

Guidelines for the early audiological assessment and management of babies referred from the Newborn Hearing Screening Programme

Version 3.1

July 2013

NHSP Clinical Group

Co-Editors: John Stevens¹, Graham Sutton², Sally Wood²

Contributors: Rachel Feirn³, Guy Lightfoot⁴, Rhys Meredith⁵, Sally Minchom⁶, Glynnis Parker⁷, Siobhan Brennan⁸, Rachel Booth⁹

¹ University of Sheffield, Sheffield, UK

² Newborn Hearing Screening Programme Centre, London, UK

³ Formerly of Children's Hearing Centre, Bristol, UK.

⁴ Dept of Medical Physics and Clinical Engineering, Royal Liverpool University Hospital, Liverpool, UK.

⁵ Audiology Dept, Abertawe Bro Morgannwg Health Board, UK

⁶ Betsi Cadwaladr University Health Board, Wales, UK

⁷ Sheffield Children's Hospital, Sheffield, UK

⁸ Regional Department of Neurotology, Sheffield Teaching Hospitals, Sheffield, UK

⁹ Audiology Dept, Central Manchester Hospitals, Manchester

Note added June 2014

Correspondence to PPC, British Society of Audiology, 80 Brighton Rd, Reading, RG6 1PS

In this document there are references to 'eSP', for e-Screener Plus, the Electronic record system for NHSP in England. Users in countries which do not use eSP should ignore these sections.

Amendment History:

Version	Date	Amendment History
1.0	March 2006	Draft after extensive correspondence with national and international audiologists. Consultation via NHSP website Feb -March 2006.
1.1	September 2006	Revised version produced following comments received
1.1	December 2006	Comments from NHSP Clinical Group incorporated. Approved by NHSP Clinical Group with minor comments
1.1	March 2007	Amendments made as agreed at Clinical Group March 2007. Submitted to Director for approval.
2.3	December 2010	Draft drawn up after extensive consultation within and outside NHSP clinical group. Further consultation via NHSP website
2.5	March 2011	Revision following comments received from consultation period and further discussion at clinical group Feb 2011
3.1	July 2013	Major revision through NHSP Clinical Group. Put out for consultation in June. Revisions made based on comments received. Issued for implementation with eSP changes

CONTENTS

1. Scope	5
2. Major changes to these guidelines from the 2011 version.....	5
3. Requirements for a newborn audiological assessment service	6
3.1 Equipment	6
3.2 Staff training and expertise.....	6
3.3 Accommodation.....	6
3.4 Communication with parents: Before the appointment	6
3.5 Communication with parents: During and after the appointment	6
3.6 Timing of tests	7
3.7 Clinical arrangements and time to allow for testing.....	7
3.8 Sedation	7
4. Test options.....	8
4.1 Use of tone pips or narrow band chirps	8
4.2 Use of headphones and inserts.....	8
4.3 ABR stimulus starting level	9
4.4 ABR stimulus level steps and testing at higher levels.....	9
5. Sequence of tests.....	10
5.1 Introduction	10
5.2 OAEs	10
5.3 AC ABR	11
5.4 BC ABR	11
5.5 Tests for ANSD.....	12
5.6 Auditory Steady State Responses (ASSR)	12
5.7 Tympanometry.....	12
5.8 Reactions to stimuli.	12
6. Special Cases	12
6.1 Permanent Unilateral hearing loss.	12
6.2 Atresia.....	12
7. ABR testing: technical considerations.....	13
7.1 Normal maximum stimulus levels	13
7.2 Definition of ABR threshold	13
8. Prediction of the estimated hearing threshold (dBeHL)	13
8.1 Introduction.....	13
8.2 Combined correction values.....	14
8.3 Entering values into prescription software for hearing aid fitting.....	15
8.4 Confidence limits (5% to 95%) of the estimated hearing threshold (eHL)	16
8.5 Prediction of the estimated hearing threshold from the ASSR threshold.....	16
9. Further testing and management.....	17
9.1 Satisfactory Hearing	17
9.2 Elevated thresholds.....	17
9.3 Mild bilateral hearing loss and Unilateral hearing loss.....	17
9.4 Further management and referral onwards.....	18
10. Reporting	18

11. Recording onto eSP	19
12. Glossary	20
Appendix A: Guidance and protocols available on the NHSP website	21
Appendix B: Some examples of different hearing impairments and expected test results.	22
Example 1: Unilateral conductive with detail on process and choice of tests	22
Example 2- Bilateral conductive	23
Example 3- Unilateral sensorineural loss	23
Example 4 – Bilateral sensorineural loss	24
Example 5 – Bilateral mixed loss	24
Example 6 – Auditory neuropathy spectrum disorder	24
Example 7 - Atresia – Refer to appendix G	24
Appendix C: Masking	25
Appendix D1: Stimulus level corrections.....	28
Appendix D2: Maximum stimulus levels for ABR using inserts	30
Appendix E1: Offsets to predict the estimated hearing level from the ABR threshold.....	31
Appendix E2: Derivation of confidence limits for the estimated hearing threshold.....	34
Appendix E3: ASSR – Provisional set of ASSR offset and stimulus correction values	36
Appendix F: Predictive value of AC ABR in PCHI cases	37
Appendix G: Testing babies with atresia	38
Appendix H: Checklist for Audiological Assessment.....	39
Appendix I: Combined dBnHL to dBeHL correction values–by transducer	40
References.....	41

1. Scope

This document gives guidance on the early audiological assessment and management of babies referred from the newborn hearing screen. The term “early” is used to denote the period between newborn screen referral to the time at which reliable behavioural assessment may be undertaken *i.e.* 7-8 months corrected age. However the focus of this guidance is on the critical period for assessment up to 12 weeks corrected age.

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. It should be read in conjunction with the latest NHSP Guidance for auditory brainstem response testing in babies and other guidance and protocols relating to newborn hearing screening, assessment and follow up available on the NHSP website (<http://hearing.screening.nhs.uk>). These are listed in Appendix A.

2. Major changes to these guidelines from the 2011 version

The main changes that have been made from the 2011 guidelines are as follows:

1. Many sections have been restructured.
2. Narrow band chirps are now acceptable as an alternative to tone pips for ABR testing, with nHL to eHL correction values being provided.
3. Revised advice on the use of TEOAE as the first test in ‘well babies’
4. BC testing at 0.5kHz and 1kHz is now acceptable, with nHL to eHL correction values provided.
5. Correction values have been changed from ‘values to be subtracted’ to ‘values to be added’.
6. A summary table of corrections by transducer has been added as a new Appendix.
7. Revised correction value for BC testing at 4kHz.
8. The highest level at which masking is not required for BC is now 15dBeHL rather than 20.
9. Removed advice suggesting switching to click ABR when the 4kHz tpABR threshold is significantly raised (>80dBnHL), and text added to use of click ABR in section 5.3.
10. Advice on when it is acceptable to exceed the normal maximum stimulus level.
11. Updated advice on entering thresholds into prescription software for hearing aid fitting.
12. More accurate data for the predictive value and confidence intervals of ABR.
13. Guidance on further management and referral has been completely rewritten, and is no longer based on bands of 4kHz ABR threshold.
14. The Appendix of FAQs has been removed.

Note that eSP is being updated in August 2013 to incorporate the changes to the new nHL to eHL correction values in this guidance.

40 **3. Requirements for a newborn audiological assessment service**

3.1 Equipment

Equipment to carry out ABR threshold measurement using tone pips (or narrowband chirps) and clicks by both air and bone conduction is required. Equipment to record TEOAEs and high frequency tympanograms is also needed. Check the NHSP website for information on equipment and for recommended equipment settings. Equipment should have a documented annual calibration, including calibration to the RETSPLs and RETFLs given on the NHSP website. Regular safety and electrical testing is also required in accordance with local protocols.

3.2 Staff training and expertise

Staff carrying out threshold measurement for both AC and BC ABR require experience and expertise in accurately interpreting ABR waveforms, determining thresholds (including when and how to use masking) and dealing with unusual or unexpected waveforms or results. They should also have expertise in cochlear microphonic and otoacoustic emissions testing, and in tympanometry in babies. It is also essential that staff within the team have training and expertise in the discussion of results with parents, the 'sharing of news' and the possible options for 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).

Because only a small proportion of babies require hearing assessments following the newborn screen (less than 3%), building up skills and expertise and ensuring a quality service requires networks, and close links with nearby sites and centres of excellence. Staff training is available both at national course level and by linkage with centres of excellence.

We recommend that a robust process for auditing of results is in place, including routine and rigorous peer review of the waveforms, threshold estimation and test procedures.

3.3 Accommodation

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

3.4 Communication with parents: Before the appointment

Where (as recommended) the initial audiology appointment is made by the screener at the point of referral from the screen, parents will receive Leaflet 3 "Your baby's visit to the audiology clinic" along with local contact information. The appointment should be confirmed in writing by the audiology service, along with clear written information including the tests that might be done, likely appointment duration, the need for the baby to be settled, facilities for preparing feeds/feeding etc. It should be clear that parents are welcome, if they wish, to be accompanied by a friend or relative, at this assessment. Also take account of current national advice on delivery of services for children.

Parents need to be made aware of the requirements for a sleeping or settled baby and where possible appointments should be timed appropriately.

3.5 Communication with parents: During and after the appointment

Assessment should be carried out by (or under the supervision of, or in conjunction with) senior clinical/scientific 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.

90 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, but using clear jargon-free terms. When ABR thresholds have been obtained it can also be useful to get the parents to listen to the threshold stimulus level (in doing this bear in mind the offset between the ABR threshold and the psychoacoustic/PTA threshold).

95 Parents should be provided with appropriate verbal and written information at the end of the assessment. This may include the checklists 'Reactions to sounds / Making sounds' if hearing has been determined to be satisfactory, or contact numbers if it has not. Where a hearing loss is confirmed the appropriate NDCS booklet (NDCS 2007-2012), local information and early support information should be given.

3.6 Timing of tests

First assessment

105 The first assessment should be started within 4 weeks of screen completion at the latest unless a delay is required to allow the baby to reach full term (0 weeks corrected age) to allow for maturation of the ABR response.

110 Long periods of natural sleep are less common with increasing age and assessment thus becomes more difficult, particularly after about 8 weeks corrected age. Therefore for babies who are more than 3-4 weeks corrected age when they complete the screen the first assessment needs to be expedited.

115 Delaying testing or not allowing sufficient time for carrying out the assessment are a false economy, as this can create more work and can delay complete assessment of the baby's hearing status.

Repeat assessment

120 Repeat assessments should normally be completed by 8 weeks corrected age for the above reasons. We also recommend that repeat assessments are normally carried out after 4 weeks corrected age given the continuing maturation of the ABR response.

Parents must be given clear explanations about the rationale for the timing of assessments.

125 Domiciliary assessment may be a viable alternative particularly it is difficult for the family to attend appointments. However this may limit the range of tests that can be carried out unless portable equipment is available for all procedures required. The domestic environment may affect the ABR results by either electrical interference or masking of the stimulus (particularly a problem with low frequency stimuli and BC). The equipment must also meet medical equipment safety standards when used in the domestic environment. We suggest that domiciliary assessment is limited to the initial assessment.

