Practice Guidance

Guidelines for the Early Audiological Assessment and Management of Babies Referred from the Newborn Hearing Screening Programme

Date: December 2021

Due for review: December 2026

OD104-98 (01/12/2021)

General Foreword

This document presents Practice Guidance by the British Society of Audiology (BSA). This Practice Guidance represents, to the best knowledge of the BSA, the evidence-base and consensus on good practice, given the stated methodology and scope of the document and at the time of publication.

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Published by the British Society of Audiology

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Declarations of interests

- Declaration of interests by the authors: ERA Training & Consultancy Ltd offer training courses in ABR testing, training and accreditation in ABR peer review and offer clinical support for centres performing ABR testing.

With thanks to:
Those who made contributions to this and earlier versions, including Verity Hill, Graham Sutton, Sally Wood, John Stevens, Rachel Booth, Sally Minchom, Rachel Feirn, Rhys Meredith, Glynnis Parker, the expert reviewers for their advice and guidance and to BSA members who provided feedback in the membership consultation.

Citation

Please cite this document in the following format:

BRITISH SOCIETY OF AUDIOLOGY (*2021*), *Guidelines for the Early Audiological Assessment and Management of Babies Referred from the Newborn Hearing Screening Programme* [Online]. Available at: https://www.thebsa.org.uk/resources/ [Accessed *date*]

Shared Decision-Making

It is implied throughout this document that the service user should be involved in shared decision-making when undertaking audiological intervention, receiving subsequent information and understanding how it will impact on the personalisation of care. Individual preferences should be taken into account and the role of the clinician is to enable a person to make a meaningful and informed choice. Audiological interventions bring a variety of information for both the clinician and the patient which can be used for counselling and decision-making regarding technology and anticipated outcomes.

Contents

Abbreviations

ABR	Auditory Brainstem Response
ABR offset	Difference between ABR and true hearing thresholds
AC	Air Conduction
ANSD	Auditory Neuropathy Spectrum Disorder
ASSR	Auditory steady-state response
BC	Bone-conduction
cCMV	Congenital cytomegalovirus
CM	Cochlear Microphonics
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 BSI reference equivalent threshold levels are used.
DPOAE	Distortion Product Otoacoustic Emissions
Inc	Inconclusive response
MEE	Middle Ear Effusion
NB chirpABR	Narrow-band chirp evoked ABR (conforming to IEC 60645-3 (2020)
NICU/SCBU	Neonatal Intensive Care Unit / Special Care Baby Unit
PCHI	Permanent Childhood Hearing Impairment - defined here as ³40dBHL average of 0.5, 1, 2 and 4 kHz PTA thresholds. It includes both sensorineural and permanent conductive impairments
PTA	Pure-Tone Audiometry/Audiogram
RA	Response Absent
RECD	Real-Ear to Coupler Difference
RETFL	Reference Equivalent Threshold Force Level
RETSPL	Reference Equivalent Threshold Sound Pressure Level
RML	Relative Masking Level. Change in the sound level at the ear that occurs when insert earphones, supra-aural earphones or bone conductors, calibrated in adults are applied to babies stimulus correction
S4H	Smart for Hearing (Electronic record system for NHSP)
TEOAE	Transient Evoked Otoacoustic Emissions
tpABR	Tone-pip Evoked ABR
VRA	Visual Reinforcement Audiometry

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. The reason for this focus on under 12 weeks corrected age is that testing is usually most productive within this time because of longer periods of natural sleep. The document can also be used to guide the assessment of babies who, through necessity are seen for diagnostic testing outside this 12 week period. 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 BSA guidance for auditory brainstem response (ABR) testing in babies (as this is the primary method of assessment in this age group) and other guidance and protocols relating to newborn hearing screening, assessment and follow up available on the BSA and NHSP websites (https://www.thebsa.org.uk/ and http://hearing.screening.nhs.uk). Earlier iterations of this document were written by the NHSP Clinical Group. This version is the work of the BSA Electrophysiology Special Interest Group.

2. Requirements for a newborn audiological assessment service

2.1 Equipment

Equipment to carry out ABR threshold measurement using frequency-specific stimuli (tone pips or narrowband chirps) and clicks by both air- and bone-conduction is required. Recommended equipment settings are given in the document 'BSA Recommended Procedure Auditory Brainstem Response (ABR) Testing in Babies" (2019) and calibration to the RETSPLs (Reference Equivalent Threshold Sound Pressure Levels) and RETFLs (Reference Equivalent Threshold Force Levels) are given on the BSA website (BRITISH SOCIETY OF AUDIOLOGY (2019) Recommended stimulus reference levels for ABR systems). Equipment to record TEOAEs and high frequency tympanograms is also needed. All equipment should have a documented annual calibration and regular safety and electrical testing in accordance with local protocols.

2.2 Staff training and expertise

Staff carrying out threshold measurement for both air-conduction (AC) and bone-conduction (BC) ABR require experience and expertise in accurately interpreting ABR waveforms, determining thresholds (including when and how to use masking and other ear-specific methods) and dealing with unusual or unexpected waveforms or results. They should also have expertise in cochlear microphonic (CM) and otoacoustic emissions (OAE) testing, and in high frequency 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).

Only a small proportion of babies require hearing assessments following the newborn screen (less than 3%), therefore 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. It is recommended that a robust process for auditing of results is in place, including routine and rigorous systematic external peer review of the waveforms, threshold estimation and test procedures. The BSA practice guidance "Principles of external peer review of auditory brainstem response (ABR) testing in babies" (BSA, 2019) details what ABR peer review should entail. Service providers, commissioners and testers should ensure that they have in place a system for the systematic external peer review of their ABR services, compliant with that document, as a component of their quality assurance infrastructure. The peer review document is available on the BSA web pages.

2.3 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.

2.4 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.

2.5 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. 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 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/pure tone audiometry (PTA) threshold).

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.

