consciously to avoid turning to sounds when anticipated, for example during testing. Sometimes a response may be seen as an eye-glide, but as many parents will testify, an older child can appear to be completely unaware of unwelcome requests and demands. As this stage is reached simple distraction techniques of testing become more difficult and eventually impossible to carry out reliably.

**Testing**

There are various factors which have to be taken into consideration if accurate results are to be obtained on testing a young child.

**Environment**

The environment in which the testing of a young child takes place is vitally important if the results are to be accurate. The room must be not only acoustically acceptable, but must also be a comfortable, inviting place, where a child can relax. An insecure, worried child is not going to cooperate fully in the necessary assessment, and anything which may help such a child to enjoy the session is invaluable.

While older children and adults may perform hearing tests seated in small, sound-treated booths, the testing of the younger child and infant should take place in a normal-sized room. There needs to be space for the child and care-giver to sit in the centre of the room with a distractor up to 2 m (6 feet) in front and a tester moving freely behind.

The room, as for a booth, should be extremely quiet and the design of audiometric rooms is a very specialized area. Such rooms are expensive to provide and a reasonable compromise for diagnostic audiometric testing is an overall sound level not exceeding 30 dB(A). However, the testing of very young children is normally carried out in free field and, ideally, even lower background sound levels are necessary in these conditions. A full discussion of the design of such rooms to meet recommended standards acoustically would be out of place in this chapter, but certain other features are worthy of consideration. For example, the sound absorbent lining to the walls of audiometric rooms is often finished with acoustic tiles, but a more welcoming environment may be created by the use of a fabric finish.

In addition to reducing the acoustic interference with testing, consideration has to be given to the visual aspects of the test room. The lighting of an audiometric room is extremely important when carrying out free field testing. There should be even illumination, with no possibility of shadows alerting a hearing impaired child to the test procedure. There should not be large windows overlooking interesting, and in particular moving, objects that may distract the child and make testing unreliable, and in the room itself there should be no distracting features such as pictures, attractive toys or equipment within the child's visual field during testing. When testing a child it is important that there are no reflective surfaces, particularly two-way mirrors for observation, which are in visual range, as again this would invalidate test results. This should be considered when designing the layout of the room, also
remembering that a window becomes a mirror after dark, but suitable blinds or curtains may solve the problem.

**Stimulus**

**Frequency**

In the past a wide variety of uncalibrated sounds were used to assess hearing. These included such items as squeaky toys, musical boxes, crinkled paper from a number of sources, and bells. While some of these may still have a place during assessment, it is now recognized that sounds for testing have to be far more frequency specific if accurate and meaningful hearing levels are to be obtained. When testing, the most important point is that the tester should be aware of the frequency spectrum of the sounds, so that an overall pattern of hearing can be deduced from the results. The aim is to build up information about a child’s hearing at various frequencies in the same way that one carries out an audiogram in the older child. During the test for threshold levels the minimum requirement should be an assessment of hearing at a low, medium and high frequency.

Many different test sounds are used in different centres. One traditional test sound which gives a wide frequency spectrum and thus remains effective as part of a test battery is the cup/spoon combination. The sound must be produced by lightly rubbing the back of the spoon around the rim of the cup, as any clinking sound will change the flat frequency spectrum.

Test sounds include the human voice, and although the frequency may be less exact, the sound ‘oo’ is usually about 500 Hz, the hummed ‘mm’ about 1 kHz and the sound ‘s’ is usually about 3 kHz. The traditional, and still very practical instruments for assessing high frequency hearing, in the UK are the Manchester and Nuffield rattles.

More recently, instruments producing warble tones have been introduced to the assessment procedure. These have the advantage of a reproducible and frequency-specific stimulus that will not give standing waves, with variation in intensity, while testing. Some are small devices designed for screening, but others are more powerful, delivering sound up to 120 dB(A) SPL in free field, with adjustable modulation of the warble, based on frequencies from 125 Hz-8 kHz. Some also produce other stimuli such as narrow band sound. For a hearing-impaired child the drum is still used to test low frequency specific information but frequency specific information from tests using warble tones is preferable particularly for fitting of a hearing-aid.

**Intensity**

During an assessment of hearing, it is essential to know not only the frequency of the sound to which the child responds, but also the intensity of the quietest sound responded to at each frequency. The only accurate was of monitoring the delivery of these sounds is with a sound level meter. Sounds used for testing in free field are normally measured in dB(A) SPL. An experienced tester may be able to produce sounds of minimal intensity reliably, making regular checks on delivery with the sound level meter. However, when a tester is relatively inexperienced, or the sound is above normal threshold levels, each needs to be
checked against a sound level meter. The distance from the ear at which the sound is produced has a marked effect on its intensity, the diminution in intensity following the inverse square law, so that the testing distance must be scrupulously observed on each occasion.