3.7 Clinical arrangements and time to allow for testing

130 Generally no more than 2 babies should be booked for diagnostic assessment with ABR in a session (half day) as it is important to allow time for babies to settle into natural sleep. Where a detailed assessment is required, there may be only 1 baby per session. Electrodes can be attached on arrival or soon after and time waiting for the baby to go to sleep can be used for other duties.

3.8 Sedation

Sedation is not necessary in babies under 12 weeks of age and should be used in babies under 12 months of age only in exceptional circumstances. Early assessment means that babies can be tested relatively easily during natural sleep.

140 **4. Test options**

4.1 Use of tone pips or narrow-band chirps

145 Tone pip or narrow-band chirp ABR (NB chirpABR) are the primary methods of measuring the hearing threshold except in specific circumstances. More details on this are given in later sections. Note that whenever tpABR is advised in the rest of this document NB chirpABR can be used as an alternative. If using NB chirpABR the offset values and confidence intervals for converting ABR thresholds in nHL to estimated hearing level (eHL) are different.

The two advantages of using chirps are:

- 150 • The ABR response is usually larger which should reduce test time (Ferm *et al* 2013, Elberling & Don 2010).
- The confidence intervals for the eHL threshold value are smaller (see section 8.4).

155 Note that as yet there is little experience of NB chirpABR in more severe hearing impairments. We provisionally recommend that NB chirpABR thresholds above 75dB_{eHL} be verified with tpABR for at least one frequency per ear, and if the thresholds differ by more than 10dB, tpABR be extended to other frequencies.

4.2 Use of headphones and insert phones

160 Use of either TDH headphones or insert earphones is acceptable provided testers are aware of the issues including those relating to stimulus level (see below), and adhere to the guidance below.

Ear ‘muffs’, as used in screening, should not be used at present as their calibration for use in babies is not fully understood.

165 **Table 1. Relative merits of headphones and insert earphones**

	Headphones	Insert earphones
Advantages	<p>Greater certainty of stimulus levels.</p> <p>Less disturbance of baby</p>	<p>Better interaural attenuation, reducing the likelihood of requiring masking</p> <p>Reduced stimulus artefact</p> <p>Easier to block sound for blocked stimulus control runs and CM testing</p> <p>No need to change transducer if CM testing needed</p> <p>Better attenuation of ambient noise</p> <p>Facilitates use of thresholds for hearing aid prescription.</p> <p>Less electrical hazard when used in theatre following myringotomy</p>
Disadvantages	<p>Small possibility of ear canal collapse if too much pressure applied</p> <p>Change in stimulus level with movement</p>	<p>Stimulus level more uncertain due to individual variation in ear canal volume.^a</p> <p>Possibility of tube blockage with wax</p>

^a Uncertainty in the insert earphone stimulus level could be reduced by the use of a probe microphone to monitor and correct the stimulus level within the neonatal ear canal, as in many OAE systems. At present no such system is commercially available

Stimulus levels in headphones and inserts

170 An important limitation of calibration of ABR equipment is that, even when calibrated using the agreed RETSPLs and RETFLs, the stimulus levels are correct only 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 on bone conduction transmission. Details of this are given in Appendix D.

180 With insert earphones the effective stimulus level could be 10 to 20dB higher, due mainly to the much smaller ear canal in babies and uncertainty of insertion depth (see appendix E). Great care must therefore be taken with maximum levels used (see section 7.1).

180 For TDH headphones the differences between levels in adult and baby ears will be small and can be ignored for practical purposes.

Notes:

1. Always visually check the ear canal prior to fitting insert earphones.
2. Use the combined correction values in Section 7 to estimate the hearing threshold from the ABR thresholds, measured using headphones or insert earphones,

190 There may come a point in the assessment, particularly where aiding is being considered, for a Real-Ear to Coupler Difference (RECD) to be measured using a probe microphone. This will enable the ABR threshold to be determined in dB SPL at the tympanic membrane, so assisting with hearing aid prescription. It could also be used to estimate the true maximum level at the tympanic membrane. This is outside the scope of this guidance.

4.3 ABR stimulus start level.

195 It is usually most efficient to start testing at a low stimulus level unless there are good reasons to do otherwise. For the initial diagnostic appointment, we recommend that the start level should be at 40dB HL - *i.e.* 10dB above discharge level for 4kHz.

200 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 will have been ruled out. Note however that if this happens (*i.e.* waking after a 40dB HL response), a repeat ABR assessment will normally be needed.

4.4 ABR stimulus level steps and testing at higher levels

205 The ABR stimulus level should normally be changed in 10dB steps. Occasionally, *e.g.* where there is strong recruitment a 5dB step may be useful, but one should avoid spending time on small changes in stimulus levels rather than achieving definitive outcomes at 10dB intervals around threshold.

210 Larger steps may be better on some occasions, where it appears a baby may stay asleep for only a few test levels. To illustrate: if we test at 40, 60 and 80dB HL and determine the ABR threshold lies between 60 and 80dB HL, this is a more useful outcome than if we had tested at 40, 50 and 60dB HL and concluded only that the ABR threshold was above 60dB HL.

215 One should consider the impact that testing at high stimulus levels may have on parents, particularly when they have not yet had the opportunity to begin to come to terms with the possibility of hearing impairment. It may sometimes be appropriate to complete testing at high levels on a second appointment.

220 Be aware of the normal maximum recommended stimulus levels for headphones and inserts (see section 7.1)

5. Sequence of tests

5.1 Introduction

225 The order and range of tests undertaken will greatly depend on the sleep state of the baby. The
advice is “Never wake a sleeping baby”. Sleep is essential for electrophysiological testing.
However otoscopy, tympanometry and the recording of OAEs may be undertaken also whilst the
baby is awake but settled. If the baby is already asleep then one would generally move
immediately to ABR and leave these other tests to the end of the assessment because of the risk
of waking the baby. However it may be possible to carry out OAE first whilst the baby is asleep
230 prior to ABR. During testing, one should always be asking ‘what is the most important information
to find out next’ in case the baby wakes up.

The electrodes are best attached before the baby goes to sleep. Attach electrodes that will enable
all the anticipated electrophysiological tests. Adding electrodes mid-test risks waking the baby and
losing a testing opportunity. Some procedures may require the use of one or two-channel
235 recording with different electrode montage -please refer to NHSP ABR guidance for details.

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.

240 A baby may be in a suitable state for testing for a few minutes or up to an hour (Janssen *et al*/
2010) so flexibility is required in testing strategy. The results from all tests need to be combined
and interpreted as a whole. Hearing impairments may be conductive, sensorineural or mixed, or
test results may suggest auditory neuropathy spectrum disorder (ANSD). In most cases BC ABR
245 supported by tympanometry (where appropriate) will help determine the nature of the hearing
impairment and help guide management. The exact order and time spent on each test will vary
and the tester needs to make contingent decisions as the test session progresses. It may not be
possible to complete the testing in one session particularly if hearing impairment is present. If
required a further test session should be carried out as soon as possible.

250

Notes:

- If middle ear effusion (MEE) is thought to be present, ABR is essential to establish the degree
of hearing loss. It is not acceptable to delay ABR threshold measurement whilst the MEE
255 resolves or is otherwise managed.
- Both ears must be tested for every baby irrespective of whether the screen referral was
unilateral or bilateral. There is a small chance that the screening equipment will give a clear
response result in an ear with a hearing impairment. The chance of this happening in both
ears is extremely low, which is why a clear response in both ears is used as the screen pass
260 criteria.
- For unilateral referrals, start with the screen ‘clear response’ ear to establish satisfactory
hearing (or otherwise). The baby may wake before the second ear is tested and establishing
the presence of satisfactory hearing in the **CR** ear is most important for the baby’s
265 development.

The rationale for testing both ears, and for testing the **CR** ear first is not always intuitive and may
need to be explained carefully to parents.

270 The next section considers the diagnostic test selection and strategy. Further examples are given
in appendix B to illustrate typical testing sequences in practice.

5.2 OAEs

275 Optionally, a TEOAE test may be used as the initial test for well babies, but only for those babies
with no risk factors that would require targeted follow up (see NHSP surveillance guidelines) and

with no parental concern about hearing^b. This reduces the number of babies requiring ABR testing because many babies are referred due to a temporary conductive loss or a technical problem with the screen and a high proportion are likely to pass TEOAE at the initial assessment. Both ears must be tested. The test should be carried out to diagnostic standard and reviewed even if screening equipment is used. Provided both ears meet the NHSP TEOAE screen pass criteria, the baby can be discharged (although sites can choose to set stricter criteria if they wish); if not then both ears require ABR testing and time must be available to proceed to this in the same appointment if required.

280

285 Allowing discharge on this basis will of course not detect ANSD. Therefore NICU/SCBU babies (in whom ANSD is more common) should always proceed to ABR testing irrespective of the TEOAE result. TEOAE tests can be carried out using an NHSP screening device or by using diagnostic TEOAE equipment which has a protocol set to the NHSP pass criteria.

290 **5.3 AC ABR**

Tone pip ABR is the main method used to estimate hearing thresholds. Masking must be used where necessary – see appendix C.

295

The minimum discharge criterion is the establishment of AC 4kHz tpABR thresholds at or below 30dBeHL in both ears. If this is the case and responses are also obtained at 5 or 10dB above this level in both ears ('gold standard' discharge criterion: see NHSP ABR guidance) no other testing will usually be required. The main reason for recommending 4kHz is that it is the most sensitive test frequency for detecting SNHL, and also, practically, it is usually the easiest tpABR response to record.

300

Most assessments will therefore start with AC 4kHz tpABR. If the threshold is raised (above discharge level) the options are:

- Test the other ear by AC at 4kHz.
- Test the same ear by BC 4kHz tpABR to determine if the raised threshold is conductive (although at this stage there may be insufficient information available to select an appropriate level of noise for masking the non-test ear).

305

After testing at 4kHz in both ears the next option could be a low frequency AC tpABR (1kHz is recommended). This should be included where the threshold is significantly raised.

310

If time permits, then the frequency recommended after 4 and 1kHz is 2kHz or 0.5kHz, depending on clinical need. Complete tests at each tone pip frequency to the required standard (see NHSP ABR guidance) before proceeding to the next frequency.

315

AC click ABR can be considered only if it is clear that it may not be possible to achieve AC tpABR thresholds, or where it is important to quickly get some estimate of hearing threshold, or where there is no tpABR response at the normal maximum stimulus levels (see section 7.1). In this latter case it usually is clinically useful to test using click stimuli (the click ABR response may be recordable at high stimulus levels with absent tpABR).

320

5.4 BC ABR

If the AC threshold is raised, establish the conductive component. BC thresholds should be measured down to 15dBeHL or lower to demonstrate good cochlear function. If the AC ABR threshold was measured at 4kHz, perform a 4kHz BC tpABR (mask if needed). If only an AC click ABR threshold was possible, then perform a BC click ABR. Although air-borne radiation from the bone vibrator may occur in the same way as for PTA it is highly unlikely this would lead to any problems in ABR testing, and Small *et al* (2007) have ruled out occlusion effects.