2.6 Timing of tests

2.6.1 First assessment

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. 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. Delaying testing or not allowing sufficient time for carrying out the assessment can create more work and can delay complete assessment of the baby's hearing status. Expedited assessment should be arranged for babies with confirmed cCMV to ensure the hearing status can be established to enable treatment to be offered within 4 weeks of birth where feasible (Bilavsky et al. 2016). Expedited assessment should also be arranged for suspected or confirmed bacterial meningitis or septicaemia (see Appendix L).

2.6.2 Further appointments

If required, further appointments should normally be completed by 8 weeks corrected age for the reasons outlined in the previous section. Repeat assessments within the newborn period are necessary in the event of incomplete first assessments or where the initial appointment suggests a sensorineural hearing loss before 4 weeks corrected age. Repeat assessments would also be beneficial in cases with the possibility of fluctuation or with a risk of a rapidly progressive loss. The tester is signposted to BSA Assessment And Management of Auditory Neuropathy Spectrum Disorder (ANSD) in Young Infants recommended procedure for repeat assessments in cases where ANSD is suspected. Parents must be given clear explanations about the rationale for the timing of assessments.

Domiciliary assessment may be a viable alternative particularly if it is difficult for the family to attend appointments. 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 acoustic 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. It is recommended that domiciliary assessment is limited to the initial assessment.

If an ABR response has been obtained previously (and ANSD has therefore been excluded) and this latter appointment is to provide more diagnostic information, perhaps for aiding, the tester could consider the use of ASSR. This is elaborated on in section 4.6.

2.7 Clinical arrangements and time to allow for testing

Sufficient time needs to be allowed for diagnostic assessment with ABR. Electrodes can be attached on arrival or soon after and then time needs to be allowed for babies to settle into natural sleep. Generally no more than 2 or 3 babies should be seen by an audiologist per session (half day), but where a detailed assessment is required, there may be only 1 baby per session.

2.8 Sedation

Sedation is very rarely necessary in babies under 12 weeks of age and should be used in babies under 12 months of age only with clear clinical reasoning. Early assessment means that babies can be tested relatively easily during natural sleep.

3. Test options

3.1 Use of tone pips or narrow-band chirps

Tone pip ABR (tpABR) or narrow-band chirp ABR (NB chirpABR) with stimuli conforming to IEC 60645-3 are the primary methods of measuring the hearing threshold except in specific circumstances. More details on this are given in later sections. If using NB chirpABR the corrections and ranges for converting ABR thresholds in nHL to estimated hearing level (eHL) are different. There are a number of possible designs of chirp that all meet IEC 60645-3 (2020) yet their specific design may influence the size of response and consequently the corrections to apply. One such design is the patented CE-Chirp, for which corrections have been suggested and implemented in S4H. Chirp designs other than the CE-Chirp may or may not offer similar advantages and could require different corrections, which should be established in clinical studies. This guidance will henceforth use the term "chirp" to imply the use and characteristics of the CE-Chirp but testers must be aware that other designs of chirps may not offer the same performance or require the same corrections.

The two advantages of using CE-Chirps are the ABR response is usually larger which should reduce test time (Ferm *et al* 2013, Elberling & Don 2010) and the ranges for the eHL threshold value are smaller (see Appendix J).

3.2 Use of supra-aural earphones and insert phones

Use of either supra-aural earphones 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. For babies with "programmable shunts" insert earphones should be used as opposed to supra-aural earphones, with the transducer placed as far from the baby's head as the tubing will comfortably allow and bone-conduction tests should not be performed on the side of any programmable shunt. This is because the magnet in transducers, if placed within 5 cm of the shunt, might unintentionally re-programme the shunt. Further information on this risk is being pursued and more detailed advice may follow.

Stimulus levels in supra-aural earphones and inserts

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 F.

Table 1. Relative merits of supra-aural earphones and insert earphones

	Supra-aural earphones	Insert earphones
Advantages	Greater certainty of stimulus levels. Higher stimulus levels possible Less disturbance of baby	Better interaural attenuation, reducing the likelihood of requiring masking Reduced stimulus artefact Easier to block sound for blocked stimulus control runs and CM testing No need to change transducer if CM testing Better attenuation of ambient noise Facilitates use of thresholds for hearing aid prescription. Less electrical hazard when used in theatre following myringotomy Less equipment contamination hazard
Disadvantages	Small possibility of ear canal collapse if too much pressure Change in stimulus level with movement	Stimulus level more uncertain due to individual variation in ear canal volume.[a] Difficult to ensure insert placement is optimal as slight movements can affect the position.

[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.

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 G). Great care must therefore be taken with maximum levels used (see section 6.1). For supra-aural earphones 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 Appendix I to estimate the hearing threshold from the ABR thresholds, measured using supra-aural earphones or insert earphones.

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 (BSA 2018). This may 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.

3.3 ABR stimulus start level

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, it is recommended that the start level should be at 40dBeHL - *i.e.* 10dB above discharge level for 4 kHz. 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 40dBeHL response), a repeat ABR assessment will normally be needed. It is also acceptable to start testing the better ear of a unilaterally referred baby at 30dBeHL (followed by 20dBeHL) to avoid having to return to this ear in cases of a unilateral permanent childhood hearing impairment (PCHI).

3.4 ABR stimulus level steps and testing at higher levels

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. An alternative approach is to make use of the soft start option available in some ABR machines.

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 80dBnHL and determine the ABR threshold lies between 60 and 80dBnHL, this is a more useful outcome than if we had tested at 40, 50 and 60dBnHL and concluded only that the ABR threshold was above 60dBnHL. 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. A balanced explanation is needed to ensure that false hope and additional worry for the parents is avoided. Be aware of the normal maximum recommended stimulus levels for supra-aural earphones and inserts (see section 6.1)

4. Sequence of tests

4.1 Introduction

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. Tympanometry can inform the calculation of noise levels in masking so there is merit in carrying this out prior to ABR testing. 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 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 recording with different electrode montage - please refer to BSA ABR guidance (BSA 2019). It is considered poor practice to turn equipment on or off whilst electrodes and transducers are connected to the patient as this can be associated with currents being passed through the electrode or transducer leads. The ABR equipment should be on and the programme active prior to connection; if a "re-boot" is needed, first disconnect electrodes and transducers then re-connect them only after the re-boot and activation of the ABR software.

