NEWBORN HEARING SCREENING AND ASSESSMENT

Guidelines for the early[1] audiological assessment and management of babies referred from the newborn hearing screening programme

Version 4

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Based on guidelines produced for NHSP (England)
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[1] The term "early" is used to denote the period between referral from the newborn screen and the time at which reliable behavioural assessment may be undertaken i.e. 7-8 months corrected age.

Main amendments from previous version (version 3)

Section number	Section description	Amendment
200	Parents observing waveforms during a test	Removed
240	Clear that ABR only present at high levels	Recommended to start with ckABR
330	Recommended start level	Recommended start level of 40-45 dBnHL NB – not a pass result for NBHSW
340	Recommended stimulus steps	Added
370	Tympanometry	Recommended that BC ABR is used as the primary tool to determine conductive component
420	Maximum stimulus levels for earphones and inserts	Added
455	Provisional correction values to estimate the PTA threshold - stage 1 and stage 2	Added
529	Prediction of PTA from ASSR –stage 1 and stage 2	Added
550-570	Insert thresholds	Added to headphone threshold management plans
Appendix C 840	Masking	BC stimulus should be first corrected for age.
Appendix E 990	Insert earphones	Further information added
Appendix I		Added

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Scope

This document gives guidance on the early audiological assessment and management of babies referred from the newborn hearing screen. It describes some prerequisites for the provision of the service, issues related to the timing and organisation of the service and issues related to the choice, timing and order of test procedures. Detailed protocols relating to the test procedures are available on the NHSP website (http://hearing.screening.nhs.uk) and are listed in Appendix A.

NBHSW has adopted these guidelines with permission of the author. The following points need to be noted.

- **There are minor modifications to allow for the differences in service models and information systems.**
- **The main changes/additions from version 3 are highlighted on page 2**
- **In Wales all traces should be peer reviewed and all sites should be participating in audit**
- **Audiologists are responsible for reviewing the test options and equipment protocols regularly on the nhsp website and alerting NBHSW to any updates**
- **Surveillance guidelines for NBHSW are documented in the Quality Manual**
- **Appendix G is a results record sheet for use by NBHSW audiologists**
- **NBHSW results should be forwarded to the programme managers**

Requirements for a newborn audiological assessment service

Equipment

Equipment to carry out ABR threshold measurement using clicks and tone pips by both air and bone conduction is required. Equipment should undergo an annual calibration to include calibration of the stimulus intensity to the provisional RETSPLs and RETFLs given on the NHSP web site (http://hearing.screening.nhs.uk). Equipment should also undergo regular safety and electrical testing in accordance with local protocols.

Staff training and expertise

Experience and expertise to carry out AC click ABR (ckABR) threshold measurement. Additionally to have, or be working towards acquiring, the expertise to carry out BC ABR and frequency-specific, tonepip ABR (tpABR) threshold measurements. Expertise includes the ability to accurately interpret ABR waveforms, to accurately determine thresholds (including when to use masking) and to know how to deal with unusual or unexpected waveforms or results. In addition staff within the team should have expertise in the discussion of results with parents, the breaking of news and the possible options in management.

Services should be aware of and strive to work within the NDCS guidance on providing family friendly services and working with deaf children under two years old and their families (NDCS, 2002).

The number of hearing assessments following the newborn screen should be relatively small (up to 3% of total births) and to build up skills and expertise it is recommended that departments forge links with nearby centres of excellence, local teaching hospital or neighbouring districts to help find the best way to provide a quality service for these children. Staff training is available both at national course level and by linkage with centres of excellence.

It is recommended that a process for auditing of results is in place, including peer review of traces and threshold estimation, and test procedures.

Accommodation

A quiet environment adequate for all recommended test procedures is required. This is usually achieved by a suitable sound-treated/proofed room. There should also be family and child friendly waiting room accommodation with space to feed, change and settle babies.

Communication with parents: Before the appointment

The leaflet “Your baby’s visit to the audiology clinic” should be given to parents along with local contact information. Requests for audiological assessment appointments must be passed to the audiologists as soon as possible and at least within 48 hours of the screen. The standard written appointment letter should be sent by the audiology department. Contacting the parents by phone prior to the appointment may be useful to ensure attendance.

Communication with parents: During and after the appointment

Assessment should be carried out under the supervision of, or in conjunction with, senior clinical staff who have the expertise to explain and discuss the results with families, answer questions and provide support. It is not acceptable for families to have to wait for days for information or explanation of results

The reason and procedure for each test should be explained to the parents. It is also important to go through the test results in detail. When an ABR threshold has been obtained it can also be useful to get the parents to listen to the threshold stimulus level so that they are aware of the sound level at which a response is obtained (in doing this bear in mind the offset between the ABR threshold and the psychoacoustic/PTA threshold).

Parents should be provided with appropriate information at the end of the assessment. This may include the standard letter containing the checklist, where hearing is normal, or contact numbers where normal hearing has not yet been determined. Where a hearing loss is confirmed the appropriate leaflet “Your baby has hearing loss” and early support information should be given. Other leaflets for mild or unilateral hearing loss will be available.

Timing of tests

The chances of being unable to complete the assessment increase beyond a corrected age of 8 weeks and become high over 12 weeks. Therefore it is recommended that the first assessment is carried out at about four weeks corrected age and subsequent assessments soon after this, unless there are good clinical reasons for delaying. For some premature babies, where screening has taken place prior to full term, it is reasonable to carry out or at least commence the assessment before 4 weeks corrected age. Hearing assessment could start from 36 weeks gestational age but, if the threshold is raised, the effect of maturation should be considered and the test should be repeated around the expected birth date (full term) . Clear explanations must be given to parents about the rationale for the timing of assessments. Assessment should be completed by 3 months of age (NBHSW standard).

Sedation

Sedation is not necessary in babies under 3 months of age and should only be used in babies under 12 months of age in exceptional circumstances. One of the advantages of early assessment is that babies can relatively easily be tested during natural sleep. Parents need to be made aware of the requirements for a sleeping or settled baby and where possible appointments should be timed appropriately.

Test options

Click and Tone pip ABR

Although in this document we are accepting the use of ckABR it is very clear that this has shortcomings in terms of frequency specificity (Oates and Stapells 1998) and that it is not possible to tell which frequency region of the cochlea is responding. It is possible that a high frequency loss could be missed if frequency-specific testing is not done. Where the baby is in a good state to test it may be better to start with tpABR. However at the time of writing ckABR is still the only technique carried out in many sites, although tone pips are being introduced. Until those carrying out the tests become more skilled at performing and interpreting tpABR we feel it is acceptable for ckABR to be used as the first test. In cases where it is clear that the ABR response may only be present

at very high stimulus levels, it may be better to start with ckABR in order to establish if there is an ABR response at all before proceeding to frequency specific tpABR.

Auditory Steady State Responses

ASSR is a promising techniques to enable more frequency specific thresholds to be measured in a given test time. However the consensus at present is that it should not be used alone for frequency specific assessment of hearing in babies (Stapells 2005). It is recommended that centres at present use tpABR or tpABR with ASSR. A protocol for NHSP centres in England to perform ASSR for the purpose of evaluation is available from the NHSP website or first editor of this protocol.

Sequence of tests

An audiological assessment that yields maximum information requires the baby to be asleep for most of the tests, since sleep is essential for electrophysiological testing. The tester therefore has a limited time frame in which to maximise the information achieved.

The order of the tests undertaken will be greatly influenced and compromised by the sleep state. A practical maxim which is appreciated by all who test at this age is “Never wake a sleeping baby”.

The electrodes can be attached whilst the baby is still awake. Otoscopy, tympanometry and the recording of OAEs may also be undertaken whilst the baby is awake but settled. However sleep is essential for the electrophysiological procedures.