325

Masking may be required (refer to appendix C). However **masking will not be needed if a clear BC ABR response is recorded at or below 15dBeHL** (see Appendix). This applies only to babies tested before 12 weeks (≤ 84 days) corrected age. It is therefore often convenient to test down to 15dBeHL or below by bone conduction without masking in the first instance to avoid the

330

^b Discharge from assessment on the basis of OAE test alone would be inappropriate for babies referred for audiological assessment for other reasons.

need to mask. If a clear response is not obtained at that level then it is likely that masking will be needed for BC testing.

335

The effective BC stimulus level is higher in babies than in adults. A correction (which varies with frequency and age) should be applied when calculating the estimated hearing level from the stimulus level in dBnHL. More details are given in section 7, in Appendix D, and in the NHSP ABR Guidance.

340

5.5 Tests for ANSD

If there is no response at the normal maximum permissible stimulus level to tpABR (see section below – normal maximum stimulus levels in babies), or only abnormal waveforms at high stimulus levels (≥ 75 dB_{eHL}), then ANSD may be present in that ear. Tests of cochlear function are then required for that ear. ANSD may be unilateral. Refer to the NHSP guidelines on CM testing and on ANSD. Note that along with CM testing, a click ABR test should be carried out at the same eHL level as the CM test.

345

5.6 Auditory Steady State Response (ASSR)

ASSR is a promising technique with objective measures of results. In most current clinical equipment one can simultaneously test both ears at multiple frequencies, although there are limitations to this at high stimulus levels. This enables 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 assessment of hearing in babies who have an elevated threshold (Stapells 2010). See provisional guidelines for using ASSR in babies (2009) on the NHSP website for more detail.

350

355

5.7 Tympanometry

This may provide evidence for the presence or absence of a conductive component in the case of 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) must always be used for babies under 6 months (refer to the NHSP guidance on tympanometry in babies under 6 months for full details).

360

365

5.8 Reactions to stimuli

Throughout all tests note any consistent behavioural reactions to the stimulus presentation. Record the type and level of stimuli at which any reaction occurs. Be rigorous in comparing any reaction to those occurring in no-sound 'control' periods before accepting it as a true behavioural response to the ABR stimuli. The type and level of stimuli at which any reaction occurred should be recorded. Results should be treated with caution and greater reliance placed on the ABR threshold where there is disagreement. Note, though, that in cases of ANSD or delayed maturation ABR thresholds cannot be used to infer behavioural hearing thresholds.

370

375

6. SPECIAL CASES

6.1 Permanent Unilateral hearing loss

Where there is a permanent unilateral hearing impairment it is particularly important to establish good hearing across the range of frequencies in the unaffected ear. Testing in the unaffected ear should normally be carried out down to 20dB_{eHL} at 4kHz with testing at 1kHz as well if possible.

380

It is also important to establish AC and BC thresholds in the affected ear.

6.2 Atresia

Appendix G gives additional guidance on how to test in cases of atresia.

385

7. ABR testing: technical considerations

7.1 Normal maximum stimulus levels

390 Table 2 gives the maximum recommended stimulus level when the equipment is calibrated to the NHSP reference levels, based on a maximum peak-to-peak stimulus level at or below 135dB SPL as measured on a standard coupler for headphones, or an IEC 60318-4 occluded ear simulator for ER-3A insert phone). These values apply for babies under 3 months corrected age.

Table 2. Normal maximum recommended stimulus levels (dBnHL)

		0.5 kHz	1 kHz	2 kHz	4 kHz	Click
TDH HEADPHONES	Exact value for 135dB SPL pk-pk	112	116.5	110	107.5	104
	Recommended value (rounded down to nearest 5dB)	110	115	110	105	100
INSERT PHONES	Exact value for 135dB SPL pk-pk	111.5	113.5	106.5	102.5	99.5
	Recommended value* (allowing for neonatal ear canal effect)	100	100	95	85	85

395

*The recommended values for inserts are provisional. They include a reduction to allow for the uplift in sound level resulting from the smaller ear canal in babies. See appendix D2 for derivation.

400 **Warning: Insert earphones.** To avoid possible damage to the cochlea, care must be taken when presenting sounds using insert earphones: adhere to the normal maximum values in the table (assuming the equipment is set to NHSP reference levels). See also earlier footnote a. It is also possible to use the RECD to estimate the true maximum level at the tympanic membrane.

Exceeding the normal maximum stimulus levels (after CM testing)

405 Where a baby has no recordable ABR at the normal maximum recommended stimulus level using clicks and tone pips, and CMs are absent., this suggests a cochlear hearing loss rather than ANSD. Is it then safe to exceed the normal maximum stimulus levels to try to measure a hearing thresholds at higher levels?

410 Each case will be different and so it is difficult to give precise guidance on this. Our current advice is where the CM is deemed absent, one may test by ABR **at 5dB above** the recommended normal maximum stimulus levels to determine if any ABR response is present. Levels more than 5dB above the levels in Table 2 must not be used since instantaneous haircell damage may result. See Example 4 in Appendix C. Note that there is a small possibility that OAE & CM are not recordable
415 even when cochlear function is present.

7.2 Definition of ABR threshold

For the NHSP programme the definition of threshold is as follows:

420 ABR threshold is defined as the lowest level at which a clear response (**CR**) is present, with a response absent (**RA**) recording at a level 5 or 10dB below the threshold, obtained under good recording conditions. Details and definitions of **CR** and **RA** are given in the NHSP guidance on ABR testing in babies.

8. Prediction of the estimated hearing threshold (dBeHL)

8.1 Introduction

425 The term dBeHL denotes the estimate of the psychoacoustic threshold derived from the ABR threshold measured in dBnHL. eSP will calculate dBeHL values from ABR results entered in dBnHL. For clarity, give ABR thresholds in both dBnHL and dBeHL in the clinical report.

This eHL estimation allows for

- Differences between the stimulus level delivered to a baby compared to an adult.- *i.e.* transducer **stimulus corrections**. These are different for different types of transducer (headphones, insert earphones and bone conductors).
- Differences between ABR thresholds (defined as in 7.2) and true hearing thresholds (defined as 50% detection of the psychoacoustic response) - *i.e.* **ABR offsets**.

For each age group, stimulus (chirp, tone pip, click) and transducer type (insert earphone, headphone and bone conductor) a single combined correction value to convert from dBnHL to dBeHL is given in the tables below. This combined correction value consists of the stimulus correction and the ABR offset. Derivations are given in Appendices D1, D2, and E1.

- *All combined correction values assume that the stimulus is calibrated in dBnHL using the adult RETSPL and RETFL data available on the NHSP website.*
- *All ages are corrected age*
- *All combined corrections are for thresholds at or above the discharge level of 30dBeHL.*

Where the threshold is less than 30dBeHL, the data in appendix E1 indicate that larger ABR offset values may be more appropriate. However this is not critical for clinical practice as the threshold is at or below the NHSP discharge level; so we suggest the combined correction values for thresholds for ≥ 30 dBeHL are used for all thresholds. However note that for thresholds less than 30dBeHL estimated hearing thresholds will be less accurate and the true thresholds may be better than predicted.

8.2 Combined correction values – by corrected age of baby at test

In the tables below combined corrections are added to the thresholds in dBnHL to give the estimated threshold in dBeHL. Combined corrections are derived by adding the stimulus level corrections in Appendix D1 and D2 and the ABR offsets given in Appendix E1.

The same corrections arranged by transducer are given in Appendix I for easy reference.

Table 3. Correction values – ABR tests up to 12 weeks (84 days) corrected age

AC Up to 12 weeks (≤ 84 days)	Tone pip / click ABR					Chirp			
	0.5k	1k	2k	4k	Click	0.5k	1k	2k	4k
Insert phones	-15	-10	-5	0	5	-10	-5	0	5
Headphones	-20	-15	-10	-10	-5	-15	-10	-5	-5
Bone conductor	5	5	-5	0	See Tab4	10	10	0	5

Table 4. Correction values - BC click – ABR tests up to 12 weeks (84 days) corrected age.

BC		Click
Gestational age	Corrected age	Combined correction value†
36 weeks	-4 weeks	+7
40 weeks	0 weeks	+4
46 weeks	6 weeks	0
52 weeks	12 weeks	-2

† For clicks, one may interpolate where the corrected age is between the values in the previous column (note this is done in eSP).

Table 5. Correction values – ABR tests between 12 weeks and 24 weeks (85 to 168 days) corrected age.

AC 13 to 24 weeks (85 to 168 days)	Tone pip / click ABR					Chirp			
	0.5k	1k	2k	4k	Click	0.5k	1k	2k	4k
Insert phones	-20	-15	-10	-5	0	-15	-10	-5	0
Headphones	-20	-15	-10	-10	-5	-15	-10	-5	-5
Bone conductor	0	0	-10	-5	-5	5	5	-5	0

465

Table 6. Correction values – ABR tests between 24 weeks and 2 years (169 to 730 days) corrected age

AC 24 wk to 2 years (169 to 730 days)	Tone pip / click ABR					Chirp			
	0.5k	1k	2k	4k	Click	0.5k	1k	2k	4k
Insert phones	-20	-15	-10	-10	-5	-15	-10	-5	-5
Headphones	-20	-15	-10	-10	-5	-15	-10	-5	-5
Bone conductor	-5	-5	-10	-10	-5	0	0	-5	-5

470

Table 7. Correction values – ABR tests over 2 years (730 days) corrected age.

AC Over 2 years (>730 days)	Tone pip/click ABR					Chirp			
	0.5k	1k	2k	4k	Click	0.5k	1k	2k	4k
Insert phones	-20	-15	-10	-10	-5	-15	-10	-5	-5
Headphones	-20	-15	-10	-10	-5	-15	-10	-5	-5
Bone conductor	-20	-15	-10	-10	-5	-15	-10	-5	-5

8.3 Entering values into prescription software for hearing aid fitting

Although some hearing aid prescription software offers the option of entering ABR thresholds in dBnHL or the estimated threshold in dBeHL the guidance is to use the estimated threshold in dBeHL.

475

Use either eSP or the tables in the section above to calculate the threshold in eHL. We strongly recommend that eSP is used to minimise the potential for error. Thresholds in eHL should be entered into the hearing aid fitting program. **The thresholds used for this may differ from those entered in eSP** (which is primarily a tool for national audit). In all these cases use common sense - it is important to avoid over-amplification.

480

Check that the correct entry option (dBnHL or dBeHL) and the correct transducer (e.g. foam insert) has been selected in the prescription and REM software.

485

If headphones were used to measure the ABR thresholds, 'insert' should still be selected as the transducer to prevent the software adding an additional headphone correction. Refer to separate NHSP guidance note on entering ABR thresholds into DSL software for further detail.