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. 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 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.

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 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 criteria.
- For unilateral referrals, start with the screen 'clear response' (***CR***) ear to confirm 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 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.

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

4.2 OAEs

Optionally, a TEOAE test may be used as the discharging test for well babies, but only for those babies with no risk factors that would require targeted follow up (see NHSP surveillance guidelines) no previous tests which may indicate the presence of ANSD (e.g. OAE Pass AABR Refer at screening) and with no parental concern about hearing. Discharge from assessment on the basis of OAE test alone would be inappropriate for babies referred for audiological assessment for other reasons. 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 as defined in Appendix B and reviewed even if screening equipment is used.

Measurement of acoustic reflexes can be informative (see Appendix C). The absence of reflexes can be associated with ANSD which would be missed in the well-baby cohort if tested on OAE alone. If reflexes are absent ABR is required. Completion of reflex testing in newborns may not always be possible.

Provided both ears meet the NHSP TEOAE screen pass criteria, the baby can be discharged (although sites can choose to set stricter TEOAE criteria if they wish; no criteria have been agreed for distortion product otoacoustic emission (DPOAE) screening); if not then both ears require ABR testing and time must be available to proceed to this in the same appointment if required.

Neonatal intensive care unit / special care baby unit (NICU/SCBU) babies and those not meeting the above criteria should always proceed to ABR testing irrespective of the TEOAE result.

4.3 AC ABR

Frequency- and ear-specific ABR is the main method used to estimate hearing thresholds. Masking or use of 2 channel recordings for demonstrating ear-specific responses must be used where necessary; if not possible a clinical note must be made notifying the reader of the limitations of the thresholds being reported – see Appendix D. The discharge criterion is the establishment of AC 4 kHz ABR 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 BSA ABR guidance on the BSA website) no other testing will usually be required. The main reason for recommending 4 kHz is that it is the most sensitive test frequency for detecting SNHL, and also, practically, it is usually the easiest frequency-specific ABR response to record. Pittman and Stelmachowicz (2003) reported only 4% of sensorineural losses in children were reverse slope losses. Sections 5.3 and 5.4 discuss pathologies for which discharging on 4kHz alone is not recommended.

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

- Test the other ear by AC at 4 kHz.
- Test the same ear by BC 4 kHz ABR to determine if the raised threshold is conductive. At this stage there may be insufficient information available to select an appropriate level of noise for masking the non-test ear, so 2 channel-recording may be useful.

After testing at 4 kHz in both ears the next option could be a low frequency AC frequency-specific stimulus (1 kHz is recommended). This should be included where the threshold is raised and the BC is consistent with a SNHL. If time permits, then the frequency recommended after 4 and 1 kHz is 2 kHz or 0.5 kHz, depending on clinical need. Complete tests at each frequency to the required standard (see BSA ABR guidance on the BSA guidance) before proceeding to the next frequency.

AC click ABR should be used only where there is no frequency-specific response at the normal maximum stimulus levels (see section 6.1) as part of ANSD investigations (BSA 2019).

4.4 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. Note that there is no "discharge level" or level for "satisfactory hearing" for bone-conduction; tests by BC should be undertaken at stimulus levels that demonstrate whether the loss revealed by AC is of conductive or sensorineural origin. If the AC ABR threshold was measured at 4 kHz, perform a 4 kHz BC ABR (mask or use 2 channel recording to gain ear specific information if needed). 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. Masking may be required (refer to appendix E). However ***masking will not be needed if a clear BC ABR response is recorded at or below 15dBeHL*** (see Appendix E). This applies only to babies tested before 12 weeks (≤ 84 days) corrected age.

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 F, and in the BSA ABR Guidance. Concerns about the accuracy of BC testing at 4 kHz has been raised by recent studies (Margolis et al 2019).
A recent study (Inga Ferm, personal communication, 2021) compared ABR air conduction thresholds and bone conduction thresholds using 4 kHz tone pips when testing babies with a corrected age of between -2 wks and 16 weeks. Tympanometry was consistent with normal middle ear function. When the current dBnHL to dBeHL age appropriate corrections were applied, the median AC to BC difference (the resulting air bone gap) was 0 dB. From this study, it would suggest there is not the same concern about the accuracy of BC testing at 4 kHz when testing babies using ABR in this age range.

4.5 Tests for ANSD

If there is no response at the normal maximum permissible stimulus level to frequency-specific ABR (see section 6.1 – normal maximum stimulus levels in babies), or only grossly abnormal waveforms at high stimulus levels (≥75dBeHL), then ANSD may be present in that ear. Grossly abnormal does not include waveforms that would be consistent with a sensory neural hearing loss at these levels. Tests of cochlear function are then required for that ear. ANSD may be unilateral. Refer to the BSA 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, using the same transducer (insert earphones) to confirm that any CM recorded is cochlear as opposed to neural in origin.

4.6 Auditory Steady State Response (ASSR)

ASSR is a promising technique with objective detection of responses. 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. See BSA guidelines for using ASSR in babies on the BSA website for more detail. Currently the BSA does not recommend discharging by using ASSR testing in lieu of ABR or AABR because cases of ANSD may possibly be missed. However, if ABR identifies a hearing loss and the next step is to obtain multi-frequency threshold to inform both diagnosis and management then ASSR is a particularly attractive alternative to ABR. If both ASSR and ABR are used and the results conflict, the ABR should be relied upon and expert opinion sought.

4.7 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 (1 kHz is recommended) must always be used for babies under 6 months (refer to the BSA guidance on tympanometry in babies under 6 months for full details).

4.8 Reflexes

Appendix C gives additional guidance on how to test for the presence of acoustic reflexes in neonates.

4.9 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.

5. Special cases

5.1 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 20dBeHL at 4 kHz with testing at 1 kHz as well if possible. It is also important to establish AC and BC thresholds in the affected ear.

5.2 Atresia

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

5.3 Congenital Cytomegalovirus (cCMV)

In cases of suspected or confirmed cCMV, ABR should be used and thresholds assessed to 20dBeHL at 4 kHz and 1 kHz. As the presence of any hearing loss can influence treatment decisions the outcomes of assessment must be communicated to the medical team responsible for the child as soon as possible following assessment. Local infection control procedures should be followed. Any hearing loss should be managed appropriately, and parent counselling offered.