If otoscopy, tympanometry or OAE testing are required as part of the diagnostic assessment, and the baby is awake at the beginning of the session, it may be possible and advantageous to carry these out at the start. However if the baby is already asleep then one would generally move immediately to electrophysiological and leave these other tests to the end of the assessment because of the risk of waking the baby.

If the baby is awake the electrodes for ABR are best attached before they go to sleep, as abrading the skin and securing the electrodes inevitably disturbs the baby. Electrode placement that will enable all the anticipated electrophysiological tests to be undertaken should be attached at this stage. Note that individual electrophysiological protocols may require the use of single or double channel recording, with different electrode montages. Adding electrodes mid-test risks waking the baby, and losing a testing opportunity.

The use of external earphones rather than inserts also minimises the risk of disturbing a sleeping baby.

The purpose of the audiological assessment is to determine for each ear if a hearing impairment is present and, where present, to determine the degree, type and configuration of the hearing impairment in as much detail as possible and as soon as possible.

The time that a baby is in a suitable state for testing can vary from around 15 minutes to an hour, so flexibility is required in the testing process. The clinically more important tests in each case should be carried out first. Usually the most important first step is to establish the degree of hearing impairment present in each ear, closely followed by whether it is sensorineural or conductive. The exact order and time spent on each test will vary and the tester needs to make contingent decisions as the test session progresses. The testing may not be completed in one session particularly if hearing impairment is present. A further test session should be carried out as soon as possible and preferably within 2 weeks.

Where the results do not meet the discharge criteria (see later) it is important to carry out a sufficient range of tests to determine the nature of the hearing impairment. The results from these tests need to be combined and interpreted as a whole. Hearing impairments may be conductive, sensorineural or mixed. In most cases BC ABR supported by tympanometry (where appropriate)

will help determine the nature of the hearing impairment and help guide management. The ckABR latency-intensity function (where measured) may be of use but should be interpreted with caution.

One important point is that even if MEE is thought to be present it is essential to proceed to ABR to establish the degree of hearing loss. It is not acceptable to delay ABR threshold measurement whilst the MEE resolves or is otherwise managed.

The following section describes a typical test sequence. Further examples are given in appendix B to illustrate typical testing sequences in practice.

Note that both ears must be tested for all babies irrespective of whether the screen referral was unilateral or bilateral. For unilateral referrals it is advisable to start with the 'good' ear to establish normality (or otherwise) there first. Although it is desirable to know the degree of hearing impairment in the affected ear, it is more important for the baby's development to establish the presence of normal hearing in the good ear. The baby may wake before testing on the second ear is complete and, if the 'good' ear was tested second, normal hearing in this ear will not have been established.

Bearing in mind the above comments, the test order suggested is as follows

1. OAEs. In the Welsh protocol, all babies referred for assessment should have ABR testing and therefore OAEs should only be carried out first if the baby is awake.

If OAEs are not performed at this stage they should always be recorded to distinguish between AN/AD and sensorineural hearing impairment so as to inform further management. CM should be measured in any cases where the recording of the OAE is compromised e.g. by a conductive loss (refer to AN/AD protocol).

2. AC ckABR to estimate hearing threshold. Mask where necessary – see appendix C. An alternative is to start with 2kHz or 4kHz tpABR.

For the most efficient use of time, it is suggested that testing should usually start at a low intensity unless there are good reasons to do otherwise. For the initial diagnostic appointment, it is recommended that the start level should be 40 to 45dBnHL. The rationale for this is that, for babies with no significant hearing problems, a strong response should be obtained at this level and, if the baby wakes before further testing, the possibility of the presence of a significant hearing impairment has been ruled out. **However this not a pass level for NBHSW and further testing should be arranged.**

Changes in level for click and tone pip ABR should normally be in 10dB steps depending on the nature of the case. Occasionally e.g. where there is strong recruitment a 5dB step may be useful but care should be taken not to spend time on small changes in stimulus levels at the expense of producing definitive outcomes at 10dB intervals around threshold. There may also be occasions where it is better to use larger steps, for example where a baby may only stay asleep for a few test levels. As an illustration of this, by testing at 40, 60 and 80dBnHL and determining that the ABR threshold lies between 60 and 80dBnHL, a more useful outcome is achieved than by having increased the level in 10 dB steps from 40dBnHL and only being able to determine that the ABR threshold is above 60dBnHL.

If there is no response at the maximum permissible stimulus level (see section below – stimulus level in babies), or only abnormal waveforms at high stimulus levels, consider the possibility of AN/AD (see NHSP AN/AD protocol) and switching (at this stage or after click BC ABR) to tests for cochlear function.

If responses are obtained at 35dBnHL (refer to the click ABR protocol for the definition of a response) in both ears no other testing will usually be required.

3. BC ckABR: If AC threshold is raised, establish the conductive component. Masking may be required (refer to appendix C). The effective stimulus level is higher in babies than in adults. A correction should be applied (refer to appendix D or the click bone conduction ABR protocol).

4. AC tpABR or AC tpABR and ASSR: If click ABR thresholds are in the mild to moderate range then a 4kHz tpABR is the easiest and probably the most important response to record. This should be followed where possible with a low frequency tpABR. (1kHz is suggested). Where the click ABR threshold is ≥90dBnHL, low frequency (suggest 1kHz) TP ABR may be more important to determine the possible presence of only low frequency hearing. A 4kHz tpABR test can be carried out but, if there is no click ABR response, it is unlikely that there will be a 4kHz tpABR response at the same stimulus level.

5. BC tpABR: Consider whether this is more relevant than AC tpABR in each case. Note that BC ASSR is not recommended at present due to BC artefact issues with current ASSR equipment.

6. Tympanometry: This may provide supporting evidence for a conductive component to a raised ABR threshold although it is important to use BC ABR as the primary tool to determine this. Tympanometry is particularly important where the BC ABR threshold is above the maximum available stimulus level and the AC threshold is at a level higher than this. In this case there is doubt as to whether the loss is purely sensorineural or whether there is a conductive component. A high frequency probe tone (1kHz is recommended - see tympanometry protocol) should always be used for babies under 4 months.

Reactions to stimuli. Throughout all tests note any consistent behavioural reactions, and the type and level of stimuli to which they are observed.

ABR testing: technical considerations

Stimulus level in babies - earphones, insert phones and ear muffs

It is important to be aware of the limitations in calibration of ABR equipment. Even when calibrated using the agreed RETSPLs and RETFLs the stimulus levels are only correct for adults. In babies the stimulus levels will be affected by

- For AC:- the ear canal volume enclosed by the transducer.
- For BC:- the effect of age and skull fusion on bone conduction transmission. Details of this are given in appendix D.

(With insert phones the stimulus level could be 10 to 20dB higher due mainly to the much smaller ear canal in babies and uncertainty of insertion depth. For more information on this refer to appendix E. For AC with earphones the differences will be small and can be ignored for practical purposes.)

Both supra-aural earphones and insert earphones are currently used in practice and the use of either is acceptable if the points noted below are adhered to. Ear muffs, as used in screening, should only be used where their calibration for use in babies is fully understood. Some users prefer supra-aural earphones as they feel that there is less disturbance of the baby. Insert earphones do offer some advantages over super-aural earphones. In particular (a) the stimulus artefact is less as the transducer can be placed away from the baby; (b) there is increased intra-aural attenuation reducing the need for masking of crossed responses and (c) it is easy to block the acoustic signal by clamping the sound tube for use in CM recording and control tests. The main drawback is the greater uncertainty of the stimulus level resulting from the variation of the enclosed ear canal volume in the neonatal ear . The exception to this is where a probe microphone is used in conjunction with the insert earphone to measure the stimulus level within the neonatal ear canal[2]. If insert earphones are used it is important that they are calibrated to the NHSP RETSPLs and the uncertainty of the stimulus level is fully understood. Proposed offset

[2] The microphone monitors the sound level in the ear canal and corrects for differences in ear canal volume. At present such a probe capable of stimulating to the high levels needed for assessment (135dB ppe SPL) is not thought to be commercially available.

values to estimate the hearing threshold from the ABR thresholds, measured using earphones or insert earphones, are given in the section on prediction of PTA from the ABR threshold.