8.4 Confidence limits (5% to 95%) of the estimated hearing threshold

490 The eHL values determined by using Tables 3 to 7 give the most likely estimates for the hearing threshold from the ABR thresholds. A clinical report should also contain an estimate of the confidence in these results. Table 8 gives a provisional set of values for the 5% to 95% confidence limits on the eHL values. More detail on the derivation of these values is given in appendix E2

495 These values are for babies tested up to 12 weeks (≤ 84 days) corrected age with thresholds above the discharge level (>30 dB_{eHL}). Provisionally we advise that the same values can be used for babies tested above this age. For babies with thresholds ≤ 30 dB_{eHL} the confidence intervals will be wider, given the greater average difference between the ABR threshold and the true threshold..

500 **Table 8. Confidence limits for eHL thresholds**

	Tone pip / click					Chirp			
	0.5k	1k	2k	4k	click	0.5k	1k	2k	4k
Upper CL	+15	+15	+10	+10	+5	+15*	+10	+5*	+5
Lower CL	-15	-15	-15	-15	-15	-15	-15	-15	-15

*Values calculated from offset and confidence interval data at 1kHz and 4kHz.

Notes

505 1. Five percent of babies will have true thresholds better than the lower confidence level given above, potentially leading to over-amplification where a hearing aid is fitted. In addition the effect of the smaller ear canal volume in babies will be to raise the sound pressure level unless the hearing aid gain has been fully compensated for this effect by measurement of an RECD.

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

515 8.5 Prediction of the estimated hearing threshold from the ASSR threshold

As with ABR it is necessary to apply an ASSR offset and transducer stimulus correction value to the ASSR threshold to obtain an estimate of the hearing threshold (dB_{eHL}) (see appendix E3 for details). Values are given for

- Babies tested at up to 12 weeks (≤ 84 days)
- Thresholds ≥ 30 dB_{eHL}

520 The combined correction values in Table 9 are added to the thresholds in dB_{nHL} to give the estimated threshold in dB_{eHL}.

525 Note that while these corrections will be given in eSP, some equipment will give their own eHL values which may differ – we recommend taking expert advice.

Table 9. Combined corrections - ASSR tests up to 12 weeks corrected age, and with thresholds >30dBeHL

ASSR Up to 12 weeks (≤84 days)	0.5 kHz	1 kHz	2 kHz	4 kHz
Insert earphones	-20	-20	-15	-15
Headphones	-25	-25	-20	-25
Bone conductor	Not available			

530 **9. Further testing and management**

Most babies will have, as a minimum, an AC threshold measured at 4kHz, and this (in eHL) will determine whether further testing is required.

9.1 Satisfactory hearing

535 Babies with estimated hearing thresholds of ≤30dBeHL at 4kHz are considered to have satisfactory hearing and may be discharged unless they have one or more of the risk factors requiring targeted follow-up at 7- 8 months corrected age (see the NHSP Surveillance and Audiological Monitoring Guidelines). In those exceptional cases where only the click ABR threshold can be measured, 30dBeHL may still be taken as indicating satisfactory overall hearing.
540 However it may be prudent to review such cases by behavioural testing around 8 months, or have a local policy on reviewing these cases.

9.2 Elevated thresholds

545 Where the 4kHz tpABR threshold is elevated above 30dBeHL in either ear, further testing is needed to determine the degree, configuration and type of any loss. Statistically most of these will be mild temporary conductive loss due to OME, but it is crucial to determine if all or part of the loss is sensorineural or permanent conductive or ANSD. This testing may include BC, AC tpABR at other frequencies, tympanometry, CMs, etc. See section 5 above.

550 BC thresholds should be measured down to 15 dBeHL to exclude a sensorineural component. While the most common cause of raised thresholds and normal bone conduction is OME, other causes such as ossicular malformation should be considered. If clinical and test findings do not fit with OME as the cause (e.g. an unusually large air-bone gap) or are otherwise inconsistent, one should refer for medical assessment. Determining if all or part of a mild/moderate loss is PCHI
555 may not be straightforward and may require two or more test sessions.

When discussing the results and management options, it is important to bear in mind the confidence intervals in predicting the estimated hearing threshold from the ABR threshold as discussed in section 8.4.

560 In the exceptional circumstances where ABR thresholds could be obtained for click ABR only, these should not be relied on alone to determine the management of the baby. Appendix F shows the predictive value of click ABR thresholds is poorer than for tpABR.

565 **9.3 Mild bilateral loss & unilateral hearing loss**

The evidence base for the benefit of early intervention is for babies with bilateral permanent hearing loss of 40dBHL and greater, averaged over 0.5, 1, 2 & 4kHz. The current evidence does not support active early intervention or aiding for children with milder bilateral losses, or for unilateral hearing loss, and there are potential disbenefits as well as benefits (Carr *et al* 2012)..
570 However clinicians need to treat all such cases individually, and discuss and agree a plan with parents, including monitoring and review.

It is important to have a good degree of confidence before informing parents that a loss is likely to be permanent, as parents often perceive this news as just as devastating as for a more severe

575 loss (Pattison *et al* 2008, Carr *et al* 2012). It is however important to be open and honest about findings. Bearing in mind the confidence interval, behavioural testing may be required before a mild PCHI can be confirmed.

9.4 Further management and referral onwards

580 For those children whose results show a definite hearing loss, whether permanent or temporary, there must be clear and agreed pathways for review and referral to other relevant services (education, audiology and audiological medicine, ENT, Paediatrics, voluntary sector, social care etc).

585 Management of a baby with confirmed permanent hearing impairment should be discussed with the parents/carers and multidisciplinary team. Options include ongoing audiological assessment and monitoring, provision of amplification and referral to early intervention services. The actual management approach adopted will depend upon the clinical findings including the likely degree and type of hearing loss, the developmental status of the baby including the existence of other disabilities and the views and wishes of the parents.

590
595 With parental consent, telephone referral should be made to the early interventionist /Teacher of the Deaf, within one working day, with a clear system for rapid visit and support, and initiation of appropriate audiological and educational management. Hearing aid fitting should be offered, when appropriate, within 4 weeks of confirmation of PCHI. Please refer to NHSP 'Guidelines for fitting hearing aids to young infants' for more detailed practical guidance on hearing aid fitting. Prompt referral for aetiological investigations should also be offered.

600 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, HV and parents using appropriate understandable language.
3. Medical consultation offered, arranged and carried out.
- 605 4. Referral to or consultation with early support 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
- 610 8. Plan for monitoring of progress and response to sound.

10. Reporting

At each test session results should be documented in detail as the session proceeds. An example worksheet is available on the NHSP website.

615 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 available on the NHSP website. Non-attendance should be reported appropriately.

The report should include:

- 620 • A brief medical history of relevant factors relating to hearing loss.
- 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. The consistent use of \leq , = & $>$ when reporting results is preferable to phrases such as "responses seen down to..."
- 625 • A note of any other factors that might affect the estimate of the hearing threshold, as measured by the ABR (e.g. possible ANSD, evidence from other tests of possible neurological damage to the brain).
- A report of any consistent behavioural reactions taking account of their limitations as described in section 5.10.
- 630 • A comment on OAE results, if this is relevant.
- A comment on tympanometry/ stapedius reflex results.

- A note of why any tests were not done, if this is relevant.
- A summary of what the results imply about the type, configuration and level of any hearing impairment recorded.
- A note of the information given to parents about the test results.
- A note of follow-up arrangements.

11. Recording onto eSP

This section should be read in conjunction with section 5.14 (Reporting thresholds) in the NHSP Guidance for ABR testing in babies, and the eSP reference guide Section 2. It is important that there is a national consistency in the recording of ABR thresholds in eSP.

Hence:

- All equipment must be calibrated to the agreed NHSP reference levels (published on the NHSP website).
- The NHSP definition of ABR threshold should be used.
- The ABR threshold in dBnHL, without any ABR offset or stimulus corrections should be recorded into eSP which will calculate the estimated thresholds in dBeHL.
- The eSP reference guide on the NHSP website gives detailed information about the recording of the audiological data including the use of symbols \leq , $=$, $>$ when entering thresholds.
- Where other factors may have affected the accuracy of the estimate of the hearing threshold, as measured by ABR, (e.g. possible ANSD, evidence from other tests of possible neurological damage to the brain) these should be added in the notes section of the eSP record.

12. Glossary

	ABR	Auditory Brainstem Response
	ABR offset	Difference between ABR and true hearing thresholds
660	AC	Air Conduction
	ANSD	Auditory Neuropathy Spectrum Disorder
	ASSR	Auditory steady-state response
	BC	Bone Conduction
	CM	Cochlear Microphonics
665	CR	Clear response
	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.
670	DPOAE	Distortion Product Otoacoustic Emissions
	eSP	e-Screener Plus (Electronic record system for NHSP)
	Inc	Inconclusive response
	MEE	Middle Ear Effusion
	NB chirpABR	Narrow-band chirp evoked ABR
675	NICU/SCBU	Neonatal Intensive Care Unit / Special Care Baby Unit
	PCHI	Permanent Childhood Hearing Impairment - defined here as ≥ 40 dBHL average of 0.5, 1, 2 & 4kHz PTA thresholds. It includes both sensorineural and permanent conductive impairments.
	PTA	Pure-Tone Audiometry/Audiogram
680	RA	Response Absent
	RECD	Real-Ear to Coupler Difference
	RETFL	Reference Equivalent Threshold Force Level
	RETSPL	Reference Equivalent Threshold Sound Pressure Level
685	Stimulus correction	Change in the sound level at the ear that occurs when insert earphones, headphones or bone conductors, calibrated in adults, are applied to babies.
	TEOAE	Transient Evoked Otoacoustic Emissions
	tpABR	Tone-pip Evoked ABR
	VRA	Visual Reinforcement Audiometry

690 **Appendix A: Guidance and protocols available on NHSP website**
(<http://hearing.screening.nhs.uk>).

Newborn and early testing

Guidance for Auditory Brainstem Response testing in babies
695 ASSR: Provisional guidance for using ASSR in babies
TEOAE testing in babies
Tympanometry in babies under 6 months. A recommended test protocol*
Automated ABR in babies
Behavioural Observation Audiometry testing in babies*
700 Guidelines on CM testing

Other tests from 6 months of age

Distraction diagnostic test protocol*
Visual reinforcement audiometry testing of infants*

705 Other relevant guidelines and documents

Surveillance and Audiological monitoring of Infants & Children following the Newborn Hearing screen.
Guidelines for the Assessment and Management of Auditory Neuropathy Spectrum Disorder in Young Infants
710 Guidelines for aetiological investigation of infants with congenital loss identified through newborn hearing screening.
Guidelines for fitting hearing aids to young infants.
eSP reference guide
Equipment-specific parameters for ABR
715 ABR masking noise calculator

*responsibility for further updating of these protocols has been handed to the British Society of Audiology (revised version from BSA not released as of July 2013)

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

720

Notes

1. These examples assume that it has been possible to carry out tpABR at the desired frequencies
- 725 2. Example 1 includes detail of the decision-making processes that occur during the testing
3. All stimulus levels (except example 1 where values in dBnHL and dBeHL are given) are in dBeHL to avoid having to give one value for insert earphones and a different value for headphones.
4. All examples relate to babies tested before 12 weeks (≤ 84 days) corrected age.