A similar monitoring schedule is advised in the case of hearing loss or satisfactory hearing; further hearing assessment is recommended every 3-6 months up to age 1 year, every 6 months up to age 3 years and annually up to age 6 years as a minimum. If OAEs are present following initial ABR and behavioural tests, OAEs can be used to monitor cochlear function going forward.

5.4 Bacterial Meningitis and Septicaemia

In cases of suspected or confirmed bacterial meningitis or septicaemia ABR should be used and should normally be carried out down to 20dBeHL at 4 kHz an
d 1 kHz (see Appendix L).

6. ABR testing: technical considerations

6.1 Normal maximum stimulus levels

Table 2 gives the maximum recommended stimulus level when the equipment is calibrated to the BSA reference levels, based on a maximum peak-to-peak stimulus level at or below 135dB SPL as measured on a standard coupler for supra-aural earphones, 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
SUPRA-AURAL EARPHONES	Exact value in dBnHL corresponding to 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 in dBnHL corresponding to 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**

*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 G for derivation.

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 calibrated to BSA 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)

Where a baby has no recordable ABR at the normal maximum recommended stimulus level using AC clicks, AC and BC tone pips, tympanometry is satisfactory 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 hearing thresholds at higher levels? 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 hair cell damage may result. See Example 4 in Appendix D. Note that there is a small possibility that OAE & CM are not recordable even when cochlear function is present.

6.2 Definition of ABR threshold

For this practice guidance the definition of threshold is as follows:
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 BSA guidance on ABR testing in babies.

7. Prediction of the estimated hearing threshold (dBeHL)

7.1 Introduction

The term dBeHL denotes the estimate of the psychoacoustic threshold derived from the ABR/ASSR threshold measured in dBnHL. Smart for Hearing (S4H) will calculate dBeHL values from ABR results entered in dBnHL. Please note, this may be different for other national databases. There are multiple databases used to collate the outcomes of newborn hearing screening and diagnostic programmes, the most common of which in the UK is currently S4H. For brevity S4H will be used throughout this document. 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. age-related transducer **stimulus corrections.** These are different for different types of transducer (supra-aural earphones, 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, earphone 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 BSA 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 BSA discharge level; so we suggest the combined correction values for thresholds for ≥30dBeHL 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.

7.2 Combined ABR 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 F and H and the ABR offsets given in Appendix I. 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

	Tone pip / click ABR					NB Chirp			
	0.5k	1k	2k	4k	Click	0.5k	1k	2k	4k
Insert phones	-15	-10	-5	0	5	-10	-5	0	5
Supra-aural earphones	-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 S4H)

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

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

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

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

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

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

7.3 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 as they may use correction factors for the conversion that are different to those suggested by the BSA documents. The conversion can be done by either using S4H to automatically do the calculations or manually using the tables in the section above. We strongly recommend that S4H is used to minimise the potential for error. Thresholds in eHL should be entered into the hearing aid fitting program for the aforementioned reason. However levels used for fitting purposes may be modified from those entered in S4H as other factors may be taken into consideration (e.g. inconclusive test results, estimation for frequencies not tested etc.) In all these cases use common sense - it is important to avoid over-amplification. For the purposes of carrying out RECD or REM measurements, 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. Even if supra-aural earphones were used to measure the ABR thresholds, 'insert' should still be selected as the transducer. Refer to separate BSA guidelines for fitting hearing aids to infants on entering ABR thresholds into DSL software for further detail."

7.4 Ranges of published values (5% to 95%) of the estimated hearing threshold

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 range of possible values in these results. Table 8 gives a provisional range.

Detail on the derivation of these values is given in appendix J.

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

Table 8. Range of published offset values for eHL thresholds

	Tone pip / click					NB 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 range data at 1 kHz and 4 kHz.

Notes

1. Five percent of babies will have true thresholds better than the lower 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.
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 8 kHz. The click ABR threshold relates to the best region of hearing in this range.

7.5 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 (dBeHL) (see appendix F for details). Values are given for:

- Babies tested at up to 12 weeks (≤84 days)
- Thresholds ≥30dBeHL

They relate to amplitude-modulated continuous tones; they are not applicable to ASSR systems employing chirp stimuli or for 40Hz ASSR tests.

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
Supra-aural earphones	-25	-25	-20	-25
Bone conductor	N/A#	-5	-15	-15

ASSR BC testing at 500Hz is not recommended because there is an unacceptably high risk of the BC stimulus artefact being erroneously detected as a physiological response.

The derivation to the values in Table 9 is described in Appendix H. The combined correction values in Table 9 are added to the thresholds in dBnHL to give the estimated threshold in dBeHL for first generation and hybrid generation systems employing modulated tone stimuli only. For second generation systems, use the estimated hearing levels calculated by the equipment. Section 10 elaborates on entering values into S4H. BSA guidance on ASSR provides further information on first, hybrid and second generation ASSR systems.

8. Further testing and management

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

8.1 Satisfactory hearing

Babies with estimated hearing thresholds of 30dBeHL at 4 kHz 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).

8.2 Elevated thresholds

Where the 4 kHz ABR 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 ABR at other frequencies, tympanometry, CMs, etc.

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 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 ranges in predicting the estimated hearing threshold from the ABR threshold as discussed in Appendix J.

Refer to the BSA guidance on ANSD (2019) for advice on testing for potential ANSD. However, ASSR tests should not be used for cases in which ANSD has not been excluded; ASSR may give inaccurate results in ANSD. If ABR and ASSR results conflict, both diagnosis and management should be based on the ABR results

8.3 Mild bilateral loss & unilateral hearing loss

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 loss (Pattison *et al* 2008, Carr *et al* 2012). It is however important to be open and honest about findings. Bearing in mind the range of published values, behavioural assessment may be required before a mild PCHI can be confirmed. Clinicians need to treat all such cases individually, and discuss and agree a plan with parents, including monitoring and review.