They may come a point in the assessment, particularly where aiding is being considered , for the stimulus level in the ear canal to be measured using a probe microphone. This will enable the ABR threshold to be determined in dBSPL and the RECD (real ear to coupler difference) to be measured so assisting with hearing aid prescription. This is outside the scope of this protocol.

Maximum stimulus levels

Earphones

For earphones the maximum recommended stimulus level when the equipment is calibrated to the NHSP reference levels is given in table 1 below. These values are based on a maximum peak to peak stimulus level at or below 135dBSPL as measured on a standard coupler.

Table 1. Maximum recommended stimulus levels for earphones (dBnHL)

	Click	**500Hz**	**1000Hz**	**2000Hz**	**4000Hz**
Exact value for 135dBSPL pk-pk	104	112	116.5	110	107.5
Recommended value (rounded down to nearest 5dB)	**100**	**110**	**115**	**110**	**105**

Inserts

The equivalent exact figures for insert phones using NHSP reference values for a ER-3A insert phone with a IEC 60318-4 occluded ear simulator are given in table 2 below.

Table 2. Maximum recommended stimulus levels for insert phones (dBnHL)

	Click	**500Hz**	**1000Hz**	**2000Hz**	**4000Hz**
Exact value for 135dBSPL pk-pk	99.5	111.5	113.5	106.5	102.5
Recommended value*	**85**	**100**	**100**	**95**	**85**

*These values are provisional. See appendix E for derivation.

Warning. As can be seen from the table above care must be taken when presenting sounds using inserts to allow for the effect of the smaller neonatal ear canal volume. The maximum values in the table should be adhered to (when the equipment is set to NHSP reference levels) unless the insert earphone probe includes a microphone to automatically adjust the stimulus level for ear canal volume.

Definition of ABR threshold

The definition of ABR threshold varies between centres. It is proposed that for the purposes of reporting and entry of the results onto eSP a common definition is used, as follows:

ABR threshold is defined as "the lowest level at which a clear response is present with a recording at 5 or 10dB below this level at which there is no recordable response".

This definition is used for the management criteria below

Prediction of PTA from the ABR threshold

It is important to provide an estimate of the expected PTA thresholds from the measured ABR thresholds. The term dBeHL has been proposed to denote this estimate. Assuming that the hearing remains unchanged an estimate can be made with knowledge of the following factors.

1. The difference between the stimulus level at the ear between adults and babies.
2. The difference between the ABR and PTA thresholds in adults.
3. The difference between the ABR threshold in adults and babies.

Further details on these factors are given in Appendix E.

Provisional correction/offset values to estimate the PTA threshold from ABR threshold

The following tables gives a provisional set of values for use in estimating the expected PTA from the ABR threshold when using earphones, inserts or a bone vibrator, where the stimulus is calibrated using the adult RETSPL or RETFL data available on the NHSP website. Details of the derivation of the values in the tables are given in appendix E.

Stage 1. Correction for the difference between the stimulus level in adults and babies.
This is required for inserts and bone vibrators when testing babies at less than 3 months corrected age. As noted above the reasons for this are the smaller ear canal volume in the baby and the effect of age on the bone conducted stimulus.

Table 3. Value to be added to the stimulus level in dBnHL to give an estimate of the true stimulus level in the baby.

	Click	500Hz	1000Hz	2000Hz	4000Hz
Insert	10	5	5	5	10
Bone vibrator	Refer to table in appendix D	0*	0*	0*	0*

* The authors are not aware of any published data for the bone vibrator when using tone pips. The recommendation is to use no correction until data is available.

Stage 2. Correction/offset for difference between ABR threshold and estimated PTA threshold for ABR thresholds > 40dBnHL*.

*The table is for use where the ABR stimulus levels are >40dBnHL (after applying the stage 1 correction). This covers the target cases for the NHSP.

Where the ABR threshold is ≤40dBnHL, after applying stage 1 correction, the data in appendix E indicates that greater values may be more appropriate. Provisionally it is recommended that the values in the table are also used for ABR thresholds between 35dBnHL and 40dBnHL. 35dBnHL is the level at which the ABR results are considered to indicate satisfactory hearing (see later section on further testing and management).

Table 4 Value to be subtracted from the ABR thresholds (as defined in the section on definition of ABR threshold above) to estimate the PTA thresholds (dBeHL). For inserts and bone vibrators the ABR thresholds will have been corrected by stage 1 first.

Click	500Hz	1000Hz	2000Hz	4000Hz
5	20	15	10	5

Notes

1. Note that for some stimuli the value of the estimated PTA threshold may be greater than the ABR threshold measured in dBnHL. For example when using an insert earphone a 4kHz tpABR threshold of 60dBnHL will give a dBeHL value of 65dBnHL.

2. Clicks are broadband stimuli and pure tone thresholds can not accurately be predicted. The ABR electrical activity recorded in response to a click stimulus comes predominately from the region 1- 8kHz. The ckABR threshold relates to the best region of hearing in this range.

3. The above values give the most likely estimates of the PTA from the ABR thresholds and the report should include an indication of the uncertainty. For example, the 5 to 95% confidence levels for the estimate of the pure tone threshold from the tpABR threshold are

of the order of ±15dB (Stapells 2000)'.For clicks, 2000Hz and 4000Hz tone pips, where the offset is less than 15dB, the 95%[3] confidence intervals should be stated as between the 'actual' ABR threshold and 15dB better than the estimated pure tone threshold. E.g. if the ABR threshold, using earphones, is 70dBnHL at 4kHz, the estimated pure tone threshold will be 65dBHL (subtracting an offset of 5dB) with a 95% confidence range of 50 to 70dBnHL. For inserts the 'actual' ABR threshold should be taken as the value after the stage one correction for ear canal volume effects. Using the same example a 4kHz tone pip at 60dBnHL delivered by insert phones will be equivalent to a 70dBnHL stimulus delivered by an earphone (adding the 10dB correction in stage 1). The estimated pure tone threshold will again be 65dBnHL with a 95% confidence range of 50 to 70dBnHL. **Important note:** For insert earphones the correction for ear canal volume effects may be used in clinical reporting but the threshold in dBnHL (in this example 60dBnHL) should be entered on eSP (see later section on data entry into eSP)

4. These data are provisional. The latest version of the protocol should be checked on the NHSP website for updates.

Prediction of PTA from the ASSR threshold

As for ABR it is necessary to apply a correction/offset to the ASSR threshold to obtain an estimate of the expected PTA threshold (dBeHL).

Stage 1. Correction for the difference between the stimulus level in adults and babies.
As for ABR it is first necessary to correct for the difference between the stimulus level in adults and babies. This is required for inserts and bone vibrators when testing babies at less than 3 months corrected age. The values for tone pips in table 3 should be used.

Stage 2 Correction/offset for the difference between the ASSR threshold and the estimated PTA threshold for ASSR thresholds > 40dBnHL(after applying stage 1 correction).
Table 5 below gives a recommended provisional set of values to be used for ASSR thresholds >40dBnHL. The derivation of these values is given in appendix E. The notes 3 and 4 above on the prediction of the PTA from ABR threshold applies to ASSR. The note on ABR thresholds of 35 to 40dBnHL also applies.