730

Example 1: Unilateral conductive loss – with detail on process & choice of tests

Test	Right	Left
AC 4kHz tpABR	Threshold ≤ 30 dBeHL	Threshold = 55dBeHL
BC 4kHz tpABR		Threshold ≤ 15 dBeHL
TEOAE	Recordable	Not recordable

Comments:

- 735 TDH headphones were used for AC ABR in this example.
 Clear AC 4kHz tpABR responses have been obtained in the right ear down to a level (30dBeHL) which is considered to indicate “satisfactory hearing”, whereas on the left the threshold is elevated BC 4kHz tpABR tests were therefore performed on the left and clear responses were recorded down to 15dBeHL, which is a level where masking is not required (see appendix C).
- 740 The AC & BC thresholds indicate a purely conductive loss in the left ear.
 The absence of TEOAE in the left ear is expected from the conductive loss.

This example is expanded to suggest how these results could be obtained in an efficient way:

- 745 • Since this was a unilateral screen referral, ABR tests commenced with the screen clear response ear (right) using AC 4kHz tpABR. An initial stimulus level of 40dBeHL was used and a classic ABR waveform recorded so a replicate was obtained, and the pair of waveforms met the NHSP criteria for clear response (**CR**).
- The stimulus level was reduced to 30dBeHL (discharge level) and again a pair of waveforms constituting a clear response were recorded.
- 750 • AC 4kHz tpABR tests were then conducted on the left, again starting at 40dBeHL.
- No classic ABR waveform was seen in the initial waveform so rather than replicating, the stimulus level was increased to 60dBeHL where a probable response was recorded. A replicate was obtained at 60dBeHL and a clear response was confirmed.
- 755 • The stimulus level was reduced to 50dBeHL and no obvious ABR seen. A replicate at 50dBeHL allowed this level to be classified as “response absent” (**RA**) from the analysis of residual noise in the waveforms.
- At this point we could have tested at either 55dBeHL or 65-70dBeHL. Since the response at 60dBeHL was reasonably large (300nV), 55dBeHL was chosen and replicated waveforms confirmed **CR**.
- 760 • The AC 4kHz tpABR threshold on the left was therefore =55dBeHL, meeting the NHSP “Gold Standard” threshold definition.
- Note that if no ABR response had been obtained at 55dBeHL then tests at 65 or 70dBeHL would have been required.
- 765 • BC ABR tests were then undertaken to determine the nature of the elevated threshold on the left. Statistically, most losses of this magnitude are likely to be conductive in nature so a pragmatic decision is to initiate BC ABR tests in a way that is most efficient for that outcome (*i.e.* a normal left BC ABR threshold).

770 For AC tests it is most efficient to start at 10dB above the discharge level. For BC tests however we need to consider the need to apply masking. For babies under 12 weeks (≤ 84 days) we can

rely on the interaural attenuation being at least 20dB. This means that masking is not needed if a BC ABR clear response is obtained at 15dBeHL. For that reason we choose an initial stimulus level of 25dBeHL, without masking at this stage (strictly at that level we cannot be sure which cochlea is responsible for the response) and if a **CR** is obtained, tests are conducted at 15dBeHL. If a **CR** at 25dBeHL is not obtained then a higher level stimulus would be needed using contralateral masking. In the current example a BC 4kHz tpABR **CR** was recorded at 25 and 15 dBeHL so the threshold is ≤ 15 dBeHL. Not using masking at the supra-threshold level does carry a minor risk and it is important to be sure that the responses at threshold are valid, with the expected latency and amplitude relationships to the supra-threshold responses.

775
780

Example 2: Bilateral conductive loss

Test	Right	Left
AC tp4kHzABR	Threshold = 55dBeHL	Threshold = 50dBeHL
BC tp4kHzABR	Threshold ≤ 15 dBeHL	Threshold ≤ 15 dBeHL
TEOAE	Not recordable	Not recordable
Tympanometry (High freq.)	Abnormal	Abnormal

Comments:

The BC tpABR thresholds were ≤ 15 dBeHL at this stimulus level masking is not required (see Appendix C).
The BC threshold levels indicate a purely conductive loss in both ears.
The abnormal tympanogram and the absence of TEOAE with BC tpABR thresholds of 15dBnHL support MEE as the cause of the apparent conductive loss.

785
790

Example 3: Unilateral sensorineural loss

Test	Right	Left
AC tp4kHzABR	Threshold ≤ 20 dBeHL	Threshold = 55dBeHL
BC tp4kHzABR		Threshold = 50dBeHL
AC tp1kHzABR	Threshold ≤ 20 dBeHL	
TEOAE	Recordable	Not recordable

Comments:

Right ear: Responses at both 4kHz and 1kHz are recorded down to 20dBeHL as it is important to establish good hearing in the unaffected ear for a unilateral PCHI case (see section 6.1). It only becomes clear we need to test the right ear to 20dBeHL after testing the left, so the order of testing would be (i)Right ear 4kHz AC (to 30dBeHL), (ii)Left ear 4kHz AC, (iii)Left ear 4kHz BC, (iv)Right ear 4kHz & (v)1kHz AC (to 20dBeHL). Some testers may prefer to routinely test the first ear to 20dBeHL thus saving time - but in the majority of cases this would prove to be superfluous.
Left ear: Tympanometry was not required as no significant air-bone gap. No masking of the non-test ear was required for the left BC tpABR threshold, as the threshold was within 5dB of the AC threshold. Had the BC threshold been lower, masking (or 2-channel BC, possibly followed by masking) would have been necessary to ensure the BC response originated from the left cochlea.

795
800

Example 4: Bilateral sensorineural loss

Test	Right	Left
AC 4kHz tpABR	Threshold > 85dBeHL	Threshold > 85dBeHL
BC 4kHz tpABR	Threshold >50dBeHL	Threshold >50dBeHL
AC 1kHz tpABR	Threshold = 85dBeHL	Threshold >85dBeHL
TEOAE	Not recordable	Not recordable
Tympanometry	Normal	Normal
CM	Not recordable at 85	Not recordable at 85

Comments:

810 With the absence of an ABR response to 4kHz tone pips at 85dBeHL it is important to test hearing at other frequencies. Here the test showed some hearing at 1kHz for the right ear. The normal high-frequency tympanograms suggest there is no temporary conductive component. The absence of TEOAE and CM is consistent with the absence of ANSD. Having established there is no CM recordable, one may test AC 4kHz at 90dBeHL. If **CR** is established (note a third run is suggested –see NHSP ABR guidance) threshold would be =90dBeHL.

815

Example 5: Bilateral mixed loss

Test	Right	Left
AC 4kHz tpABR	Threshold = 80dBeHL	Threshold = 80dBeHL
BC 4kHz tpABR	Threshold = 45dBeHL	Threshold = 50dBeHL
AC TP 1kHz ABR	Threshold = 70dBeHL	Threshold = 70dBeHL
BC 1kHz tpABR	Threshold = 30dBeHL	Threshold = 30dBeHL
TEOAE	Not recordable	Not recordable
Tympanometry	Abnormal	Abnormal

Comment:

820 Such cases present a possible masking dilemma for BC with a risk of cross-masking. BC tests were conducted without masking in the first instance and since the right and left BC thresholds differed by less than 20dB (the minimum BC interaural attenuation) there is no need for masking.

Example 6: Auditory neuropathy spectrum disorder

Test	Right	Left
AC 4kHz tpABR	Threshold > 85dBeHL	Threshold > 85dBeHL
BC 4kHz tpABR	Threshold >50dBeHL	Threshold >50dBeHL
AC click ABR	Threshold > 85dBeHL	Threshold > 85dBeHL
CM	Not tested	Recordable
TEOAE	Recordable	Not recordable

Comments:

825 Absence of AC click ABR at 85dBeHL indicates PCHI or ANSD.
TEOAE recordable for the right ear is consistent with the presence of ANSD.
The presence of TEOAE means that there was no need to do CM in this ear.
As there was no recordable TEOAE on the left ear, CM testing was required to check for ANSD

830

Example 7: Atresia – see Appendix G

Appendix C: Masking

835

The principles of masking are similar to those for pure tone audiometry with the following differences:

840

845

850

855

- Rather than using an interactive plateau-seeking method (which is time consuming) we calculate the level of noise needed to mask the particular stimulus being used and apply that level of noise to the non-test ear. If the stimulus level is changed the noise level is changed by the same amount ('synchronous masking').
- The values of interaural attenuation (trans cranial transmission loss) of the stimulus are different in newborns from those in adults. This leads to some changes to the normal rules used to decide when masking is needed. See Table C1.
- We must take account of the level of noise needed to effectively mask an ABR stimulus in the same ear as the noise. This is referred to as the relative masking level (RML). Values of RML have been published by Lightfoot, Cairns & Stevens (2010) and are shown in Table C2.
- There are no standards available for the calibration of masking noise in ABR equipment so one needs to account for the way in which the ABR system's noise is calibrated. For the purposes of this appendix it will be assumed that masking noise is calibrated in dB SPL (e.g. 30dB of noise is 30dB SPL). The NHSP noise calculator spreadsheet takes account of how different systems' noise is calibrated; the user simply enters the model of ABR equipment.
- Since ABR stimuli (even tone pips) have a wider bandwidth than pure tones, unfiltered (white) noise is used as the masker.
- There are obviously practical limits to masking levels when testing babies. The baby may wake up if excessive levels are applied

860

Table C1. Minimum values of interaural attenuation in adults (provisional values for newborns under 12 weeks (≤ 84 days) corrected age are estimated as 20dB greater than these values). The final AC values used are reduced by 10dB as a 'safety margin' to allow for poor fitting of the stimulus transducer.

Stimulus	Headphones	inserts	BC
Click	48	55	0
4k pip	52	64	0
2k pip	45	54	0
1k pip	47	56	0
0.5k pip	45	50	0

865

Table C2. Relative Masking Levels in dB (from Lightfoot, Cairns & Stevens, 2010)

RML_{upper} is used when calculating the required noise level

RML_{lower} is used when assessing the risk of cross-masking

Stimulus	RML_{upper}	RML_{lower}
Click	33	18
4k pip	28	13
2k pip	33	13
1k pip	28	13
0.5k pip	33	18

870

A comprehensive description of the calculation of noise level needed to mask the ABR was published in BSA News issue 59 (2010) and is available on the NHSP website.

Noise calculator

875

The masking calculation depends on several factors such as type of equipment, transducer, stimulus and the baby's age at test, and we recommend this is done using the NHSP noise calculator, which accounts for these factors. There should be easy access to this when carrying out ABR assessment. The noise calculator can be downloaded from the NHSP

website and runs under Microsoft Excel. Only versions of the calculator dated 2013 or later include the age-specific stimulus level corrections and ABR offsets contained in these guidelines, so older versions should not be used.

880

The calculator indicates the need for masking, the level of noise to use and warns when there is a risk of cross-masking.