Subject

When testing children it is very important to use the appropriate method for the child's overall developmental stage (Table 6.1), and this must be roughly assessed prior to starting the test. Application of a wrong method will lead to lack of cooperation from the child and unreliable results. Some measure of a child's developmental level can be obtained by providing suitable toys for the child to play with while taking a history from the care-giver, and observing the use of these toys. A child who has developed an understanding of miniature toys and shows reasonable play with these items is usually able to condition to sound in free field, and may accept headphones and proceed to an audiogram. A child who only understands the use of real objects and does not have any concept of the symbolic significance of a miniature toy is likely to need testing by distraction techniques.

Table 6.1 Clinical testing in children

<table>
<thead>
<tr>
<th>Test</th>
<th>Developmental age</th>
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<tbody>
<tr>
<td>Startle reaction to speech (65 dB)</td>
<td>Any age from birth</td>
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<tr>
<td>Stilling to sound</td>
<td>6-16 weeks</td>
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<tr>
<td>Distraction tests</td>
<td>4-30 months</td>
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<tr>
<td>Visual reinforcement audiometry</td>
<td>6-30 months</td>
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<tr>
<td>Conditioning audiometry</td>
<td>From 2 years</td>
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<tr>
<td>Pure tone audiometry (air and bone)</td>
<td>From 30 months</td>
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<tr>
<td>Audiometry with masking</td>
<td>From 5 years</td>
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<tr>
<td>Speech tests (of increasing complexity)</td>
<td>From 21 months</td>
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</tbody>
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Distraction tests of hearing

This technique, which requires two trained testers, was originally described by Ewing (1957) and later in greater detail by Sheridan (1968). One tester remains in front of the child and is responsible for maintaining the child's attention in the correct state for testing and is able to observe the reactions of the child. The other tester is behind the child and produces the test sounds when the child's attention is in the appropriate state. This requires good coordination between the testers, which is best achieved when the two concerned are used to working as a pair.

The test lay-out is demonstrated in the figure with the test sounds being produced 1 m from the child's ear (apart from the Nuffield rattle, which is used at 30 cm), and on a horizontal plane. The sounds are produced behind the child, and it is important that the tester and equipment do not come into visual range and that the distractor does not look at the tester at any time. There should also be no chance of tactile stimulation, which can occur if the tester is too close to the child, particularly with vigorously shaken rattles producing air currents. It is also important that the distractor should be experienced in judging the attention levels of young children. The younger the infant the easier it is to attract and fix the attention...
visually, so overdistraction, which parents commonly quote as a problem during testing, must be avoided. As a child gets older, and in particular over the age of 12-15 months, continuous distraction varying in degree may become necessary, as these children start to look around when there is nothing of interest to watch in front.

The distraction technique is most sensitive at 7-10 months of age, and some of the problems that may be encountered on testing children of different developmental levels are mentioned previously. Thompson and Weber (1974) reported median thresholds to noise through a loud speaker of 45-55 dB at 3-5 months, 35-45 dB at 6-11 months and 35-40 dB at 12-17 months, when testing normal hearing infants by behavioural observation audiometry. In practice, slightly lower thresholds are observed with 'live' presentation of the sound.

Visual reinforcement audiometry

In some centres, this method is used in addition to the normal distraction techniques, in particular to test the hearing of children over the age of 1 year. This method is said to reduce the habituation to sound seen in this age group, and to reinforce the localization of a sound stimulus. The sound stimulus is presented through loud speakers accompanied by a visual stimulus, such as a flashing light or animated toy near to or above the loud speaker. Moore and Wilson (1978) reported less habituation when using an animated toy for reinforcement. They felt this approach was reliable from 5 months of age, and after using a complex sound at 70 dB SPL for conditioning they reported thresholds of under 20 dB SPL at 500 Hz, 1 kHz and 4 kHz on testing the older infant. The 'distractor' is still essential during this test to control the prestimulus level of activity and attention.

Conditioning audiometry

This is also known as performance testing and play audiometry as the child is taught to join in a 'game' with the tester. Although some children below the age of 2 years can carry out this type of task, and many 2 year olds are able to cooperate reasonably in the test, it is most useful in children aged 30 months and over. Basically, the child is taught to carry out some simple task in response to a sound stimulus, for example putting a brick in a box, a wooden man in a bus, or a peg in a board. The task is first taught with visual reinforcement, either using the word 'go' with visible mouth movements and facial expressions, or using a free field audiometer with the stimulus button visible. The visual stimulus is then withdrawn and the minimum response level obtained for the test sounds. Thompson and Weber (1974) reported median thresholds to noise, on using play audiometry, of 26 dB SPL at 24-29 months, and 13 dB SPL at 30-35 months of age.