8.4 Further management and referral onwards

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 etc).

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.

With parental consent, referral should be made to the Early Years Support Team for Sensory Impairment 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. Prompt referral for aetiological investigations should also be offered.

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.
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
8. Plan for monitoring of progress and response to sound.

9. Reporting

At each test session results should be documented in detail as the session proceeds. An example worksheet is available on the BSA website. 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 BSA website. Non-attendance should be reported appropriately.

The report should include:

- A brief medical history of relevant factors relating to hearing loss.
- A summary of the electrophysiological results (in dBnHL and dBeHL), 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 ≤, = & > when reporting results is preferable to phrases such as "responses seen down to…"
- 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.
- 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.

10. Recording onto S4H

This section should be read in conjunction with section 5.14 (Reporting thresholds) in the BSA Guidance for ABR testing in babies, and the S4H reference guide Section 2. It is important that there is a national consistency in the recording of ABR thresholds in S4H.

- All equipment must be calibrated to the agreed BSA reference levels (published on the BSA website).
- The BSA definition of ABR threshold should be used.
- The ABR threshold in dBnHL, without any ABR offset or stimulus corrections should be recorded into S4H which will calculate the estimated thresholds in dBeHL. In the case of chirps, the corrections made by S4H assume the use of CE-Chirps, for which corrections have been established. If non-CE-Chirps are used make a clinical note in S4H stating the

equipment and software version used. If corrections applicable for the chirp are available, calculate and report the estimated thresholds in dBeHL, in both S4H and in the clinical report.

- The ASSR threshold in dBnHL (using corrections as recommended by the device manufacturer) should be recorded into S4H, for all generations of ASSR system. The dBeHL values (calculated from the values in Table 9) are applicable only to first and hybrid generation systems employing modulated tone stimuli. For second-generation ASSR systems the ASSR thresholds in dBeHL calculated by S4H should be ignored and manufacturer-provided dBeHL values entered as a clinical note in S4H and used for further management. A change in the way S4H handles ASSR data was implemented in 2021, in which S4H no longer calculates the estimated hearing level. Following the implementation of this change, the estimated hearing level should be entered as follows. For first and hybrid generation systems employing modulated tone stimuli, calculate the values from Table 9; for second generation systems, use the values calculated by the equipment. BSA guidance on ASSR provides further information on first, hybrid and second generation ASSR systems.
- The S4H reference guide on the BSA website gives detailed information about the recording of the audiological data including the use of symbols ≤, =, > 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 S4H record.

Appendix A: Substantial changes from Guidelines for the early audiological assessment and management of babies referred from the Newborn Hearing Screening Programme Version 3.1 July 2013

- Detail regarding discharge using TEOAE has been elaborated to specify “a TEOAE test may be used as the discharging test for well babies, but only for those babies with no risk factors that would require targeted follow up (see NHSP surveillance guidelines) no previous tests which may indicate the presence of ANSD (e.g. OAE Pass AABR Refer at screening) and with no parental concern about hearing.”
- Removal of reference to TDH earphones, using instead the more generic “supra-aural earphones”
- Addition of advice regarding reflexes in newborns
- New discharge criteria for bacterial meningitis 20dBeHL at 1 kHz and 4 kHz. New guidance for testing and monitoring cCMV.
- Advice regarding programmable shunts included
- Stimuli are now referenced to IEC 60645-3 (2020) and limitations relating to the corrections for various designs of chirps are noted
- References to other guidance updated or removed

Appendix B: Diagnostic OAE

Babies without risk factors as outlined by NHSP can be discharged using the same criteria as specified by NHSP. If however a site chooses to use a diagnostic OAEs the parameters in Table B.1 are recommended. Typically diagnostic testing takes longer and transient evoked otoacoustic emissions (TEOAE) diagnostic testing may be continued until 3 or 4 frequency bands have a SNR ≥ 6dB. For further detail the reader is referred to BSA Recommended Procedure: Otoacoustic Emissions Testing in Paediatric and Adult Audiology (in preparation at the time of writing)

Recommended stimulus and recording parameters for TEOAE testing (table adapted and modified from Dhar and Hall, 2011. Parameters may vary with manufacturers/devices).

Stimulus parameters	Recommended Setting
Type	Click
Duration	80µs pulse
Level	81 – 87 dBpeSPL (e.g. 0.3Pa)
Rate	50/s
Polarity	Alternating paradigm
Recording parameters	**Recommended Setting**
Analysis time	12-20 ms
Frequency scale	0- 6kHz
Frequency resolution	49 Hz (for FFT)
Noise rejection threshold	~ 47 dB SPL
Sets of averaging buffers	Two (A and B) averaged simultaneously to alternate stimuli
Points/octave (Resolution)	2 (1/2-octave recordings commonly used)
Amplitude of response	≥ -10 dB SPL (A + B)
Amplitude of noise	≤ -5 to -20 dB SPL (A – B) (ideally)
Acceptable SNR	≥ 6 dB (response signal – noise)
Number of accepted sweeps	Minimum of 260
Test time	Can be preset –e.g. 90 sec or 5 min
Frequency range	1.0- 4.0 kHz (commonly used) 0.5 – 5.5 kHz (currently available in most commercial devices)

Appendix C: Acoustic Stapedial Reflex (ASR)

The following is guidance around carrying out reflex measurements in babies referred from the newborn hearing screen. Reflex testing should be carried out immediately following tympanometry. This test procedure should be read in conjunction with the BSA Tympanometry Recommended Procedure; the sections on General considerations, Equipment, Calibration and Subject Preparation all apply to reflex testing.

Test procedure

Fit a clean tip of suitable size and shape to the probe and straighten the ear canal (e.g. by gently pulling the pinna downwards and outwards). Point the probe in the direction of the tympanic membrane to avoid the risk of sealing the tip against the wall of the canal. Movement of the infant and crying can result in a false peak in the tympanogram. The baby does not need to be asleep but should be resting quietly during the test.

A 1000 Hz probe tone and 2000 Hz stimulus tone is recommended to a maximum 100dBnHL.