Table 5. Values to be subtracted from the ASSR thresholds to estimate the PTA thresholds (dBeHL). For inserts and bone vibrators the ASSR thresholds will have been corrected by stage 1 first.

500Hz	1000Hz	2000Hz	4000Hz
20	15	15	15

Further testing and management based on ckABR

Babies with AC ckABR thresholds >35 dBnHL require further assessment including BC ckABR, tympanometry, tpABR as described above. Services that do not yet have the facility to carry out these measurements need to be aware of the limitations of relying on AC ckABR thresholds to predict the longer term audiological status and the need to exercise caution in the management of these babies particularly where the thresholds are in the 40 – 75 dBnHL range. Appendix F gives data relating to the positive predictive value (PPV) of AC ckABR thresholds.

[3] Warning: It should be remembered that 5% of babies will have true thresholds better than this 15dB confidence interval, potentially leading to over amplification where a hearing aid is fitted. In addition the effect of smaller ear canal volumes in babies will be to raise the sound pressure level unless the hearing aid gain has been fully compensated for this effect. .

Headphone Thresholds ≤ 35 dBnHL / Insert thresholds≤25dBnHL

Babies with AC ckABR thresholds of ≤35 dBnHL are considered to have satisfactory hearing and may be discharged unless the baby fits the criteria for targeted distraction testing. If this is the case the baby should be referred for a follow-up test at 7- 8 months corrected age.

Headphone Thresholds 40 to 45dBnHL / Insert thresholds 30 to 35dBnHL

This group may have a minor hearing impairment (which could be temporary or permanent) or there may be another reason for the raised ABR threshold. Note that BC ABR can be used to determine if a significant part of the raised threshold is due to a conductive component.

Headphone Thresholds 50 to 75 dBnHL / Insert thresholds 40 to 65dBnHL

These babies require further assessment with BC ABR, tympanometry and tpABR. If there is an air bone gap the most common explanation is MEE. If the bone conduction thresholds are normal and tympanometry is consistent with MEE follow up could be left until 8 months. If the bone conduction thresholds are not normal or the tympanometry results are not consistent with MEE other management will be appropriate. This may include referral to ENT/Audiovestibular Medicine , repeat ABR, myringotomy and theatre ABR[4] (where the results are consistent with MEE), provision of amplification (perhaps on a trial basis) and referral to early intervention services. The actual management approach adopted will depend upon the clinical findings including the likely degree of hearing loss, the developmental status of the baby including the existence of other disabilities and the views and wishes of the parents.

Headphone Thresholds ≥80 dBnHL / Insert thresholds ≥70 dBnHL

These babies almost certainly have a PCHI, (see table appendix F) or AN/AD . However care should be taken in the use of any labels such as ‘severe’ or ‘profound’ as the true PTA threshold may differ considerably from the measured ABR threshold. Further assessment with BC ABR, tympanometry, tpABR (along with confirmation that other factors that affect the ABR such as AN/AD or hydrocephalus are not present) give greater confidence in being able to predict the PTA of each ear

Reporting

At each test session results should be documented in detail as the session proceeds. An example worksheet is given in appendix G.

It is important that appropriate professionals are kept informed of the outcome of each episode of the assessment (even if few or no results are obtained). An example of a report is shown in Appendix H. Non-attendance should be reported appropriately.

The report should include:

- A summary of the electrophysiological results including warnings where the threshold has not been accurately determined, where threshold is above the maximum available stimulus level or where the results are subject to poor recording conditions.
- A note of any other factors that might effect the estimate of the hearing threshold, as measured by the ABR (e.g. possible AN/AD, evidence from other tests of possible neurological damage to the brain)
- A statement of the relationship between the electrophysiological thresholds and the predicted psychoacoustic threshold
- A report of any consistent behavioural reactions to the stimuli used and at what level. E.g. ‘No behavioural responses were observed to any of the stimulus level used. For AC clicks this was up to 70dBnHL in the left ear and 75dBnHL in the right ear.’
- A comment on OAE results, if this is relevant.
- A comment on tympanometry/ stapedius reflex results (if done)
- A note of why any tests were not done, if this is relevant.

[4] If theatre ABR involves grommet insertion be aware of the possibility of a temporary threshold shift.

- A summary of what the results imply about the type, configuration and level any hearing impairment recorded.
- A note of the information given to parents about the test results.
- A note of follow-up arrangements

A shorter report with a summary of the clinical findings should be sent to the GP,HV and other professionals.

Action after hearing assessment

Children whose hearing is satisfactory on assessment may still require further follow-up (refer to surveillance guidelines)

For those children whose results do not show satisfactory levels of hearing there must be clear and agreed pathways for referral to other relevant services (Education, Audiology and audiological medicine, ENT, Paediatrics, voluntary sector, social care etc). For children with confirmed hearing impairment requiring educational input, this means same day telephone referral to education, with a clear system for rapid visit and support, and initiation of appropriate audiological and educational management

It can be useful to keep a checklist with the notes to ensure that the appropriate actions have been initiated. The following items should be included:-

1. Parent information (written and verbal) complete
2. Results of hearing assessment documented and copied to all appropriate professionals including GP and HV
3. Medical consultation arranged and carried out.
4. Referral to or consultation with education arranged (with appropriate consent)
5. Appropriate referrals to other professionals made
6. Follow-up programme of further hearing tests organised.
7. Provision of amplification where appropriate.

Glossary

ABR	Auditory brainstem response
AC	Air conduction
AN/AD	Auditory Neuropathy/Auditory dys-synchrony
ASSR	Auditory steady state response
BC	Bone conduction
ckABR	Click-evoked ABR
CM	Cochlear microphonics
Corrected age	Age adjusted for prematurity (based on 40 week term)
dBeHL	Estimated PTA from electrophysiological thresholds
dBnHL	Stimulus level relative to adult psycho acoustic threshold. In these guidelines the NHSP reference equivalent threshold levels are used.
DPOAE	Distortion product otoacoustic emissions
MEE	middle ear effusion
NICU/SCBU	Neonatal intensive care unit / Special care baby unit
PCHI	Permanent Childhood Hearing Impairment - defined here as ≥40dBHL average of 500,1000,2000 & 4000Hz PTA thresholds. It includes both sensorineural and permanent conductive impairments.
PPV	Positive predictive value
PTA	pure tone audiometry/audiogram
RETFL	Reference equivalent threshold force level
RETSPL	Reference equivalent threshold sound pressure level
TEOAE	Transient otoacoustic emissions
tpABR	tone-pip evoked ABR

References

American Speech-Language Hearing Association (2004). Guidelines for the audiologic assessment of children from birth to 5 years of age.

National Service Framework for children (executive summary). Dept of Health (2004) http://www.dh.gov.uk/en/Policyandguidance/Healthandsocialcaretopics/Childrensservices/Childrenservicesinformation/DH_4089111

NDCS (2002). Quality Standards in the Early years: Guidelines on working with deaf children under two years old and their families.

NHSP (2002-2005) website (http://hearing.screening.nhs.uk) for NDCS leaflets and protocols
Your Baby's visit to the Audiology Clinic NDCS 2002
Your baby has a hearing loss NDCS 2002
Your baby has a hearing loss in one ear NDCS 2005
Your baby has a mild hearing loss NDCS 2005

Hyde M (2005). Infant Hearing Program (Ontario, Canada) . Audiological Assessment Protocol and Support Documentation.

Picton TW, Sasha John M, Dimitrijevic A, Purcell D (2003).Human steady-state responses. International Journal of Audiology 42 177-219.

Oates P and Stapells DR (1998). Auditory brainstem response estimates of the pure tone audiogram: current status. Seminars in Hearing 19(1) 61-85.