With the younger child there are various strategies that may be necessary during testing in order to complete the task. Several different play activities may be used in succession, and obvious suprathreshold stimuli may be interspersed to reinforce the conditioning when attention flags. The crucial ability in the child is that of being able to wait and make no response when there is no stimulus present. The younger child or those with attention problems may respond after a certain time regardless of any stimulus, and this activity needs to be discouraged without losing the child's confidence in his ability to play the game.
Once children are able to condition reliably to sound the only factor preventing them from carrying out an unmasked pure tone audiogram is the acceptance of headphones. With modern technology, many young children have seen or even used headphones for stereo radios and hi-fi units and will happily cooperate at around 30 months of age. However, some children do take longer to accept strange instruments and may be over 3 years of age before they will carry out an audiogram. Warren (personal communication) has suggested the use of an earphone on a wall-mounted Flexarm to overcome the difficulty in accepting headphones. Some children will accept a bone vibrator more readily, and bone conduction thresholds may be obtained first. Many children can cope with masking from the age of 4-6 years and, from the age of 7 years, virtually all normal children are able to be tested for hearing thresholds in the same way as adults.

**Testing the 'difficult' child**

The decision as to which test is appropriate in a particular child to estimate the hearing thresholds and speech discrimination ability depends on the overall developmental age of the child, and not the chronological age. Thus, for example, a child of any age who is developmentally at the 9-month level would be best tested by distraction techniques. The validity of this approach was assessed by Flexner et al (1985) who tested children with different degrees of mental handicap and found comparable results with children of the similar developmental levels.

When a child's developmental level is below 3-4 months, behavioural methods of testing are not sufficiently reliable for accurate assessment of hearing. Under these circumstances, one of the so-called 'objective' methods of assessing hearing is necessary, for example electrocochleography or auditory brainstem evoked response. Although such tests do have their limitations (see below and Chapter 7), they may be the only available method of gaining any information on the hearing ability of a very young or handicapped child.

Children with visual impairment may respond differently to sound from their normally-sighted peers, and this must be taken into account when testing their hearing. A young child with very poor vision is unable to relate a sound to a source and will react to sounds by stilling and listening. If the sound appears to be that of an object with which he is familiar, he may reach out a hand for the object, while keeping the body and head still and continuing to listen. Many visually-impaired children respond reasonably reliably to voice at minimal intensities, but do not respond to other test sounds, particularly warble tones, unless presented at suprathreshold levels. It can be difficult with some of these children to be sure that they can hear to minimal levels, and if there is any doubt at all, 'objective' tests of hearing should be used as optimal hearing is essential in a child with a visual loss to achieve the maximum sensory input.

Once partially-sighted children are able to use their residual vision effectively, following either correction or training, they will attempt to localize a sound source and also start to respond at lower intensities. When using distraction techniques large, brightly-coloured objects are required, and on occasions a torch light may be helpful to attract the attention to the front. When a visually-handicapped child has reached the age where conditioning tests are more suitable the task chosen must be appropriate to the child's visual-motor skills. This
usually includes larger objects and a simple task, such as dropping a brick into a basket, rather than fitting tasks.

Some children, particularly those with various forms of cerebral palsy, may be difficult to test because of the limitations they have in carrying out voluntary movements. This problem may also occur against a background of involuntary movement, making the presence or absence of a response difficult to assess with certainty. Even when a child can localize a sound by head or eye movement, the response may be slow and require prolonged presentation of the stimulus. The older child may understand the task during conditioning tests, but only be capable of one or two different movements in response. A familiar caregiver is essential to interpret the child's communications. Again ‘objective’ tests are needed when there is any doubt about the hearing levels. Some of these children may have been affected by perinatal problems, for example severe asphyxia or hyperbilirubinaemia, and be thus at high risk of hearing impairment.

Children with autistic features can be difficult to test if there are problems in gaining their attention. They may show only fleeting regard for a distractor and any objects being used, and are sometimes very difficult to keep in one area for testing. These children may also show little interest in voice, although many will respond very promptly to warble tones and rattles. If there are persistent problems in obtaining reliable results due to a child's behaviour, ‘objective’ tests may be necessary, but experienced testers can usually obtain hearing levels in these children.

In a similar way, a hyperactive child or any child with attention problems may be difficult to test and may require a variety of different techniques to complete a hearing assessment. Again, in some children, it may be necessary to resort to ‘objective’ tests, but this is not normally the case.

**Speech tests**

From a functional point of view the most important measure of a child's hearing is the ability to hear and discriminate speech. If children have hearing difficulties it may be helpful to gain a measure of their discrimination of speech sounds not only in optimal conditions, in a sound-treated room, but also in the presence of background noise, such as their normal school environment. This is also an important aspect in monitoring the function of a child with hearing aids.

In the older child, speech detection and discrimination tests can be carried out in a similar way to tests on adults. This is by presentation of phonetically balanced words through headphones with the instruction to the child to repeat the word/sound that they hear, with scoring for correctly heard phonemes. The word lists for younger children may have to be simplified, and suitable material in the UK would include the Manchester junior word lists. However, such tasks are not possible for routine use in children under the age of 7-8 years. Even above this age there may be some problems in testing. The younger the child the more likely it is that he/she will give no response if unable to recognize a complete word, thus giving an underestimate of ability, and some children may have articulatory problems that make it difficult to score the response accurately.
For the younger child different approaches are needed to estimate speech discrimination thresholds. (In practice, the parameters measured are the optimal discrimination score, and the sound level at which this is achieved.) Tests at this age are generally more acceptable if delivered live rather than through loud speakers, and involve the use of closed sets, that is a finite number of objects or pictures are presented and the child's response is limited to picking out one of these (as pass or fail). The results are not directly comparable to open methods, and are influenced by set size. The task needs to be presented as a game, and it is important that children should not feel that they are failing, as they will cease to cooperate. Thus the approach used must be appropriate to the child's developmental level. The vocabulary also needs to be appropriate to the child's level of verbal comprehension, and this cannot be predicted from the general level of abilities and has to be gained from the history. A hearing-impaired child will probably have a smaller vocabulary than his/her peers, limiting the items that can be used for testing, and he may, in fact, not recognize any words using hearing alone, so that a speech discrimination test is not possible.