Reflex present is defined as a response when the change in admittance, in either direction, exceeds 0.04 mmho and the change increases with stimulus level. A reflex may be reported as absent if the above criterion is not satisfied and recording conditions being good.

Reflex measurements should always be repeated, to check that the result is repeatable and not due to artefacts such as baby movement. If it has not been possible to repeat a reflex measurement or if the repeat suggests a different outcome then the result should be reported as inconclusive.

After reflex testing has been completed the probe tip shall be removed and all contaminated tips shall be disposed of or cleaned as per local policy.

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

These examples assume that it has been possible to carry out frequency-specific ABR at the desired frequencies. Example 1 includes detail of the decision-making processes that occur during the testing. All stimulus levels are in dBeHL to avoid having to give one value for insert earphones and a different value for supra-aural earphones. All examples relate to babies tested before 12 weeks (≤84 days) corrected age.

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

Test	Right	Left
AC 4 kHz tone pip ABR (tpABR)	Threshold ≤ 30dBeHL	Threshold = 55dBeHL
BC 4 kHz tpABR		Threshold ≤ 15dBeHL
TEOAE	Recordable	Not recordable

Comments:
Supra-aural earphones were used for AC ABR in this example.

Clear AC 4 kHz 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 4 kHz 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.

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:

- Since this was a unilateral screen referral, ABR tests commenced with the screen clear response ear (right) using AC 4 kHz 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 BSA 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.
- AC 4 kHz tpABR tests were then conduced 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.
- 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***.

- The AC 4 kHz tpABR threshold on the left was therefore =55dBeHL, meeting the BSA "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.
- 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).
- 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 identify ear-specific information by either applying masking or using 2 channel recording. 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 or 2 channel recording. In the current example a BC 4 kHz tpABR ***CR*** was recorded at 25 and 15 dBeHL so the threshold is ≤15dBeHL. 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.
- Tympanometry may be useful in this case for which further information is available in the BSA Tympanometry Recommended Procedure.

Example 2: Bilateral conductive loss

Test	Right	Left
AC 4 kHz tpABR	Threshold = 55dBeHL	Threshold = 50dBeHL
BC 4 kHz tpABR	Threshold ≤ 15dBeHL	Threshold ≤ 15dBeHL
TEOAE	Not recordable	Not recordable
Tympanometry (High freq.)	Abnormal	Abnormal

Comments:

- The BC tpABR thresholds were ≤15dBeHL at this stimulus level masking is not required.
- 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 15dBeHL support MEE as the cause of the apparent conductive loss.

Example 3: Unilateral sensorineural loss

Test	Right	Left
AC 4 kHz tpABR	Threshold ≤ 20dBeHL	Threshold = 55dBeHL
BC 4 kHz tpABR		Threshold = 50dBeHL (M)
AC 1 kHz tpABR	Threshold ≤ 20dBeHL	
TEOAE	Recordable	Not recordable

Comments:
Right ear: Responses at both 4 kHz and 1 kHz are recorded down to 20dBeHL as it is important to establish good hearing in the unaffected ear for a unilateral PCHI case (see section 5.1). 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 4 kHz AC (to 30dBeHL), (ii) Left ear 4 kHz AC, (iii) Left ear 4 kHz BC (ear-specific), (iv) Right ear 4 kHz & (v) 1 kHz 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.

Example 4: Bilateral sensorineural loss

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

Comments:
With the absence of an ABR response to frequency-specific stimuli at 85dBeHL it is important to test hearing at other frequencies. Here the test showed some hearing at 1 kHz for the right ear. The 1 kHz responses were definite so ANSD is not suspected on the right and CM testing was undertaken only on the left.

The normal high-frequency tympanograms suggest there is no temporary conductive component. The absence of TEOAE and CM on the left is consistent with the absence of ANSD. Having established there is no CM on the left, one may test AC 4 kHz at 90dBeHL, using insert earphones, 5dB above the normal recommended maximum level. If ***CR*** is established (note a third run is suggested as we cannot test at a higher level –see BSA ABR guidance) threshold would be =90dBeHL.

Example 5: Bilateral mixed loss

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

Comments:
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 4 kHz tpABR	Threshold > 85dBeHL	Threshold > 85dBeHL
BC 4 kHz tpABR	Threshold >50dBeHL	Threshold >50dBeHL
AC click ABR	Threshold > 85dBeHL	Threshold > 85dBeHL
CM	Present	Present
TEOAE	Recordable	Not recordable

Comments:

- Absence of AC click ABR at 85dBeHL indicates PCHI or ANSD. There is also merit in also carrying out 1kHz to rule out low frequency contribution to the CM.
- TEOAE recordable for the right ear is consistent with the presence of ANSD.
- As there was no recordable TEOAE on the left ear, CM testing was particularly important to check for ANSD. On the right, where an OAE was recorded, the CM was strictly unnecessary but was performed to obtain a benchmark against which any future CM test could be compared.

Appendix E: Masking

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

- 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 (transcranial 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 in needed. See Table E1.
- 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 E2.
- 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 ABR noise calculator spreadsheet (available at http://abrpeerreview.co.uk/resources.html) takes account of how different systems' noise is calibrated; the user simply enters the model of ABR equipment. A similar ASSR noise calculator is now available for use in masked ASSR tests employing modulated tone stimuli
- 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

Table E1. 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	Supra-aural earphones	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

Table E2. 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

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 BSA website.

Noise calculator
The masking calculation depends on several factors such as type of equipment, transducer, stimulus and the baby's corrected age at test, and we recommend this is done using the ABR noise calculator, which accounts for these factors. The masking calculator is a time saving device and guide. There should be easy access to this when carrying out ABR assessment. The noise calculator can be downloaded from http://abrpeerreview.co.uk/resources.html and runs under Microsoft Excel. Only versions of the calculator dated 2019 or later include the age-specific stimulus level corrections and ABR offsets contained in these guidelines, so older versions should not be used. The calculator indicates the need for masking, the level of noise to use and warns when there is a risk of cross-masking. When identifying appropriate masking levels, users must take responsibility for their own clinical decisions.