Rance G and Tomlin D (2006). Maturation of the auditory steady state response in normal babies. Ear & Hearing 27 20-29.

Sininger Y S, Abdala C, Cone-Wesson B (1997). Auditory threshold sensitivity of the human neonate as measured by the auditory brainstem response. Hearing research 104 27-38.

Stapells DR (2000). Threshold estimation of the tone evoked auditory brainstem response. A literature Meta-Analysis (2000). J Speech Lang Path & Audiology 24(2) 74-82

Stapells DR (2005).Website http://www.audiospeech.ubc.ca/haplab/clinic.htm

Voss SE and Herrman BS (2005). How does the sound pressure generated by circum-aural, supra-aural and insert earphones differ for adult and infant ears? Ear and hearing, Dec 2005, 636-650.

Watkin PM, Baldwin M. (1999) Confirmation of deafness in infancy. Arch Dis Child 81:380-389

Webb HD.(1993). Auditory screening in high risk neonates : An evaluation of the bone conduction ABR. M Med Sci thesis University of Sheffield, UK.

Appendix A: Protocols available on the NHSP website.

Newborn and early Testing

Click ABR testing in babies
Bone conduction ABR testing in babies
ABR testing in babies using tone pip stimulation
TEOAE testing in babies
Tympanometry in neonates and infants under 4 months
Automated ABR in babies
Behavioural observation audiometry testing in babies

Other tests from 6 months of age

Distraction diagnostic test protocol
Visual reinforcement audiometry testing of infants

Other relevant protocols

Assessment and Management of Auditory Neuropathy / Auditory Dys-synchrony: A Recommended Protocol
Medical Management of infants with significant congenital hearing loss identified through the national newborn hearing screening programme: Best Practice Guidelines

Appendix B: Some examples of different hearing impairments and expected test results.

Example 1 – Unilateral conductive

Test	Right	Left
AC click ABR	Response at 35dBnHL	Threshold = 60dBnHL
BC click ABR		Threshold = 25dBnHL
AC TP 4kHz ABR	Response at 40dBnHL	
TEOAE	Recordable	Not recordable

Comments:
A clear ckABR response has been obtained in the right ear at a level (35dBnHL) which is considered to be "within normal limits". For the left ear BC ABR is at a level (25dBnHL) where masking is not required. The BC threshold level is such that results indicate a purely conductive loss in the left ear. A 4kHz tpABR was carried out for right ear to check for the presence of good high frequency hearing. The absence of TEOAE in the left ear is expected from the conductive loss.

Example 2- Bilateral conductive

Test	Right	Left
AC click ABR	Threshold = 60dBnHL	Threshold = 60dBnHL
BC click ABR	Threshold = 25dBnHL	Threshold = 20dBnHL
BC TP 4 kHz ABR	Response at 25dBnHL	Response at 25dBnHL
TEOAE	Not recordable	Not recordable
Tympanometry (High freq.)	No peak present	No peak present

Comments:
The BC ckABR thresholds are both at a level where masking is not required. The BC threshold levels are such that the results indicate a purely conductive loss in both ears. A 4kHz BC tp ABR was carried out to check for the presence of good high frequency hearing. The absence of a peak for tympanometry and the absence of TEOAE with BC ckABR thresholds of 25dBnHL is supportive of MEE as the cause of the apparent conductive loss.

Example 3- Unilateral Sensorineural loss

Test	Right	Left
AC click ABR	Response at 35dBnHL	Threshold = 60dBnHL
BC click ABR		Threshold = 55dBnHL
AC TP 4kHz ABR	Response at 40dBnHL	Threshold = 60dBnHL
TEOAE	Recordable	Not recordable

Comments:
A 4kHz tpABR was carried out for right ear to check for the presence of good high-frequency hearing. The 4kHz tpABR in the left ear was to check for possible ski-slope loss. A 1kHz tpABR in the left ear might also have been carried out to better determine the configuration of the hearing loss. Tympanometry was not required as there was no significant air-bone gap. No masking was required for the BC click ABR threshold in the left ear as the threshold was within 5dB of the AC threshold.

Example 4 – Bilateral sensorineural loss

Test	Right	Left
AC click ABR	Threshold > 100dBnHL	Threshold > 100dBnHL
BC click ABR	Threshold >60dBnHL	Threshold >60dBnHL
AC TP 1kHz ABR	Threshold 105dBnHL	Threshold >110dBnHL
TEOAE	Not recordable	Not recordable
Tympanometry	Peak present	No peak present

Comments:
The absence of an ABR response to clicks at 100dBnHL might have indicated that there would be no tpABR responses. However the 1kHz tpABR test showed some hearing at 1kHz for the right ear. The presence of a peak in the high frequency tympanometry provides evidence of the absence of any conductive component for the right ear. The absence of a peak for the left is inconclusive. The absence of TEOAE is consistent with the absence of AN/AD but a CM test might have been carried out to confirm this.

Example 5 – Bilateral mixed loss

Test	Right	Left
AC click ABR	Threshold = 80dBnHL	Threshold = 80dBnHL
BC click ABR	Threshold = 40dBnHL	Threshold = 45dBnHL
AC TP 4kHz ABR	Threshold = 80dBnHL	Threshold = 90dBnHL
TEOAE	Not recordable	Not recordable
Tympanometry	No peak present	No peak present

Comment:
4 kHz tpABR was carried out to check for a ski slope loss. A 1kHz tpABR might also have been carried out to better determine the configuration of the hearing loss. BC tpABR might also have been useful as a direct measure of the frequency specific cochlear threshold.

Example 6 – Auditory neuropathy

Test	Right	Left
AC click ABR	Threshold > 100dBnHL	Threshold > 100dBnHL
BC click ABR	Threshold >60dBnHL	Threshold >60dBnHL
Cochlear microphonic		Clear response
TEOAE	Recordable	Not recordable

Absence of AC ABR and at 100dBnHL and BC ABR at 60dBnHL indicates PCHI or AN/AD. TEOAE recordable for the right ear is consistent with the presence of AN/AD. The presence of TEOAE means that there was no need to do CM in this ear. CM was required to check for AN/AD in left ear as there was no recordable TEOAE.

Example 7 - Bilateral Atresia

Start with BC testing and check whether thresholds are low enough to exclude stimulus crossover. (<=25dBnHL - with stimulus level corrected for age). Then test by AC ABR to measure the degree of conductive loss (with masking as required).

Example 8- Unilateral Atresia

Test the normal ear first and include frequency specific testing. Then proceed to BC ABR in affected ear and then if possible AC ABR in the affected ear (with masking as required).

Appendix C: Masking

Masking in ABR

The principles of masking are similar to those for pure tone audiometry except that the values of inter-aural attenuation of the stimulus and level of masking required are different which leads to some changes to the normal rules. There are no standards available as yet for the calibration of masking facilities in ERA equipment. There are obviously practical limits to masking levels when testing babies. It is easy to wake the baby up if excessive levels are applied.

Click ABR.

The inter-aural attenuation for AC clicks (difference between the sound level of the stimulus at the ipsilateral ear and the contralateral cochlea) is estimated to have a minimum value of 50dB for babies. This value only applies when using earphones. A provisional value when using inserts is not yet available.

The inter-aural attenuation for BC clicks in babies, based on the BC ABR threshold, ranges from 20 to 30dB (Webb 1993). This is greater than in the adult , the difference being assumed to result from the lack of fusion of the skull bones in babies.

The ABR response to a click stimulus is largely determined by acoustical energy in the range 1 to 8kHz. Given the options available on most equipment broadband or white noise should therefore be used to provide masking. A higher level of masking noise is required to mask clicks compared to a pure tone if these are at the same level in dBnHL. It is recommended that sites calibrate their masking source in terms of effective masking. To carry out this calibration, the stimulus and masking noise should be fed into the same earphone. Effective masking is the lowest masking level where the stimulus is inaudible.