From the age of 18 months a rough measure of speech discrimination may be obtained in a cooperative child by using toys and a parent (for example daddy, teddy and dolly) as recipients, and items such as a cup, spoon or shoe. The child can then be asked to give the cup to teddy, and the quietest level at which this can be carried out accurately, as measured on a sound level meter, recorded. The game, as with all tests for the younger age groups, needs to be carried out first with lip-reading and facial expression visible and a normal intensity of voice, and only when the child can reliably perform the task under these circumstances should the mouth be covered and the voice dropped.

As children get older, toys from an established test such as the Kendal toy test or the modification by McCormick (1977), used in the UK, can be introduced gradually. These tests contain items that have similar vowel sounds but different consonants, for example cup/duck, cow/house, shoe/spoon. Suitable words would obviously vary in different countries and cultures. A child aged around 2 years may only be able to cope with a limited number of items, which must be used in pairs, but by 3 years of age most children can cope with the whole test, containing 15 items, without difficulty. The child is asked to identify the item, and when the task is understood the minimum level at which all the items can be successfully identified is recorded. In a normal hearing child under optimal conditions this test can be completed at 35-40 dB(SPL). If a raised level of speech is needed for discrimination, the level is recorded and any particular word confusions noted, as they may give additional evidence as to the type of hearing problem being encountered.

Older children learn to relate pictures to objects, and picture tests can be used instead of the above toy tests. In a child with a short attention span, the two approaches can be combined as a way of varying the game, to obtain reliable results. As school age approaches the range of vocabulary suitable for the speech tests increases (a discussion on suitable word pairs for screening and testing English speaking 5 year olds can be found in Haggard, Wood and Carroll, 1984). In the older child, it may be possible to extend the testing session long enough to record the percentage of correct responses at various intensities, as well as the level needed for 100% accuracy, whereas in a younger child the latter may be the only level obtainable within a test session.
During tests for speech discrimination a child may have other problems that necessitate a modification to the test procedure. For example if a child has visual problems, the objects or pictures used may have to be larger than usual and a smaller number of items may be dictated by available space. The child will also need to become familiar with the layout of the objects, so that they can be identified easily without prolonged scanning of the whole field.

A child who has difficulty in controlling voluntary movements accurately enough to pick out the requested object will need fewer objects with wide spacing to make the task physically possible. For a child who can only use eye pointing as a form of identification, the objects need to be well spread out so that there is no confusion over that chosen.

**Speech perception in the hearing impaired**

The hearing impaired are a special group with respect to speech discrimination tests, and a full coverage of such a specialized field is not appropriate in this chapter. Hearing-impaired individuals gain their information on speech content from both visual and auditory inputs, and a full assessment should encompass the use of both modalities separately and in combination. This section will cover only the simpler aspects of the assessment of the level of auditory input.

On initial assessment some children may be able to carry out a speech discrimination task using a limited number of known items, with a measurable response when a raised intensity of voice is used. Other children may have insufficient understanding of words to carry out such a task at all. A further group may be able to pick out items correctly when they are also allowed to use lip or speech-reading, but cannot carry out the task using auditory input alone.

Further information is required regarding the speech reception skills of these groups of children, but for testing to take place, the children need to develop an appropriate vocabulary. The first information requires is some measure of the child's ability to distinguish words under optimal conditions. One such test was designed for hearing-impaired children by Ross and Lerman (1970) using monosyllabic word lists, with the response identified on picture plates. Further information on the hearing of children who have low scores on this test can be obtained using a spondee-recognition score as described by Cramer and Erber (1974). Children fall into two groups - those who can distinguish the words accurately and those who only have the ability to perceive the time and intensity patterns of speech. Another test, using a combination of monosyllables (for example bed), trochees (for example table), and spondees (for example toothbrush), can differentiate those children who are able to recognize words accurately, those who can recognize stress patterns, and those who cannot use their hearing to recognize either. Although these types of tests are not helpful in isolation, they do give information which can then be applied to modify hearing aid fittings and rehabilitative programmes.
Objective tests of hearing

Impedance audiometry

This is covered fully in Chapter 8, but some aspects of its applicability are worth emphasizing again in relation to the testing of hearing in young children. There are three measurements used in impedance audiometry, the middle-ear compliance, the tympanogram and acoustic reflex measurements. In isolation all these measures are of limited value, but a good deal of information can be obtained, particularly from the latter two, when they are viewed in combination. When taken in conjunction with other tests of hearing and otoscopy they contribute significantly to the overall picture.