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 supra-aural earphones and insert earphones):
As a general rule of thumb and assuming the non-test cochlea is normal, then masking should be considered for stimulus levels above 65dBnHL.

Bone-conduction:
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.

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 BSA discharge criterion and a conductive hearing impairments 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.

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

The above rules of thumb do not guarantee that masking is needed but rather that the ABR noise calculator should be used for a more accurate calculation.

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
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. A variety of values can be tried and a cautious approach would be to employ the highest noise level suggested. The risk of cross-hearing depends critically on the sensitivity of the non-test cochlear (BC threshold). We may have tested this to obtain an ABR result of, say, ≤15dBeHL but unless we have information to the contrary, we should use 0dBeHL for the non-test ear BC threshold since this is the worst-case value.

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 establishing ABR threshold, keeping a fixed relationship between stimulus and noise levels.

The BSA gold standard should be applied whenever masking is used.

Two-channel BC ABR and the presence of ABR wave I to infer ear-specific thresholds
These methods are covered in Appendix B of the BSA Guidance for ABR testing in babies. Note that if 2-channel BC ABR or the presence of ABR wave I suggests that the contralateral cochlea is responsible for the recorded ABR or is equivocal, masking will be necessary to establish the BC ABR threshold in the test ear.

Appendix F: Stimulus level corrections

These are the differences between the stimulus level delivered to a baby's ear compared to an adult's ear. These corrections apply to both ABR and ASSR.

1. Bone-conduction

The bone-conduction stimulus is calibrated on data derived from a group of normally-hearing adults. Provisional RETFL values are available on the BSA 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.

Table F1.1. 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 F1.2
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 F1.1 are derived as follows:-

Corrected age <=84 days (12 weeks)
The values for 0.5 kHz and 1 kHz are taken from a paper by Ferm, Lightfoot & Stevens (2013). For 2 kHz 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 4 kHz the value has been derived from data in papers by Cone-Wesson and Ramirez (1997) and Small & Stapells (2008) again applying weighting as for 2 kHz. 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).

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.

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 (2 kHz).

Corrected age >730 days (2 years)
There is no BC stimulus correction over the age of 2 years

Table F1.2. 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 F1.2 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).

2. Air conduction

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

Table F1.3. 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 to168 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 F1.3 are derived as follows:-

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 8 kHz for neonates compared to adults. The value for clicks was 20dB. Marcoux (2011) found values of 2, 6 and 7dB at 0.5 kHz, 2 kHz and 4 kHz 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.

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.

Supra-aural earphones

No correction of the stimulus level is necessary for supra-aural earphones

[a] The mean of the three studies at 4 kHz 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.

Appendix G: Normal maximum stimulus levels for ABR using inserts (babies under 3 months corrected age)

For a maximum stimulus level of 135 dB SPL peak-to-peak the equivalent values in dBnHL for insert phones using BSA reference values for a ER-3A insert phone with a IEC 60318-4 occluded ear simulator are given in row 1 of table G1.1 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 F1.3 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 dBnHL to give the maximum setting of the stimulus level to avoid exceeding 135 dB SPL in the ear canal.

Table G1.1. Recommended maximum stimulus levels BSA reference values

	0.5 kHz	1 kHz	2 kHz	4 kHz	Click
Value for 135dB SPL pk-pk (dBnHL)	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 (dBnHL)	101.5	103.5	96.5	87.5	84.5
Recommended value (dBnHL)	**100**	**100**	**95**	**85**	**85**

Appendix H: Offsets to predict the estimated hearing level from the ABR/ASSR threshold

There is a considerable amount of data published on the mean differences between ABR threshold and behavioural thresholds. The tables H1.1 to H1.3 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. 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. Recent work has included investigation of level-specific correction factors (McCreery et al., 2015 Stevens et al., 2014) however sufficient consensus in the literature has not been reached to include level-specific correction factors at the time of writing.

Table H1.1. 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 H1.1
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% range in values when applied to estimating the PTA from the ABR threshold in the individual of about ±15dB.

Table H1.2. ASSR – Adults with and without hearing-impairment (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 H1.2
Mean values and standard deviations (SDs) have been derived from summary tables of studies given by Picton *et al* (2003) using modulated tone stimuli 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 people with hearing impairment from the ASSR threshold. These data are relevant to modulated tone ASSR at 80-90 Hz. Refer to the BSA guidance for ASSR testing for 2nd generation ASSR systems using chirp stimuli.

Table H1.3. ASSR - Results for normal and infants with hearing impairment (from Rance *et al* 2005)

	Mean difference (SD) between ASSR threshold and subsequent behavioural threshold (dB)			
Subject Group	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

Notes on table H1.3
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 visual reinforcement audiometry (VRA) behavioural thresholds measured between 6 and 23 months of age. These data are relevant to modulated tone ASSR at 80-90 Hz. Refer to the BSA guidance for ASSR testing for 2nd generation ASSR systems using chirp stimuli.

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:-

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

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 :-

1. The difference between the stimulus level at the ear between adults and babies is not significant when delivered by supra-aural earphones.

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.

The resulting values are given in the table H1.4 below.

Table H1.4. Derivation of ABR 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

Notes on Table H1.4.

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 2 kHz. 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 4 kHz tpABR response.

Narrow-band chirp ABR offsets

The offsets for chirps are based on a study in normal babies at 1 and 4 kHz (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.

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.

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

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	4k
≤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 weeks (>168 days)	-20	-15	-10	-10	-5	-15	-10	-5	-5

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

BC	Tone pip/click ABR					Chirp			
Corrected age	0.5k	1k	2k	4k	Click	0.5k	1k	2k	4k
≤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

BC Click

Corrected age	Gestational age	Click†
-4 weeks	36 weeks	
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 S4H).

Appendix J: Derivation of ranges of published values (5% to 95%) for the estimated hearing threshold

The eHL values determined by using in Section 7 in the main text give the most likely estimates for the hearing threshold from the ABR / ASSR thresholds. A clinical report should also contain an estimate of the range of possible values in these results. Table 8 in the main text gives a provisional range. Note that this information is not yet available on S4H.