The above information leads to the following proposed rules:(NB values will differ if using insert phones)

1. Masking should be used whenever the AC ckABR threshold difference is > 50dBnHL(allowance should be made for any conductive component of the non test ear – see rule 3)
2. Masking should be applied whenever the BC ckABR threshold difference is >20 dB. (NB this value only applies to babies under the age of 3 months, a lower value should be used for babies over the age of 3 months)
3. Masking should also be applied whenever the AC ck ABR threshold in the test ear is >50dB above the BC threshold of the non test ear.

In practice this leads to the levels for masking described below. Masking should start at these values and be repeated , if possible , with masking levels raised by 10dB to ensure that the ckABR response is not due to the stimulus crossing to the better ear. It is assumed that the masking noise is calibrated in effective level for clicks.

For AC ckABR the initial masking level to the non test ear should be 45dB below the stimulus level to the test ear.
[Masking level = stimulus level – 50 (inter-aural attenuation.) + 5 (margin for error)]
N.B. If the non test ear has a conductive loss then this needs to be taken into account.

For BC ckABR the initial masking level to the non test ear should be 15dB below the stimulus level to the test ear. The BC stimulus should first be corrected for age (see appendix D).
[Masking level = stimulus level – 20 (inter-aural attenuation.) + 5 (margin for error)]

However where the BC stimulus level (corrected for age) is <= 25dBnHL the crossed over stimulus will be at a maximum of between -5 and 5dBnHL. At this level it is very unlikely that there will be an ABR response from the crossed stimulus and the current recommendation is

that there is no need to mask in this situation. However, if possible, the BC ckABR threshold should be measured to below 25dBnHL in the test ear to increase the certainty that in this case there is no crossed response.

Two channel BC ABR

Published reports in the literature have shown that the wave V latency and presence of wave I in the ABR can be used to distinguish between an ipsi-lateral ABR response and a contra-lateral ABR response and so offer an alternative to masking. Details of this method are given in the NHSP bone conduction protocol.

Examples:

AC ckABR.

Test ear AC ckABR threshold = 70dBnHL, AC ckABR threshold <= 20dBnHL in non test ear.

Repeat test at 70dBnHL with masking at 25 dB (effective level)
If the 70dBnHL response disappears increase the stimulus level by 10dB and the masking level by 10dB.(synchronous method – preferred to minimise test time)
Continue until the response reappears in the presence of masking.
Increase the masking noise by a further 10dB and check that the response remains.
Alternatively if the response remains in the presence of masking at the initial level increase the masking noise by a further 10dB and check that the response remains.

BC ckABR.

BC stimulus age correction 6dB, test ear BC ckABR threshold 40dBnHL, AC ckABR threshold <=20dBnHL in the non test ear
Repeat 40dBnHL BC test with masking at 25+6dB (effective level) in non test ear.
If the 40dBnHL response disappears increase stimulus level by 10dB and masking level by 10dB.(synchronous method – preferred to minimise test time)
Continue until the response reappears in the presence of noise.
Increase the noise by a further 10dB and check that the response remains.
Alternatively if the response remains in the presence of masking at the initial level increase the masking noise by a further 10dB and check that the response remains.

Tip: The threshold response is defined as the lowest clear response. However it may be easier to start with a stimulus level 5 or 10dB above this level with the masking increased by the same amount. The responses will be larger and it will take less time to determine whether the response is crossed or not. The precise masked threshold can then be determined by testing closer to threshold at the end of this process.

Tone pip ABR

The principles are the same as for clicks. However no published or unpublished data is known for the values for inter aural attenuation for AC and BC tone pips, the effective level of masking and the effect of age on BC stimulus levels. It is recommended that until such data is available conservative assumptions for intra-aural attenuation (AC 40dB, BC 10dB)are used, a broadband masking noise is used, calibrated as described above, and reference is made to the current values in table 3 for any age corrections to tone pip stimuli..

Appendix D: Bone conduction stimulus level correction for age.

This information is also given in the NHSP bone conduction ABR protocol. Note that data is only available for click stimuli at present.

The bone conduction stimulus will be calibrated on data derived from a group of normally hearing adults. Provisional RETFL values are available on the NHSP website. Sites should check that equipment has been calibrated to these values.

When the BC stimulus is applied to a baby the effective stimulus is stronger compared to when applied to an adult. A correction therefore needs to be applied which is dependent on the age at which the baby is tested. The table below gives the values that should be added to the stimulus level calibrated in dBnHL to estimate the true effective stimulus level. Interpolated values should be used if the baby's age falls between the values in the table. There is no standard unit to describe the corrected values. A note should be recorded in the BC ABR report to say that a stimulus correction for age has been applied e.g. BC ABR threshold = 50dBnHL (age correction to stimulus applied).

Values (Webb 1993) that should be added to the stimulus level calibrated in dBnHL to give the effective stimulus level in a neonate

Gestational age	**36 weeks**	**40weeks**	**46 weeks**	**52 weeks**
Correction (dB)	12	8.5	5.5	3

Appendix E: Estimating the pure tone psychoacoustic threshold from the ABR/ASSR threshold (offset values)

There is a considerable amount of data published on the mean differences between the ABR/ ASSR threshold and behavioural thresholds. The tables below summarise the ABR data from a meta analysys by Stapells (2000) and the ASSR data from a summary by Picton et al (2003). There is a wide variation between the results of individual studies. Factors that probably contribute to this are the variation in methods of ABR stimulus calibration, the duration of the ABR test time, the definition of ABR threshold and in young children the nature and calibration of the behavioural measure to which the ABR threshold is compared.

tpABR. Results from Stapells (2000) meta-analysis show mean elevation of the tpABR thresholds (dBnHL) over the PTA thresholds as follows

	Mean (95% CI of population mean) of difference between tpABR and behavioural thresholds (Stapells 2000)			
Subject group	500Hz TP	1000Hz TP	2000Hz TP	4000Hz TP
Adults (normal hearing)	20.4 (18.8-21.9)	16.2 (14.9-17.4)	13.4 (12.3-14.4)	11.8 (10.7-12.8)
Adults (sensorineural)	13.4 (11.0-15.8)	10.3 (8.4-12.1)	8.4 (6.3.-10.3)	5.2 (2.4-8.0)
Infants/young children (normal hearing)	19.6 (18.8-20.5)	17.4 (16.0-18.7)	13.6 (11.8-15.5)	15.5 (14.1.-16.8)
Infants/young children (sensorineural)	5.5 (3.0-8.0)	4.9 (2.4-7.3)	0.6 (-1.6-+2.7)	-8.1 (-12.1- -4.1)

Notes on table

The mean difference is less for subjects with a sensorineural hearing loss. The standard deviation in the difference between the tp ABR threshold and the PTA in individuals varied considerably across studies analysed by Stapells. The average was about 7dB. This gives a 5% to 95% confidence in values when applied to estimating the PTA from the ABR threshold in the individual of about ±15dB.

ASSR. Results for normal and hearing impaired adults from Picton et al (2003)

	Mean difference and range across studies between ASSR threshold and behavioural threshold			
Subject group	500Hz	1000Hz	2000Hz	4000Hz
Adult normals	19	17.6	15.4	14
Average SD	11.2	10.8	11	10.8
Adult hearing impaired	10	6	6.5	4.5
Average SD	10	7.5	8	8.5

Notes on table

Mean values and ranges have been derived from summary tables of studies given by Picton et al (2003). The values are similar to those for tpABR. The average standard deviation (SD) across the studies indicates a similar confidence level when estimating the PTA for hearing impaired subjects from the ASSR threshold.