Many young children do have middle ear abnormalities, the most common being the temporary presence of fluid. Impedance audiometry gives particularly useful information on middle ear function, which can aid diagnosis, and also monitor progress in young children with conductive hearing losses.

Acoustic reflex measurements are used in the more detailed assessment of a sensorineural hearing loss, to distinguish a cochlear from a neural lesion. In an ear with a cochlear disorder, Jerger and Hayes (1984) demonstrated the decline in the acoustic reflex sensation level in proportion to the degree of hearing loss. The reflex threshold remains at around 85 dB (a normal level) until the hearing loss exceeds 40-50 dB HL and may still be elicited at 110 dB with hearing losses of 80 dB HL. A combination of acoustic reflex threshold measurement and reflex decay was felt to be reasonably sensitive in eighth nerve lesions (Olsen, Noffsinger and Kurdziel, 1975). This aspect of impedance audiometry may be of help in the investigation of a hearing-impaired child.

In addition, Jerger et al (1974) have suggested that, in the presence of normal middle ear function, the acoustic reflex can predict the sensorineural hearing level. This prediction is based on the relationship between the acoustic reflex hearing threshold level to pure tone signals and broad band noise. In ears with a sensorineural hearing loss the reflex threshold level for noise becomes elevated, whereas that for pure tones remains relatively stable, declining as described previously. This has been suggested as a further method of testing hearing in the young infant and difficult to test child, although other workers have not found this technique to be helpful.

One of the problems in carrying out impedance audiometry in young children is that some will not tolerate the probe for a sufficient time to complete the necessary measurements. This also occurs in difficult to test children, who are often fairly strong and active. The more modern screening tympanometers, although easier to handle in these groups of children, do not have broad band sound as a stimulus and can give unreliable reflex thresholds (Bennet and Mowat, 1981; Wood, Lutman and Fernandes, 1982).

Evoked response audiometry

This is fully covered in Chapter 7, but some points are worth repeating in the context of testing of hearing. The usual aim of such tests in children is to gain an indication of hearing threshold in those who are too young or handicapped to be tested by ‘subjective’
methods. There is no place for these tests in estimating thresholds in children who can cooperate with other forms of testing, as both distraction and conditioning methods give more information regarding the hearing levels at a wider range of frequencies.

The ideal test for use in children, based on evoked responses, would be of short duration, reliable during sleep or sedation, and would predict accurately the thresholds of hearing at a range of frequencies. In practice, such a test is not yet available, although research is continuing. Present techniques include electrocochleography and auditory brainstem evoked responses, while the SN10 response, middle latency responses and the 40 Hz test, first described by Galambos, Makeiz and Talmachoff (1981), continue to be evaluated. These latter techniques appear to be affected by sleep and sedation, and use in children will be restricted by this.

Both electrocochleography and auditory brainstem evoked responses are applied clinically, each having different advantages and disadvantages. Electrocochleography requires general anaesthesia and is an invasive technique, but while the child is asleep, a good view of the tympanic membrane can be obtained, with minor procedures, such as removal of wax, myringotomy and even the insertion of ventilation tubes also being carried out. It is also possible to make ear moulds, if required, before a difficult to test child awakes. The testing can also be carried out over a more prolonged period of time, if necessary, without fear of the child waking in the middle of the procedures.

Auditory brainstem evoked responses require a still child, and young infants are often in a suitable state for testing following a feed. Older and more disturbed children require sedation if they are to stay still for testing, and children of any age are liable to wake after 45-60 minutes, thus limiting the testing that can be carried out in any one session. This test gives more information regarding the auditory pathways, but neurological abnormalities may affect later waves in such a way as to make threshold estimation unreliable.

Historically, the stimulus used in both auditory brainstem evoked responses and electrocochleography has been a click, with reasonable correlation found between the thresholds obtained in children and their behavioural thresholds to frequencies of 2-3 kHz. The use of tone pips and filtered clicks to gain more frequency specific information has been disappointing (Kileny, 1981; Sohmer and Kinarti, 1984). One promising method is the use of tone bursts in notched noise or high pass noise, but problems still occur with frequencies below 1 kHz.

In practice, the results of electrophysiological tests, although not giving an exact measure of hearing, are invaluable when combined with other tests of hearing to build up an overall picture of a child’s auditory function.

**Screening**

Screening programmes to identify children who have abnormal hearing are in use in many countries. The early screen is normally carried out at some time during the first year of life, and the aim of this programme is to identify at an early age children who are hearing impaired, and in particular those who need amplification, in order to start the rehabilitative programme as soon as possible. This is then supplemented in many areas by preschool
screening, which should identify any children who may have been missed at the earlier screen, particularly those with mild losses, high-frequency losses and persistent middle ear effusions. Further screening is frequently carried out at school entry and at intervals during school life, and the aim of these screens is predominantly to identify those children with middle ear disease, although some sensorineural hearing losses are first identified at this time.