885

Deciding whether masking is needed when testing newborns under 12 weeks (≤84 days) corrected age

Masking is necessary if the level of the stimulus reaching the non-test ear cochlea is more than the level of stimulus reaching the test ear cochlea.

Air conduction (both headphones and insert earphones):

890

As a general rule of thumb and assuming the non-test cochlea is normal, then masking should be considered for stimulus levels above 65dBnHL (tone pips and clicks).

Bone conduction:

895

As a general rule of thumb and assuming the non-test ear cochlea is normal, then masking should be considered for stimulus levels above 15dBeHL.

900

In most babies with normal cochlear function it is possible to obtain a clear response (**CR**) for BC ABR down to a stimulus level of 15dBeHL. For this reason, when a baby's AC ABR threshold does not reach the NHSP discharge criterion and a conductive hearing impairment is suspected, bone conduction ABR without masking should be undertaken in the first instance. If **CR** is obtained at two levels 5 to 10dB apart suggesting a threshold of ≤15dBeHL then masking is not needed since the response must arise from the cochlea on the side of the vibrator. If the masking calculator is not available whilst testing, the table C3 below gives the equivalent nHL values for the different test stimuli at 15dBeHL at (and below) which it is safe to test without masking.

905

Table C3. Bone conduction: For babies tested up to 12 weeks corrected age. Equivalent nHL values for 15dBeHL.

	0.5 kHz	1 kHz	2 kHz	4 kHz
Tone pip	10	10	20	15
NB chirp	5	5	15	10

910

The above rules of thumb do not guarantee that masking is needed but rather that the NHSP noise calculator should be used.

915

It is unlikely that interaural attenuation will abruptly switch to adult values at 12 weeks (> 84 days) corrected age. However a cautious approach in the absence of research data would be to assume adult values, thus deducting 20dB from the rules of thumb above.

Masking the ABR

920

Enter all appropriate information into the noise calculator including the equipment type, stimulus transducer, masking transducer, stimulus type, stimulus level and, where known, values of the test and non-test ear air-bone gaps. The latter is unlikely to be known and must be estimated from all available clinical information. When there is insufficient clinical information to be certain of the presence of and degree of an air-bone gap in the non-test ear, enter a value of 30dB.

925

Using the levels of stimulus and masking noise suggested by the calculator, obtain a waveform. If this fails to show evidence of an ABR response do not replicate at this stage. Increase both stimulus and noise levels by 10dB and repeat recording. Where a candidate response is seen a replicate should be obtained and assessed. Follow the usual procedure for

930 establishing ABR threshold, keeping a fixed relationship between stimulus and noise levels.
The NHSP gold standard should be applied whenever masking is used.

Appendix B provides some examples in which masking is used.

Two-channel BC ABR

935 The method for this is covered in Appendix B of the NHSP Guidance for ABR testing in babies.
Note that if 2-channel BC ABR suggests that the contralateral cochlea is responsible for the
recorded ABR, masking will be necessary to establish the BC ABR threshold in the test ear.

Appendix D1: Stimulus level corrections

1. Bone conduction

940 The bone conduction stimulus is 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. The same BC stimulus is effectively stronger when applied to a baby owing to the smaller mass that the bone vibrator needs to stimulate. A correction therefore needs to be applied, which is dependent on the age at which the baby is tested.

945

Table D1.1. BC stimulus corrections by age

Corrected age (days)	0.5 kHz	1 kHz	2 kHz	4 kHz	Click
≤84 days	25	20	5	10	See Table D1.2
85 to 168 days	20	15	0	5	0
169 to 730 days	15	10	0	0	0
>730 days	0	0	0	0	0

The tone pip corrections in Table D1.1 are derived as follows:-

950 **Corrected age ≤84 days (12 weeks)**

The values for 0.5kHz and 1kHz are taken from a paper by Ferm, Lightfoot & Stevens (2013). For 2kHz tone pips the value has been derived based on the papers by Vander Werff *et al* (2009), Fox & Stapells (1993) and Small & Stapells 2008, applying weighting and stimulus correction as in Ferm, Lightfoot & Stevens (2013). For 4kHz the value has been derived from data in papers by Cone-Wesson and Ramirez (1997) and Small & Stapells (2008) again applying weighting as for 2kHz. The paper by Small and Stapells (2008) is an ASSR study but has been included given the small number of papers for ABR. No data were found for a graduated effect of age between 0 and 12 weeks corrected age. The 0.5 kHz results were combined in a meta-analysis with published results by Vander Werff *et al* (2009), Fox & Stapells (1993) and Cone-Wesson & Ramirez (1997). There are tentative data from ASSR studies (Small & Stapells 2008) to suggest the low frequency age effect is still present beyond 12 months of age (although reduced).

955

960

Corrected age 85 to 168 days (13 to 24 weeks)

The BC stimulus correction is retained for all frequencies but there is a reduction of 5dB. The basis for retaining a reduced correction is the evidence from Small & Stapells (2008) of a continued presence of BC stimulus lift above the age of 12 weeks.

965

Corrected age 169 to 730 days (25 weeks to 2 years)

There is some evidence (Small and Stapells 2008) that a BC stimulus correction value should be applied for babies between the corrected age of 24 weeks and 2 years. The reduction in the correction is continued with values being adjusted by a further 5 dB unless already at zero (2kHz).

970

Corrected age >730 days (2 years)

There is no BC stimulus correction over the age of 2 years

975

Table D1.2. Stimulus level corrections by age for click BC (to 1 dB)

Gestational age	36 weeks	40 weeks	46 weeks	52 weeks
Corrected age	-4 weeks	0 weeks	6 weeks	12 weeks
Difference (dB)	12	9	6	3

The values in Table D1.2 are derived from the difference between AC and BC click ABR thresholds in babies with normal AC click ABR thresholds, reported by Webb (1993) (rounded to the nearest 1dB).

980

2. Air conduction

Insert earphones:

985 Insert earphones can give higher levels of sound in the smaller neonatal ear canal.

Table D1.3. Provisional stimulus correction for insert earphones by age.

Corrected age (days)	0.5 kHz	1 kHz	2 kHz	4 kHz	Click
≤84 days	5	5	5	10	10
85 to 168 days	0	0	0	5	5
169 to 730 days	0	0	0	0	0
>730 days	0	0	0	0	0

The values in Table D1.3 are derived as follows:-

990

Corrected age 0-84 days

Voss and Herrman (2005) report the results of a modelling study investigating the differences in sound levels in infant and adult ears using circumaural, supra-aural and insert phones. Their data for insert earphones show an effect dependent on frequency varying between 5 and 8dB. 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 0.5, 1.5, 4 and 8kHz for neonates compared to adults. The value for clicks was 20dB. Marcoux (2011) found values of 2, 6 and 7dB at 0.5 kHz, 2kHz and 4kHz for the difference between infant and adults by looking at the real ear to coupler differences in stimulus level. Taking all these data into account^a the provisional values in Table D1.3 are proposed to correct for the effect of the smaller baby ear canal volume compared to an adult. A fixed value has been used up to 12 weeks corrected age as the data in the literature show too much inter-subject variability to deduce a trend within this age band.

995

1000

1005

Corrected age >84 days

If ABR testing is done above a corrected age of 12 weeks (84 days) consideration will need to be given to the changes that will occur to the stimulus correction values. These correction values are likely to gradually reduce with age from birth. For insert earphones, it was decided to approximate this gradual reduction in a stepwise fashion in two stages - the first at 12 weeks (84 days) and the second at 24 weeks (168 days) corrected age. A minimum step size of 5dB was used.

1010

Headphones

No correction of the stimulus level is necessary for headphones

^a The mean of the three studies at 4kHz was 14dB. The Sininger study differed considerably from the other two studies, so these latter were given greater weight resulting in the choice of 10dB.

1015 **Appendix D2: Normal maximum stimulus levels for ABR using**
 1020 **inserts (babies under 3 months corrected age)**

1025 For a maximum stimulus level of 135 dB SPL peak-to-peak the equivalent values in dB nHL for insert phones using NHSP reference values for a ER-3A insert phone with a IEC 60318-4 occluded ear simulator are given in row 1 of table D2.1 below. These values apply to adult ears. For neonatal ears the correction required to allow for the effect of the smaller ear canal volume is taken from table D1.3 above. To calculate the maximum recommended stimulus levels for insert earphones a cautious approach has been taken until more data are available: this is the 5 dB safety margin. Thus the overall correction shown in row 4 is calculated. This correction is subtracted from the value in dB nHL to give the maximum setting of the stimulus level to avoid exceeding 135 dB SPL in the ear canal.

Table D2.1. Recommended maximum stimulus levels NHSP reference values

	0.5 kHz	1 kHz	2 kHz	4 kHz	Click
Value for 135dB SPL pk-pk (dB nHL)	111.5	113.5	106.5	102.5	99.5
Estimated effect of neonatal ear canal volume + 5dB (dB)	+10	+10	+10	+15	+15
Value allowing for neonatal ear canal effect (dB nHL)	101.5	103.5	96.5	87.5	84.5
Recommended value (dB nHL)	100	100	95	85	85

1030

Appendix E1: Offsets to predict the estimated hearing level from the ABR threshold

1035 There is a considerable amount of data published on the mean differences between ABR/ASSR threshold and behavioural thresholds. The tables E1.1 to E1.3 below summarise the ABR data from a meta-analysis by Stapells (2000), the ASSR data for adults from a summary by Picton *et al* (2003), and a study by Rance (2005) on a large sample of babies.

1040 There is a wide variation between the results of individual studies. Factors that probably contribute to this are the variation in methods of ABR/ASSR stimulus calibration, the duration of the ABR/ASSR test time, the definition of ABR/ASSR threshold and in young children the nature and calibration of the behavioural measure to which the ABR/ASSR threshold is compared.

1045 **Table E1.1. Tone pip ABR. Results from Stapells (2000) meta-analysis show mean elevation of the tpABR thresholds (dBnHL) over the PTA thresholds**

	Mean (95% CI of population mean) of difference between tpABR and behavioural thresholds (Stapells 2000)			
Subject group	0.5 kHz	1 kHz	2 kHz	4 kHz
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 E1.1

1050 The mean difference is less for subjects with a sensorineural hearing loss. The standard deviation in the difference between the tpABR threshold and the PTA in individuals varied considerably across the 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 ± 15 dB.

1055

Table E1.2. ASSR – Results for normal and hearing-impaired adults (from Picton *et al* 2003)

	Mean difference (SD) across studies between ASSR threshold and behavioural threshold (dB)			
Subject group	0.5 kHz	1 kHz	2 kHz	4 kHz
Adults (normal hearing)	18.1 (11.7)	17.1 (10.8)	15 (11.2)	13.1 (11.0)
Adults (hearing-impaired)	7.7 (8.6)	4.9 (6.7)	9.2 (15.0)	5.4 (7.7)

Notes on table E1.2

1060 Mean values and standard deviations (SDs) have been derived from summary tables of studies given by Picton *et al* (2003) and 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.