Ranges have been calculated for babies tested before 12 weeks (≤84 days) corrected age with thresholds above the discharge level (>30dBeHL). They can be provisionally applied above this age within the age range covered by this guidance. For babies with thresholds ≤ 30dBeHL the ranges will be wider given the greater average difference between the ABR / ASSR threshold and the true threshold.

The range of published values (5% to 95%) for the estimate of hearing levels from the tpABR threshold are of the order of ±15dB (Stapells 2000). Stevens *et al* (2013) reported a slightly higher possible range of prediction intervals but this was comparing ABR results (post newborn hearing screen) 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 / ASSR threshold. This means that the upper range level may be less than +15dB particularly for the higher frequency tpABR and the click ABR where the ABR offset values are lower.

Example:

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

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

So for supra-aural earphones the limit of the range will be 15dB or will follow the offsets (table E1.4) where they are less than 15dB. Values are shown in Table J2.1. The lower limit of the ranges will all be 15dB.

Table J2.1. Range of published values (5% to 95%) for predicted thresholds in dBeHL

	Tone pip / click					NB 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

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 range of published values (5% to 95%) which will remain the same as those given in table J2.1.

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 0.5 kHz where the 5dB reduction in ABR offset from 20dB to 15dB does not affect the range of 15dB.

Appendix K: Testing babies with atresia

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

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 5.1 (unilateral cases) it was noted that testing should be carried out down to 20dBeHL in the unaffected ear at both 1 kHz as well as 4 kHz if possible. In summary, testing for unilateral atresia should be as follows:

1. **Test unaffected ear by AC using 4 kHz and 1 kHz tone pips or chirps**
   At least 2 frequency-specific thresholds should be obtained. Test down to at least 20dBeHL or establish threshold. If elevated, test by BC ABR using 4 kHz tone pips or chirps. Also perform diagnostic OAEs and tympanometry if relevant.
2. **Test affected ear (i) by BC using 4 kHz tone pips or chirps (ii) (if possible) by AC using 4 kHz tone pips or chirps.**

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

Bilateral Atresia
The aim is to find out as much as possible about the hearing in both ears. These children will probably need support and aiding in any case. In summary testing for bilateral atresia should be as follows:

1. **Test each ear by BC using 4 kHz tone pips or chirps**
   Masking: if thresholds are ≤ 15dBeHL for 4 kHz 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 BSA Guidance on ABR testing in babies Appendix B)
2. **Test each ear by AC using 4 kHz tone pip or chirps to measure the degree of conductive loss**

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

Masking - In all cases it is advisable to use the ABR noise calculator (available on http://abrpeerreview.co.uk/resources.html. Always use the latest version (at least 2019)

If in doubt seek expert help.

Appendix L. Guidelines for audiological follow up of babies diagnosed with bacterial meningitis and/or meningococcal septicaemia

This appendix was originally Appendix A of "Guidelines for surveillance and audiological referral of infants & children following the newborn hearing screen" Version 5.1 published by NHSP Clinical Group. They were produced to help clinicians develop local protocols for hearing assessment in babies up to the age of one year who have been diagnosed with bacterial meningitis and/or meningococcal septicaemia.

General information
The responsibility for ensuring referral for hearing testing in this group of babies resides with the responsible Paediatrician. Protocols need to be in place to ensure referral from the paediatric wards or NICU/SCBU to the responsible clinician in Audiology. Hearing assessment needs to be carried out within four weeks of the child being well enough to be tested. **Urgent assessment is required to identify severe/profound hearing loss which may require cochlear implant(s) before any cochlear ossification takes place. The timing of tests needs to be practical and flexible. The aim should be to determine ear-specific and frequency-specific auditory thresholds as soon as possible, to identify hearing loss of any degree or configuration.** Children can also have complex developmental problems following meningitis.

Under 12 weeks corrected age:
The baby should be referred for assessment irrespective of whether or not they have been screened and irrespective of the screen result. as they are very high risk for having a hearing loss. Testing would normally be by ABR under natural sleep, preferably using both high and low frequency stimuli. If this is not possible, a diagnostic OAE test would be helpful, but in this case further assessment (for ABR or behavioural testing) should be arranged.

Between 12 weeks and 7 months corrected age:
Options should be discussed by the audiologist with parents and include one or more of

- ABR under natural sleep (especially if the baby is still quite young), preferably with both high and low frequency stimuli;
- Diagnostic OAE test;
- ABR under sedation (for older infants, if there is considerable parental/professional concern or if it has not been possible to obtain a reliable test without sedation);
- Waiting until behavioural testing around 7 months (if the baby is close to this age), bearing in mind the importance of urgent assessment as discussed above).

Over 7 months corrected age:
The baby should be referred to Audiology on discharge from hospital and seen within 4weeks. Testing would normally be by VRA using ear-specific and frequency-specific stimuli. A significant hearing loss should be excluded. If ear- and frequency-specific information cannot be obtained for whatever reason, the child should be further reviewed to rule out any milder degrees of loss.

For all ages, following a systematic review (Rodenburg-Vlot et al. 2016) there appears to be no good evidence supporting the need for further follow up if the hearing is found to be satisfactory following bacterial meningitis, so we do not make recommendations. However, this is a matter for local policy.

Appendix M. 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.

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

1. ***Prior to test session***
   Stage 'A' check including check on transducers and leads (supra-aural earphones, insert earphones and bone conductor).
2. ***Start of test session***
   All electrodes for tests applied before starting (including nape if needed).
   Electrodes leads correctly plugged in.
3. ***Before each set of tests***
   Check Supra-aural earphones/insert earphones /bone conductor produce sound
   Check earphone/insert applied to correct ear.
4. ***No response***
   Check sound from supra-aural earphones/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)

Tests

1. Check that the appropriate test(s) from the following list have been carried out.
   AC 4 kHz ABR
   AC 1 kHz ABR
   C 4 kHz ABR
2. Masking
   Has masking been carried out when needed?
3. Check for ANSD where ABR abnormal or absent at high stimulus levels.
4. Tympanometry
5. Otoacoustic Emissions
6. Observation of any consistent behavioural reactions to stimuli.

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