**Identification of hearing loss by infant screening**

Screening of hearing by the distraction method (see above), has been carried out in infancy for many years in the UK. The EEC study reported by Martin and Moore (1979) highlighted the disappointing results of this programme, with only 55% of those children with a loss of 50 dB or greater being identified by the age of 3 years. Local authorities in the UK have attempted to improve the screening, so that hearing-impaired children are identified in the first year of life, but although in some districts the results of screening are said to be satisfactory, the most recent figures from Newton (1985) in Manchester revealed that the mean age at identification of presumed congenital hearing loss was 23.3 months. These figures would be typical of the results of screening in many districts in the UK. Two main problems are encountered, the first being the initial passing on screening of many children with hearing impairment, the proportion in Manchester being 44%, and the second being the low attendance rate for screening in many districts. The children who are not brought for screening are a particular worry because according to the law of inverse care (Brimblecombe, 1975) these children may be at higher risk of handicap than those who attend relevant screening.

These problems are also encountered in screening programmes in other countries. For example, Tell, Levi and Feinmesser (1979) documented the results of the screening programme in the well-baby clinics in Jerusalem, with 85% of infants attending a check at 7 months. Of the 28 known deaf children who should have been identified in infancy only 24 had actually been screened and of these 10 had passed the initial screen.

These figures become more alarming when placed alongside the report of the Saskatoon conference (1978) which recommended that hearing-impaired children should be identified and remediation started in the first 6 months of life. Workers with hearing-impaired children have subjectively noted the improvement in vocalizations and language development of these children and Markides (1986) has demonstrated the significantly superior speech intelligibility of children fitted with hearing aids in their first 6 months compared with those fitted in the second half of the first year or the second and third years of life, who all performed very similarly. The aim of a modern screening programme should thus be, to identify children with hearing impairment within the first 6 months of life, so that the majority of these children can have hearing aids fitted by 3-4 months of age. Present infant screening programmes alone are unable to meet these aims.

Routine infant screening in the USA has been discouraged because of the poor results, with the emphasis being placed on testing of high-risk infants (Table 6.2). This has been effective in identifying 65-70% of infants with a congenital hearing loss in their first few months (Mencher, 1977), but the remaining infants with no risk factors need to be identified by an alternative method.
Table 6.2 High risk factors for hearing impairment

(1) Positive family history of childhood hearing impairment.
(2) Intrauterine infections (for example rubella, cytomegalovirus, syphilis, toxoplasma).
(3) Anatomical abnormalities of the ears, head and neck.
(4) Birthweight less than 1500 g.
(5) Severe neonatal asphyxia.
(6) Hyperbilirubinaemia of 342 micromol/L or over (less in preterm)
(7) Bacterial meningitis.
(8) Ototoxic drug administration.

Neonatal screening

The time at which infants are most accessible for screening is in the neonatal period. Where there is a hospital-based obstetric service the majority of neonates could be screened, if an effective method were available. However, in areas where many babies are born at home or taken home within a few hours, any neonatal screening programme must rely on motivating the parents sufficiently to attend a hospital or clinic for the hearing test. When the aim of a programme is to identify hearing impairment before 6 months of age, neonatal screening is theoretically the most efficient way of reaching the target population.

If such a screening programme is to be implemented it is essential that facilities are available to help those infants identified as a result of the programme. When the screening is carried out at 7-9 months the fitting of hearing aids following a fuller assessment is reasonably easy, and in many countries there are rehabilitative programmes available for children of this age and their parents.

However, the position is not so straightforward if some form of neonatal screening is used. Following the screening there need to be facilities for assessing the babies in more detail, and this involves electrophysiological testing, particularly auditory brainstem evoked responses, in addition to careful behavioural observation to estimate the hearing thresholds. There also need to be facilities for investigation and rehabilitation of those infants found to be hearing impaired. Hearing aids can be fitted to these young babies, but this requires far more skill and experience than in the older child, both in estimating the desirable degree of amplification and in ear mould fitting (Seeward et al, 1985; Nolan et al, 1986). The personnel involved in working with the families in rehabilitation programmes must also be experienced in the development of very young infants, and this expertise is not widely available because training has previously concentrated more on the older infant and toddler. Without the necessary back-up facilities neonatal screening is not a viable proposition.

Behavioural screening in neonates

Various studies have been carried out to evaluate screening programmes that use observation of a neonate's behaviour in response to sound to identify those with a possible hearing impairment. The Nova Scotia conference on early identification of hearing loss recommended that the sound applied should be random noise with low-frequency attenuation of 30 dB/octave below 750 Hz, a rise-decay time of 5 ms and duration of 0.5-2.0 s. The interval between test presentations should be a minimum of 15 s and the sound intensity
should not exceed 90 dB SPL at the pinna. It was also recommended that there should be two independent observers for each test.

It was pointed out by Gerber, Jones and Costello (1977) that such a test would only pick up those who are profoundly deaf and these reservations were confirmed by Downs (1978), who found that screening in this way only identified 60% of those later found to be hearing impaired, missing mild and moderate losses with average hearing levels better than 75 dB.