Application to babies

In babies only the ABR/ASSR threshold can be measured. However an estimate of the expected pure tone threshold (dBeHL) from the neonatal ABR/ASSR threshold (assuming no change to hearing status) can be made from the data from adults, noted above, by taking into account two additional factors.

1. The difference between the stimulus level at the ear between adults and babies.
2. The difference in the ABR/ASSR threshold between adults and babies.

ABR – Provisional set of offset values for ABR thresholds >40dBnHL

Earphones

The meta analysis of Stapells(2000) for sensorineural hearing impaired adults gives values, rounded to the nearest 5dB,of 15,10, 10 and 5dB for the elevation of the tpABR over the PTA at 500Hz, 1000Hz, 2000Hz and 4000Hz respectively. The following assumptions have then been made to derive a set of offset values.

1. The difference between the stimulus level at the ear between adults and babies is not significant.
2. The definition of threshold in this protocol is the lowest clear response. An estimated correction of 5dB has been applied on the basis that much of the published data is likely to have been carried out under ideal test conditions and the threshold in some studies is likely to have been defined with a less strict criteria than the lowest clear response.
3. No correction has been applied for the difference between the ABR threshold in adults and babies. The reason for this is that it was not possible to find sufficiently consistent data in the literature.
4. Adult data was used in preference to paediatric data from the analysis by Stapells (2000) as the measure of the behavioural threshold (PTA) is likely to be more consistent across the individual studies.

The figures derived from the meta-analysis (Stapells 2000) with the 5dB added are given in the table below. The equivalent figures proposed in the Ontario newborn hearing screening program are also shown (Hyde 2005) . The difference is only 5dB at two frequencies. After considering various factors the editor and contributors reached a provisional decision to opt for the same figures as the Ontario program, the value for clicks being set to that for 4kHz tpABR

Provisional offset values for ckABR and tpABR

ABR threshold	500Hz	1000Hz	2000Hz	4000Hz
Stapells(2000) + 5dB	20	15	15	10
Ontario program	20	15	10	5

Insert earphones:

Insert earphones can give higher levels of sound in the smaller neonatal ear canal as discussed in the main text. Voss and Herrman(2005) report the results of a modelling study investigating the differences in sound levels in infant and adult ears using circum-aural, supra-aural and insert phones. Their data for insert earphones shows an effect dependent on frequency. The effect is different at the probe tip compared to the tympanic membrane. Rance and Tomlin (2006), in a study on the ASSR threshold in normal babies, report a difference in stimulus levels when measured in the ear canal or in a 2cc coupler. They found for babies at 0 weeks of age a difference of 6.5dB at 500Hz and 15dB at 4kHz. Sininger et al (1997), using a fixed stimulus voltage into an ER-2 transducer for clicks and tone pips, found that the stimulus sound level measured in the ear canal was 0.8, 4.7, 27 and 27 dB higher at frequencies of 500Hz, 1.5kHz , 4 and 8 kHz for neonates compared to adults. The value for clicks was 20dB. Taking all this data into account provisional values (in table below) are proposed, for inserts phones ,to be added to the stimulus level in dBnHL to correct for the effect of the smaller baby ear canal volume

compared to an adult. The correction factors are only applicable to babies under 3 months corrected age.

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Provisional correction to insert phone stimulus level for the effect of the smaller baby ear canal volume

Click	500Hz	1000Hz	2000Hz	4000Hz
10	5	5	5	10

Recommended maximum stimulus levels when using insert earphones

For a maximum stimulus level of 135dBSPL peak to peak the equivalent values in dBnHL for insert phones using NHSP reference values for a ER-3A insert phone with a IEC 60318-4 occluded ear simulator are given in the table below. These values apply to adult ears. For neonatal ears a correction is required to allow for the effect of the smaller ear canal volume. The values in the table above are a provisional estimate of the mean correction. To calculate the maximum recommended stimulus levels for inserts a cautious approach has been taken until more data is available. The values used in the calculation are 5dB greater than those in the table above. The recommended values are then the results of subtracting these corrections rounded down to the nearest 5dB (the exception being the value for the click where the figure is rounded up 0.5dB rather than down 4.5dB)

	Click	**500Hz**	**1000Hz**	**2000Hz**	**4000Hz**
Value for 135dBSPL pk-pk	99.5dBnHL	111.5dBnHL	113.5dBnHL	106.5dBnHL	102.5dBnHL
Estimated effect of neonatal ear canal volume + 5dB	**15dB**	**10dB**	**10dB**	**10dB**	**15dB**
Value allowing for neonatal ear canal effect	84.5dBnHL	101.5dBnHL	103.5dBnHL	96.5dBnHL	87.5dBnHL
Recommended value	**85dBnHL**	**100dBnHL**	**100dBnHL**	**95dBnHL**	**85dBnHL**

Bone conduction

The authors are not aware of a similar meta-analysis of the elevation of BCABR thresholds over behavioural thresholds. Provisionally, the same offset values as for AC have been proposed, as given in the table below. The stimulus levels in dBnHL should first be corrected for the effect of age (see appendix D) before applying these values to estimate the hearing threshold.

	Click	500Hz	1000Hz	2000Hz	4000Hz
Earphone	5	20	15	10	5
Bone	5	20	15	10	5

ASSR – provisional set of offset values

Earphones

A provisional set of values (see table below) has been derived, based on the data summarised by Picton et al (2003) (table above) for hearing-impaired adults (values rounded to the nearest 5dB) and by making the following assumptions.

1. The difference between the stimulus level at the ear between adults and babies is not significant
2. The elevation of ASSR thresholds over behavioural thresholds is greater in babies compared to adults. Evidence for this is provided by the data (replicated in the table

below) in Picton et al (2003) for ASSR thresholds for normal babies. This should be compared to the values for normal adults in the table above. Picton et al (2003) estimates the effect to be of the order of 10-20dB. The offset values have been increased (provisionally) by 10dB to take this into account.

ASSR. Normal thresholds in babies (Picton et al 2003)

	ASSR threshold in normal infants			
Frequency	500Hz	1000Hz	2000Hz	4000Hz
Threshold (dBHL)	34-56	20-52	18-60	24-50

Adult data was used in preference to paediatric data from the summary by Picton et al (2003) for same reasons as selecting the adult data for ABR offsets.

Provisional offset values for ASSR

ASSR threshold	500Hz	1000Hz	2000Hz	4000Hz
> 40dBnHL	20	15	15	15

Insert earphones

Stimulus levels for insert phones have first to be corrected for the effect of the smaller baby ear canal volume compared to an adult.

Provisional values to be added to the stimulus level in dBnHL to correct for the effect of the smaller baby ear canal volume compared to an adult are given in the table below. The correction factors for inserts are only applicable to babies <3 months corrected age. The values should be added to the stimulus level in dBnHL before applying the offset values in the table above.

500Hz	1000Hz	2000Hz	4000Hz
5	5	5	10

Appendix F: Positive predictive value of AC ckABR to PCHI

The relationship between electrophysiological thresholds in the neonatal period and final hearing status depends on a number of factors including the accuracy of the ABR threshold, the presence of temporary conductive hearing loss, delayed neural maturation and the development of hearing loss after the neonatal stage. The positive predictive value for the ABR result is a measure of its ability to predict the final hearing status. The results of two studies on the PPV are summarised in Table 1.