1065

Table E1.3. ASSR - Results for normal and hearing-impaired infants (from Rance *et al* 2005)

Subject Group	Mean difference (SD) between ASSR threshold and subsequent behavioural threshold (dB)			
	0.5 kHz	1 kHz	2 kHz	4 kHz
Infants (normal hearing) Mean (SD)	30.4 (6.7)	31.0 (6.2)	22.4 (6.7)	27.5 (7.5)
Infants (hearing-impaired) ASSR threshold = 70dB	19.3	17.2	12.1	15.0
Infants (hearing-impaired) ASSR threshold = 100dB	8.2	7.3	5.2	5.4

1070

Notes on table E1.3

Mean values and SDs have been taken from Rance *et al* (2005). Results were obtained from 556 subjects, 285 with normal hearing and 271 with sensorineural hearing loss. ASSR thresholds were measured (at one frequency) at up to 3 months and compared with subsequent VRA behavioural thresholds measured between 6 and 23 months of age.

1075

Applying adult data 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:-

1080

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 offset values

1085

A set of offset values for the elevation of the tpABR threshold over the pure tone threshold is proposed from the meta analysis of Stapells (2000) and the following assumptions :-

1090

1. The difference between the stimulus level at the ear between adults and babies is not significant when delivered by headphones.
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 are likely to have been gathered under ideal test conditions and threshold in some studies is likely to have been defined with a less strict criterion 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 were used in preference to paediatric data from the Stapells (2000) analysis as the measure of the behavioural threshold (PTA) is likely to be more consistent across the individual studies.

1095

1100

The resulting values are given in the table E1.4 below.

Table E1.4. Derivation of offset values (tpABR above PTA thresholds)

	0.5 kHz	1 kHz	2 kHz	4 kHz	click
Stapells(2000) + 5dB	-20	-15	-15	-10	----
Correction to align overall corrections with Ontario	0	0	+5	0	0
ABR click/tone pip offsets	-20	-15	-10	-10	-5
ABR chirp offsets	-15	-10	-5	-5	n/a

1105 **Notes on Table E1.4.**

The equivalent figures proposed in the Ontario newborn hearing screening programme (Hyde 2008) which are also used in the DSL hearing aid prescription technique, are also shown. The only difference is 5dB at 2kHz. After considering various factors we reached a provisional decision to opt for the same figures as the Ontario programme (which uses insert earphones). The figure for click ABR has been based on the fact that the click ABR is a larger response and tends to have a slightly better threshold than the 4kHz tpABR response.

1110

Narrow-band chirp offsets

The offsets for chirps are based on a study in normal babies at 1 and 4kHz (Ferm, Lightfoot & Stevens, 2013). The results indicated that the ABR offset for NB chirpABR should be 5dB less than that for tpABR. The values for NB chirps in the tables are therefore all 5dB less than the equivalent tone pip values. Note that an assumption has been made that the difference in the combined correction values between NB chirps and tone pips from this study can be applied to different types of NB chirps, babies with thresholds at and above the discharge level of 30dBeHL, at other frequencies, to bone conduction and to all ages covered by these guidelines. This assumption needs to be borne in mind when using the NB chirp combined correction values.

1115

1120

Bone conduction

The authors are not aware of a similar meta-analysis of the elevation of BC ABR thresholds over behavioural thresholds. We have therefore provisionally proposed the same ABR offset values as for air conduction.

1125

Appendix E2: Derivation of confidence limits for the estimated hearing threshold

1130 The eHL values determined by using tables in Section 7 in the main text give the most likely estimates for the hearing threshold from the ABR thresholds. A clinical report should contain an estimate of the confidence in these results. The following describes the derivation of the provisional (5% to 95%) confidence intervals in Table 9 in the main text. Note that this information is not yet available on eSP.

1135 Confidence limits have been calculated for babies tested before 12 weeks (≤ 84 days) corrected age with thresholds above the discharge level (>30 dB HL). They can be provisionally applied above this age within the age range covered by this guidance. For babies with thresholds ≤ 30 dB HL the confidence intervals will be wider given the greater average difference between the
1140 ABR threshold and the true threshold.

The 5% to 95% confidence levels for the estimate of hearing levels from the tpABR threshold are of the order of ± 15 dB (Stapells 2000). Stevens *et al* (2013) reported a slightly higher value for the 5% to 95% prediction intervals but this was comparing ABR results (post newborn hearing screen)
1145 with PTA/VRA thresholds around 4 years of age where other factors may increase variation.

The estimated hearing level should be no worse than the ABR threshold. This means that the upper confidence level may be less than +15 dB particularly for the higher frequency tpABR and the click ABR where the ABR offset values are lower.

1150 **Example:**

1kHz ABR Threshold	50 dBnHL
1kHz Hearing Threshold	35 dB HL
Confidence Level at AC 1kHz TP	± 15 dB
Range of possible Hearing Thresholds	20 to 50 dB HL
4kHz ABR Threshold	50 dBnHL
4kHz Hearing Threshold	40 dB HL
Confidence Level at AC 4kHz TP	-15 dB / +10 dB
Range of possible Hearing Thresholds	25 to 50 dB HL

1155 For NB chirp ABR (using CE-chirps) Ferm *et al* (2013) found that the ABR offset was reduced by about 5 dB for 1 and 4 kHz. This has the effect of further reducing the upper limits as shown in Table E2.1.

1160 So for headphones the upper confidence intervals will be 15 dB or will follow the offsets (table E1.4) where they are less than 15 dB. Values are shown in Table E2.1. The lower confidence intervals will all be 15 dB.

Table E2.1. Confidence limits for predicted thresholds in dB HL

	Tone pip / click					chirp			
	0.5k	1k	2k	4k	click	0.5k	1k	2k	4k
Upper	+15	+15	+10	+10	+5	+15	+10	+5	+5
Lower	-15	-15	-15	-15	-15	-15	-15	-15	-15

- 1165 For insert earphones an adjustment needs to be made for the effect of the smaller ear canal compared to an adult which lifts the stimulus level. This changes the combined ABR offset and stimulus correction values when calculating the eHL values from the ABR thresholds. However it should not affect the 5% to 95% confidence intervals which will remain the same as those given in table E2.1.
- 1170 For NB chirpABR the upper limit values are further reduced as noted above. The upper limits are all reduced by 5dB compared to those for tone pips except at 0.5kHz where the 5dB reduction in ABR offset from 20dB to 15dB does not affect the confidence limit of 15dB.

1175 **Appendix E3: ASSR – Provisional set of ASSR offset and stimulus correction values**

The following derivation is for ASSR thresholds where

- Threshold is greater than 30dBeHL
- Corrected age at test is up to 12 weeks (≤84 days)

1185 From a number of studies comparing the relationship between ASSR threshold and behavioural thresholds in infants we have used the data from Rance *et al* (2005) because the study was longitudinal and had a large number of subjects (n=575). The linear relationship between ASSR AC threshold (measured with inserts) and subsequent behavioural threshold suggested that the differences decrease with increasing severity of hearing loss. Table E3.1 presents the regression line equations.

1190 **Table E3.1. Relationship between ASSR threshold and subsequent VRA threshold (Rance *et al* 2005)**

Frequency	0.5 kHz	1 kHz	2 kHz	4 kHz
Equation	$Y = 0.73X + 33.0$	$Y = 0.75X + 30.3$	$Y = 0.81X + 22.9$	$Y = 0.76X + 28.3$

(where X = behavioural threshold. Y= ASSR threshold)

1195 The behavioural thresholds are from VRA which gives minimum response levels (MRLs) not estimated hearing levels, so a correction is required. The MRL-eHL relationship is described by Parry *et al* (2003) for normal infants. Because these values may not apply to hearing-impaired infants (where recruitment may be present) with whom this guidance is concerned, we have therefore used a provisional correction of half of the Parry *et al* values (Table E3.2).

1200 **Table E3.2. VRA Minimum Response Levels for Normal-hearing Infants (from Parry *et al* 2003) and proposed MRL to eHL correction**

Frequency	0.5 kHz	1 kHz	2 kHz	4 kHz
Mean (SD) (dB HL)	16.4 (5.9)	13.3 (6.1)	7.1 (5.5)	6.4 (6.2)
MRL to eHL correction = half above values (dB HL)	8.2	6.7	3.6	3.2

1205 Rance's (2005) report gave different offset values for different degrees of hearing impairment but for the purpose of this guidance we decided to provide a single set of offset values to cover all hearing impairments. This obviously is not as accurate as giving values for each degree of hearing impairment, but the error is estimated at no more than 8dB between 40 and 90dBeHL. The single offset value for inserts has been calculated to give the best fit between 30 and 100dBeHL using the MRL correction values in Table E3.2. The Headphone values have been calculated by applying the insert stimulus corrections in reverse.

1210 **Table E3.3. Value to be added to the ASSR AC thresholds to give estimated hearing thresholds (dBeHL)**

Transducer	0.5 kHz	1 kHz	2 kHz	4 kHz
Inserts	-20	-20	-15	-15
Headphones	-25	-25	-20	-25

Appendix F: Predictive value of AC ABR in PCHI cases

1215

The relationship between the ABR threshold from the post newborn screen assessment and the final hearing status will be affected by a number of factors including the accuracy of the ABR threshold, the presence of temporary conductive hearing loss, delayed neural maturation and development of hearing loss after the neonatal stage. The predictive value of the AC ABR result is a measure of its ability to predict the final hearing status. Section 8.4 of the main text gave estimates for the confidence intervals in the estimated true hearing threshold (eHL). The purpose of this appendix is to look at how good these confidence intervals are in predicting the long term outcome.

1220

1225

Note that the data in the previous version of these guidelines (2011) on the positive predictive value of click ABR has been superseded by the data given below on click ABR.

1230

There are little published data on the predictive value of tpABR, but a study by Stevens *et al* (2013) compared the hearing thresholds on follow up with those obtained in the post-newborn screen assessment by 1kHz tpABR, 4kHz tpABR and click ABR. Two-thirds of the follow up tests were PTA or play audiometry and one-third insert VRA. The mean age for follow up results was 3.86 years. For 4kHz, 97% of the follow up results were within ± 15 dB of the regression line and the 5% and 95% prediction intervals for the regression lines were ± 18 dB. The paper noted that these results were similar to those reported for adults and children when 4kHz tpABR was carried out at the same time as the behavioural testing.

1235

The similarity of these results to the confidence intervals in section 8.4 (whose derivation is described in Appendix E2) gives strong support for the latter's use in the estimation of the true hearing threshold.

1240

The results at 1kHz showed a wider scatter compared to 4kHz, with 72% of values lying within ± 15 dB of the regression line. The 5% to 95% prediction intervals were ± 29 dB. The results therefore indicate that the long term outcome may be less accurate than that predicted by the confidence intervals for 1kHz in section 8.4 of the main text.

1245

The results for click ABR when compared to the 0.5,1,2,4 kHz average follow up were that 64% of values lay within ± 15 dB of the regression line with the 5% to 95% prediction intervals for the regression line being ± 37 dB. The paper also found similar results for click ABR when compared to each of the 0.5, 1, 2 and 4kHz follow up frequencies. These results demonstrate the poorer predictive value of click ABR and the limitations of relying on AC click ABR thresholds in predicting the long term audiological status.