The false positive rate using behavioural observation following the recommended protocol is high, so that many infants need referral for further evaluation. The Halifax study, reported by Durieux-Smith and Jacobson (1985), observed a false positive rate of around 50% in normal and at-risk neonates, rising to 86% in babies from the neonatal intensive care unit.

Various methods have been tried to improve the reliability of behavioural testing by eliminating observer error and measuring the reactions to sound using instrumentation. These modifications use body and head movements and changes in respiration or heart rate as parameters of response, and not the aural-palpebral reflex which is the most consistent behaviour observed.

The first instrument, the Crib-o-gram (Simmons, 1978), is in use in parts of North America. Early reports suggested that the test had a false positive rate of 9% and only missed one in 29 children with confirmed moderate/severe hearing loss. However, many children who failed the test were lost to follow-up.

The study reported by Durieux-Smith and Jacobson (1985) also compared the results of the Crib-o-gram with auditory brainstem evoked responses in a neonatal intensive care unit (the Ottawa study). At 38 weeks' gestational age or greater, 72.4% of infants with normal auditory brainstem evoked responses were correctly identified by the Crib-o-gram, with the figure falling to 63.8% in infants of 31-37 weeks' gestational age. Only one of the three infants in the 31-37 week group having auditory brainstem evoked responses thresholds of 50 dB HL or greater was identified by the Crib-o-gram, whereas in the full-term group the Crib-o-gram identified all those with thresholds on auditory brainstem evoked responses of 60 dB HL or greater. It thus appears that the Crib-o-gram has a high false positive rate, particularly in terms of the further evaluation needed by infants who fail the test, but does identify term babies with hearing losses of 60 dB or greater.

In the UK, the Linco Bennett or auditory response cradle was developed, and the results of the preliminary trial, involving 6000 neonates were reported by Bhattacharya, Bennett and Taylor (1984). Of those babies screened, 8% failed the first screen, 1.7% failed two screens and following auditory brainstem evoked responses there was said to be a false positive rate of 1.2%. Eighteen neonates were found to be hearing impaired and three have later been found to have hearing problems, presumed to be progressive in nature, but follow-up was limited in that it was only available on two-thirds of those tested at 3 years of age.

The auditory response cradle is designed for use on full-term babies but, with some modifications (Davis, 1984), it can be used on neonates in a special care baby unit, where the incidence of hearing impairment is higher than in the normal nursery. The false positive rate
has varied in different units, rising to 20% in the special care babies, but seems consistently lower than that achieved with the Crib-o-gram. However, longer term follow-up is needed to confirm the number of hearing-impaired children not identified by the screen.

**Electrophysiological methods of screening**

The test that has been evaluated for screening a newborn population is auditory brainstem evoked response. Different figures emerge from different centres, which may well reflect differences in the infants tested as well as methodology used. In the UK, Bradford et al (1985) screened special care babies using 100 dB SPL clicks, and reported absent responses in 8.2%, that is 10 babies, with nine of these having sensorineural hearing loss. So far no false negatives have been reported.

In Canada, the results from a number of centres are reported by Sanders et al (1985). Their criteria for failing auditory brainstem evoked responses are taken as absent response at 30-40 dB, often combining with abnormal morphology at 60-70 dB. Using these more stringent criteria, 10-30% of babies in neonatal intensive care units will fail the first auditory brainstem evoked response screen. When retested 2-4% of the high-risk infants and those in the intensive care units are found to have a moderate to profound sensorineural hearing loss, with a further 6-8% having unilateral or conductive losses. These results are similar to figures reported by Galambos, Hicks and Wilson (1984).

All reports agree that auditory brainstem evoked responses provide overall accurate diagnostic information on hearing levels in almost all newborns tested. However, the test is time consuming and requires experienced personnel as well as specialized equipment. Because of the high cost and lower yield it is difficult to justify screening the whole neonatal population by this means. However, in the at-risk group, including those babies in the special care unit, screening by auditory brainstem evoked responses is justifiable because of the higher yield of hearing-impaired children within this much smaller population.

Within the special care unit, behavioural testing is being evaluated, the main justification being that less skilled personnel are needed to carry out these forms of screening. There is a high false positive rate with many infants needing follow-up by auditory brainstem evoked responses. In view of the relatively high incidence of hearing loss and the additional information available regarding neurological function when using auditory brainstem evoked responses, this latter technique would seem a more sensible tool to use for the primary screen.

**7-9 months screen**

Whether or not neonatal screening is being used in a community, the hearing screen at 7-9 months of age continues to play a role in the identification of hearing-impaired children. In areas where the technology needed to carry through a neonatal programme is not available, this later screen provides the first opportunity to identify affected children. Even when children have undergone an earlier screen it is possible that they have a hearing loss, either progressive in nature, or missed by the earlier test because it is a mild loss or because of administrative errors. The screen at 7-9 months is also an opportunity to identify those children with middle ear disease, who can then be followed-up in case intervention is needed later.
However, if this screen is to play an important part in identifying hearing impairment, the testing needs to be improved so that more reliable results are obtained than those documented previously. It is important that those who carry out the screening are both well trained and regularly assessed to ensure accuracy of the test method. The rooms used for testing must be reasonably quiet and the background noise and the level of screening sounds should be monitored with a sound level meter. The test sounds should cover the full range of frequencies, with different programmes employing a variety of noise makers.