Table 1: PPV for an AC ckABR with respect to a PCHI of > 40 dB (Interim data)

Click AC ABR threshold (dBnHL)	**50**	**60**	**70**	**80**
Watkin & Baldwin (1999)	8%	32%	60%	100%
Stevens (2006) (Provisional data-unpublished)		30%	67%	100%

Appendix G: NBHSW results record sheet

Diagnostic Neonatal Hearing Assessment

Results record sheet

Name Hospital, *Town/City*

Date printed

Name	GP name
Address	GP address
NHS number	d.o.b.
Local number	Gestation (weeks) by date/by exam
Referral reason	Corrected age at initial test date
Risk factors for PCHI	

Electrophysiological results

Key: = indicates result is threshold; > indicates no response at this level; < indicates response at this level but lower levels not tested
Where masking has been used result is followed by (M)
Results are in dBnHL relative to normal adult thresholds with age correction applied to click BC results
The recording conditions are satisfactory unless noted by a * with a foot note

ABR

Date	Stimulus and Transducer	Right (dBnHL)	Left (dBnHL)	Right (Estimated, dBeHL)	Left (Estimated, dBeHL)	Peer review date

OAE results

Date	Type	Right	Left

Tympanometry results

Date	Right			Left		
	Probe tone frequency	Details	Shape	Probe tone frequency	Details	Shape

Other tests (Add as necessary)

Date		Right	Left
	Cochlear Microphonic		

*In infants, under the age of 3 months, the static compliance and the middle ear pressure are not applicable.

Notes on test result

Management plan?

Appendix H: Example of a Report

Audiological Report / Assessment Summary

Department Heading

Date of report:……

Name	GP name
Address	GP address
NHS number	d.o.b.
Local number	Gestation
	Referral reason
Test dates: 1/…… 2/…… 3/…….	

Electrophysiological results

Key: = indicates result is threshold; > indicates no response at this level; < indicates response at this level but lower levels not tested
Where masking has been used result is followed by (M)
Results are in dBnHL relative to normal adult thresholds with age correction applied to click BC results
The recording conditions are satisfactory unless noted by a * with a foot note

	Date	Stimulus	Right (dBnHL)		Left (dBnHL)	
ABR			ac	bc	ac	bc
	Date 1	Click	>60		>60	
	Date 2	click	=80	>55+	=80	>60
	Date 2	4kHz tone pip	=85		=85	

OAE results

	Date	Right	left
TEOAE	Date 1	inconclusive	Not recordable

Tympanometry results

	Date	Right		left	
Static compliance*	Date 1				
Middle ear pressure*					
Probe frequency		1000Hz		1000Hz	
Tympanogram shape		Normal		Normal	
Acoustic reflexes		ipsi	contra	ipsi	contra
0.5 kHz					
1 kHz					
2 kHz					
4 kHz					

*In infants, under the age of 3 months, the static compliance and the middle ear pressure are not applicable.

Notes on test results

+ artefact too large to test at higher levels
baby awoke before 1 kHz tone pip testing was possible

Summary and conclusions

The click AC ABR results indicate that a bilateral hearing impairment is present with an estimated psycho acoustic hearing threshold of about 70dBnHL for each ear. No BC ABR responses were obtained at near the maximum stimulus levels indicating that there is a significant sensori neural component in each ear. The absence of a conductive component is supported by the normal results for tympanometry.
The tone pip AC ABR results indicate that 4kHz thresholds are similar to those indicated by the click AC ABR results. The baby awoke before it was possible to carry out tone pip ABR at 1kHz.
XX did not give any behavioural responses to any of the stimuli used which were up to 10dB above the measured ABR thresholds.
The results were explained to XX's parents in terms of the estimated hearing thresholds and probable type of hearing impairment. The thresholds levels were demonstrated.
XX was seen by the consultant physician immediately following the test procedure. Please refer to his letter for further details of follow-up.

Signed:

Name:

Designation:

Copies to:

Newborn AC ABR: estimated values to subtract from ABR thresholds to obtain an estimate of the psychoacoustic/PTA threshold.

ABR threshold	Click	500Hz	1000Hz	2000Hz	4000Hz
>40dBnHL	5	20	15	10	5

The 5 to 95% confidence levels for the estimate of the pure tone threshold from the tpABR threshold are of the order of ±15dB* (Stapells 2000)'. In applying the 95% confidence interval , the upper limit will not be worse than the ABR threshold e.g. the estimated pure tone threshold for a 4000Hz tone pip ABR threshold of 75dBnHL would be 70dBnHL with a 95% confidence interval of 55dBnHL to 75dBnHL.

Appendix I. Check List for Audiological Assessment

This check list is intended as an 'aide memoir' to be kept with the equipment. Refer to the main text of these guidelines and to specific test protocols (Appendix A) for detailed checks and procedures.

General

Check screening record for any responses recorded (AOAE or AABR).
Check corrected age and consider effect on ABR waveforms and threshold.
Check the medical notes for any conditions that might affect any of the tests.

Electrophysiological testing

Prior to test session.
Stage 'A' check including check on transducers and leads (earphones, insert phones and bone conductor).

Start of test session
All electrodes for tests applied before starting (including nape if needed).
Electrodes leads correctly plugged in.

Before each set of tests
Earphone/inserts/bone conductor produce sound
Earphone/insert applied to correct ear.

No response
Check sound from transducer.
Check leads correctly plugged in.

High level of non physiological background noise
Check electrode impedance.
Check baby at least 1.5 metres from any mains electrical source (monitors, mains leads, fluorescent lights etc)

Tests

AC Threshold
Tone pip ABR at appropriate frequencies. Consider ASSR if useful.
Click ABR where accurate thresholds are not possible with tone pip ABR.
Observation of any consistent behavioural reactions to stimuli

BC Threshold and presence of a conductive component to any raised threshold.
BC ABR click or tone pip as required.
Tympanometry

Check for AD/AN where ABR abnormal
Diagnostic OAE plus cochlear microphonic if required

1225 ***Appendix J. Details of Outcomes of Initial Assessment: NBHSW***

Outcome	***ABR result A/C click stimuli***	***Result of Test***	**Action**	**Plan to be entered on assessment form**
DNA after 2 appts (after 1st DNA – contact parents and HV if appropriate) Declined assessment	-	Non attender, test at 7/12	▪ Add name to TDT ▪ Provide report* ▪ Notify Professional Lead ▪ Letter No. 8 to parent and further appointment if requested (DNA only) ▪ Fill out assessment result form ▪ Letter No. 7 to GP and HV	DNA rebook
Attended test but no result	-	Unable to test – requires further assessment	▪ Verbal explanation to parent. ▪ Requires further assessment appointment ▪ Provide report* ▪ Note in parent held record ▪ Fill out assessment result form	Rebook
Definite result in one ear only	<= 35dBnHL	Pass assessment procedure in one ear but unable to test second ear.	▪ Verbal explanation to parent ▪ Requires further assessment or audiological follow up appointment/TDT ▪ Leaflet (Hints for Parents) if appropriate ▪ Provide report* ▪ Note in parent held record ▪ Fill out assessment result form	Not significantly deaf
Pass	Bilateral <= 35dBnHL With TDH ear phones	Pass	▪ Verbal explanation to parent ▪ Leaflet (Assessment- clear response) ▪ Add name to TIDT if fit criteria ▪ Provide report* ▪ Note in parent held record. ▪ Fill out assessment result form	Normal for the purposes of NBHSW
Fail	One or both ears >35 dBnHL	Further assessment procedures to be carried out	▪ Verbal explanation to parent, ▪ Requires further assessment or audiological follow up appointment/TDT ▪ Provide report* ▪ Note in parent held record card. ▪ Consider carrying out advanced assessment with Professional Lead present ▪ Fill out assessment result form	Not significantly deaf Possibly deaf Significantly deaf

* Reports should be provided to Professional lead, Divisional Coordinator, GP, HV and Paediatrician on all cases where reports indicated except for cases when advanced assessment is indicated when the PL and DC only should be notified pending further results.