1250

Appendix G. Testing babies with atresia

1255 **Summary guidance for babies up to 12 weeks (84 days) corrected age.**
These notes are aimed to give a brief summary of how to approach testing in cases of atresia. They should be read in conjunction with the section in the main text on sequence of tests.

1260 **Unilateral Atresia**

The aim is to establish that the unaffected ear definitely has normal hearing and find out as much as possible about hearing in the affected ear. This obviously applies to all permanent unilateral cases, and in section 5.11 (unilateral cases) it was noted that testing should be carried out down to 20dBeHL in the unaffected ear at both 1kHz as well as 4kHz if possible.

1265

In summary, testing for unilateral atresia should be as follows:

1) Test unaffected ear by AC using 4kHz and 1kHz tone pips.

1270 At least two frequency-specific thresholds should be obtained. Test down to at least 20dBeHL or establish threshold.

If elevated, test by BC ABR using 4kHz tone pips. Also perform diagnostic OAEs and tympanometry if relevant.

1275

2) Test affected ear (i) by BC using 4kHz tone pips (ii) (if possible) by AC using 4kHz tone pips

Masking may be required – use masking calculator (see below)

1280 **Bilateral Atresia**

The aim is to find out as much as possible about the hearing in both ears. These children will probably require support and aiding in any case.

1285 In summary testing for bilateral atresia should be as follows:

1) Test each ear by BC using 4kHz tone pips.

1290 Masking: if thresholds are ≤ 15 dBeHL for 4kHz BC ABR there is no need for masking. If thresholds are above 15dBeHL masking is problematical: one possibility is to use 2-channel BC ABR without masking (refer to NHSP Guidance on ABR testing in babies Appendix B).

2) Test each ear by AC using 4kHz tone pips to measure the degree of conductive loss.

1295

1300 Masking: The degree of conductive loss may be enough to cause cross masking. In such cases it is acceptable to conduct AC tpABR without masking, but be aware that there will be doubt concerning which ear is responding. An alternative approach is to conduct 2-channel AC tpABR without masking; the ear generating the ABR may be apparent from the ipsilateral & contralateral ABR waveforms (see Appendix B of the NHSP Guidance for ABR testing in babies and apply the advice on 2-channel BC testing to 2-channel AC testing).

1305

Masking - In all cases it is advisable to use the NHSP ABR masking level calculator (on NHSP website <http://hearing.screening.nhs.uk>). Always use the latest version (at least 2013)

If in doubt seek expert help.

1310 **Appendix H. Checklist for Audiological Assessment**

This is intended as a quick reference sheet to be kept with the equipment. Refer to the main text of these guidelines and to specific test guidance/protocols (Appendix A) for detailed checks and procedures.

1315 **General**

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

Electrophysiological testing

1320 **1/ Prior to test session.**

Stage 'A' check including check on transducers and leads (headphones, insert earphones and bone conductor).

2/ Start of test session

- 1325 All electrodes for tests applied before starting (including nape if needed).
Electrodes leads correctly plugged in.

3/ Before each set of tests

- 1330 Check Headphones/insert earphones /bone conductor produce sound
Check headphone/insert applied to correct ear.

4/ No response

- 1335 Check sound from headphones/insert earphones /bone conductor.
Check leads correctly plugged in.

5/ 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)

1340 **Tests**

1/ Check that the appropriate test(s) from the following list have been carried out.

AC 4kHz tpABR

AC 1kHz tpABR

- 1345 AC click ABR where accurate thresholds not possible with tone pip ABR

BC 4kHz tpABR

BC click ABR where accurate thresholds not possible with tone pip ABR

1350 **2/ Masking**

Has masking been carried out when needed?

3/ Check for ANSD where ABR abnormal or absent at high stimulus levels.

1355 **4/ Tympanometry**

5/ Observation of any consistent behavioural reactions to stimuli.

1360

Appendix I: Combined ABR dBnHL to dBeHL correction values – by transducer

1365 In the tables below, combined corrections are **added** to the thresholds in dBnHL to give the estimated threshold in dBeHL. Derivation is explained in section 8.

AC - INSERTS	Tone pip/click ABR					Chirp			
	Corrected age	0.5k	1k	2k	4k	Click	0.5k	1k	2k
≤12 weeks (≤84 days)	-15	-10	-5	0	5	-10	-5	0	5
13 to 24 weeks (85–168 days)	-20	-15	-10	-5	0	-15	-10	-5	0
> 24 wk (>168 days)	-20	-15	-10	-10	-5	-15	-10	-5	-5

AC - HEADPHONES	Tone pip/click ABR					Chirp			
	Corrected age	0.5k	1k	2k	4k	Click	0.5k	1k	2k
All ages	-20	-15	-10	-10	-5	-15	-10	-5	-5

1370

BC	Tone pip/click ABR					Chirp			
	Corrected age	0.5k	1k	2k	4k	Click	0.5k	1k	2k
≤12 weeks (≤84 days)	5	5	-5	0	See below	10	10	0	5
13 to 24 weeks (85 - 168 days)	0	0	-10	-5	-5	5	5	-5	0
25 weeks to 2 years (169 - 730 days)	-5	-5	-10	-10	-5	0	0	-5	-5
>2 years (>730 days)	-20	-15	-10	-10	-5	-15	-10	-5	-5

1375 **BC Click**

Corrected age	Gestational age	Click†
-4 weeks	36 weeks	+7
0 weeks	40 weeks	+4
6 weeks	46 weeks	0
12 weeks	52 weeks	-2

† For clicks, where the corrected age is between the values in the previous column, interpolation may be used (note that this is done in eSP).

References

- 1380 Carr G, Kean M, Sutton G (2012). *Parental perceptions of early identification and management of unilateral hearing loss*. Presentation at BAA Annual Conference Manchester Nov 2012.
- Cone-Wesson B, Ramirez GM. (1997). *Hearing sensitivity in newborns estimated from ABRs to bone-conducted sounds*. J Am Acad Audiol 8(5): 299-307.
- 1385 Elberling C, and Don M (2010). *A direct approach for the design of chirp stimuli used for the recording of auditory brainstem responses* J Acoust Soc Am 128: 2955–2964.
- Ferm I, Lightfoot G, Stevens J. (2013). *Comparison of ABR response size, test time and estimation of hearing threshold using frequency specific chirps and tone pips stimuli in newborns*. Int J Audiol 52(6): 419-23
- 1390 Ferm I, Lightfoot G, Stevens J (2013). *Stimulus level corrections for low frequency bone conduction ABR in babies under three months corrected age*. Int J Audiol (submitted)
- 1395 Foxe JJ, Stapells DR (1993). *Normal infant and adult auditory brainstem responses to bone-conducted tones*. Audiology 32(2): 95-109.
- Hyde M (2008). *Audiological Assessment Protocol and Support Documentation*. Infant Hearing Program (Ontario, Canada).
- 1400 Janssen R, Usher L, Stapells DR (2010). *The British Columbia Children’s hospital tone-evoked ABR protocol: how long do infants sleep, and how much information can be obtained in one appointment*, Poster at NHS conference Como 2010.
- 1405 Lightfoot G, Cairns A, Stevens J (2010) *Noise levels required to mask stimuli used in auditory brainstem response testing*. Int J Audiol 49: 794–798
- Marcoux AM (2011). *Maturation of auditory function related to hearing threshold estimations using the auditory brainstem response during infancy*. Int J of Pediatric Otorhinolaryngology. 75(2): 163-170.
- 1410 NDCS (2002). *Quality Standards in the Early Years: Guidelines on working with deaf children under two years old and their families*. National Deaf Children’s Society. www.ndcs.org.uk/document.rm?id=112
- 1415 NHSP website (<http://hearing.screening.nhs.uk>) for NHSP parent information leaflets
Your Baby’s visit to the Audiology Clinic (2012).
Your baby has a hearing loss (2007).
1420 Your baby has a hearing loss in one ear (2007).
Your baby has a mild hearing loss (2007).
- NHSP website (<http://hearing.screening.nhs.uk>) for NHSP guidance documents
1425 NHSP Guidance for Auditory Brainstem Response testing in babies (2013).
NHSP Guidance note on entering ABR thresholds into DSL software (2013).
NHSP Guidelines for Cochlear Microphonic Testing (2011).
NHSP Tympanometry in babies under 6 months – a recommended test protocol (2008).
NHSP Provisional guidelines for using Auditory Steady State Responses (ASSR) in babies (2009).
- 1430 Oates P and Stapells DR (1998). *Auditory brainstem response estimates of the pure tone audiogram: current status*. Seminars in Hearing 19(1): 61-85.
- 1435 Picton TW, Sasha John M, Dimitrijevic A, Purcell D (2003). *Human steady-state responses*. Int J Audiol 42: 177-219.

- Parry G, Hacking C, Bamford J, Day J. (2003). *Minimum response levels for visual reinforcement audiometry in infants*. Int J Audiol 42: 413-417.
- 1440 Pattison E, Carr G, Sutton G, Kean M (2008). *Parental perceptions of the experience and impact of the early identification and management of unilateral hearing loss following newborn hearing screening*. Poster at Newborn Hearing Screening Conference Como 2008
- 1445 Rance G, Roper R, Symons L, Moody L, Poulis C, Dourlay M, Kelly T (2005). *Hearing threshold estimation in infants using Auditory Steady-State Responses*. J Am Acad Audiol 16: 291-300.
- Sininger YS, 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.
- 1450 Small SA, Hatton JL, Stapells DR (2007). *Effects of Bone Oscillator Coupling Method, Placement Location, and Occlusion on Bone-Conduction Auditory Steady-State Responses in Infants*. Ear & Hearing 28(1): 83-98.
- 1455 Small SA, Stapells DR (2008). *Maturation of bone conduction multiple auditory steady-state responses*. Int J Audiol. 47(8): 476-488.
- Stapells DR (2000). *Threshold estimation of the tone evoked auditory brainstem response. A literature Meta-Analysis*. J Speech Lang Path & Audiology 24(2): 74-82
- 1460 Stapells DR (2010). Haplab Website <http://www.courses.audiospeech.ubc.ca/haplab/>
- Stevens J, Boul A, Lear S, Parker G, Ashall-Kelly K, Gratton D (2013). *Predictive value of hearing assessment by the auditory brainstem response following universal newborn hearing screening*. Int J Audiol 52(7): 500-506)
- 1465 Vander Werff KR, Prieve BA, Georgantas LM (2009.) *Infant air and bone conduction tone burst auditory brain stem responses for classification of hearing loss and the relationship to behavioral thresholds*. Ear Hear 30(3): 350-368.
- 1470 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 Hear 26: 636-650..
- Watkin PM, Baldwin M (1999). *Confirmation of deafness in infancy*. Arch Dis Child 81:380-389
- 1475 Webb HD (1993). *Auditory screening in high risk neonates: An evaluation of the bone conduction ABR*. M Med Sci thesis University of Sheffield, UK.