It is also important, if the screen is to be of value, that it reaches as many infants as possible. Attempts are being made to educate professionals and parents regarding the importance of hearing loss in the young child, and the range of normal development. In Canada, the task force on Childhood Hearing Impairment (1984) has prepared information kits designed to increase the knowledge of health care professionals regarding hearing loss, to promote awareness of the preventative aspects and encourage earlier referral for diagnosis and management. This is to be distributed principally to primary care physicians, paediatricians and otolaryngologists. A speech and hearing check list modified from one produced by the Alexander Graham Bell Association for the Deaf is used as a guide to normal development.

In the UK, a checklist of normal hearing behaviour has been designed by McCormick (Nottingham) to be given to parents following delivery. It is designed to encourage parents to seek advice from their health visitor if they are concerned about their child's hearing, and an open access audiology service is provided to test infants at any age, with routine health visitor screening to supplement this. McCormick et al (1984) have documented identification of hearing loss at a much lower age following this approach.

**Experimental methods of screening in the first year**

**Assessment using the postauricular myogenic response**

This response was first described by Kiang et al (1963) and recently a new instrument for detecting the response has been suggested as suitable for use in an 'objective' test for infant screening (Flood et al, 1982). This test was evaluated using a portable instrument on infants at around 6 months of age. Such a test was suggested because it was said to be easy to carry out and did not need the quiet conditions and skilled personnel of the routine distraction tests. A click stimulus was used at 60 dB HL and, if necessary repeated at 80 dB HL. Children who did not pass the test were further assessed using conventional methods. The place of such a method in screening infants is still being assessed, and it is suggested that it may be suitable for a wide age range, excluding neonates following a feed, for whom it is unreliable. The preliminary trials were said to demonstrate that a positive response, while not giving a precise hearing threshold, does indicate that the infant has adequate hearing to develop normal speech.

**Otoacoustic emissions**

These emissions were first described by Kemp (1978) following acoustic stimulation, and trials are being undertaken to evaluate the detection of such emissions as a means of screening for hearing impairment (Johnsen, Bagi and Alberling, 1983). Use of this technique remains experimental at this time.
Preschool screening

Screening of hearing between the ages of 1 and 5 years is not universal, but is carried out in individual areas at various ages. In practice, it is often combined with an assessment of language development and the age chosen is around the third birthday, because children of this age are more cooperative in both aspects of the assessment. However, it could be argued that the screening should be carried out earlier so that remediation can be started in those who need help.

The tests used to screen hearing are usually a conditioning technique in free field using 'go', 's' or a range of pure-tone or warble-tone stimuli, plus a test of speech discrimination, as described previously. This is supplemented in some areas by tympanometry. This screen is carried out in order to identify those children with sensorineural losses missed by earlier screens, particularly those with mild or high-frequency losses, and also those children with persistent middle ear effusions, with resultant hearing problems.

School screening

Screening of children for hearing problems has been carried out for over 50 years in schools in various countries, but the distribution of screening is patchy. Reports on the results of screening consistently show that 4-6% of those tested have hearing impairment and Fisch (1981) argued that school screening was very effective and should be extended to all areas. A sweep test is frequently employed using a stimulus of 20-25 dB HL at frequencies 250 Hz-4 kHz, and this is supplemented in some areas by speech tests and tympanometry.

Bennet and Mowat (1981) reported on the validity of impedance measures in school screening and found that moderate sensorineural losses were not identified by impedance studies including stapedial reflex thresholds, as might be expected, and that tympanometry failed a significant number of children who passed a sweep test carried out at the same time. The two procedures took the same length of time. Tympanometry alone thus appears to be too sensitive as a tool for routine screening, particularly in view of the fluctuant nature of many middle ear effusions, although if repeated it will identify those children with persistent problems. Bluestone et al (1983) felt that screening tympanometry was best confined to the high-risk groups, such as children with Down's syndrome, cleft palates or language delay.

Haggard, Wood and Carroll (1984) argued that the best combination of tests for school screening would be otoadmittance measures to identify pathological problems, and a speech test in noise on those who failed the first screen to identify those with hearing disability. These latter children would then be referred for further assessment, plus a few referred directly following the otoadmittance screen because of abnormalities such as very high compliance. This was felt to be an economic method that would identify virtually all children with problems, with the assumption that children with congenital and severe, acquired hearing losses should already have been identified.

Whichever method of screening is favoured, and at whatever age, there is agreement between the professionals involved that it continues to be an essential tool in identifying hearing impairment in infants and children, so that the adverse consequences of hearing loss can, so far as possible, be averted.