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Recommended Procedure

Visual Reinforcement Audiometry

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General foreword

This document presents a Recommended Procedure by the British Society of Audiology (BSA). A Recommended Procedure provides a reference standard for the conduct of an audiological intervention that 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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Comments on this document are welcomed and should be sent to:

British Society of Audiology

80 Brighton Road, Reading

Berkshire, RG6 1PS, UK

info@thebsa.org.uk

www.thebsa.org

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2. Introduction

This document is a revision of the protocol produced by the Newborn Hearing Screening Programme (NHSP, 2008); the revision was conducted by the BSA Professional Practice Committee (see Appendix A). As with NHSP's version, the content here is guided by evidence where possible. However, there is insufficient research in this area and recommendations in this document are based on the opinion or reported practice of experts in the field. General references that have guided the content of this document are provided and specific references have been stated where considered helpful. We welcome further research in this area.

Visual reinforcement audiometry (VRA) is a key behavioural test for young children. It is central to completion of the diagnostic process for those hearing-impaired infants identified by newborn screening. Furthermore, contemporary paediatric amplification fitting methods rely on solid foundations of measurement to ensure the validity and reliability of hearing aid fitting. It is hoped that the standardised VRA technique described here will facilitate training of Audiologists and be of use in research studies.

There are many points of debate relating to set-up and methodology for this test technique and it is recognised that alternative approaches exist some aspects of the technique. However, a decision was taken to adopt the particular approach described here for the purposes of standardisation. It is advised that only experienced Audiologists (or those led by such colleagues) should consider deviating from this protocol. Appendix B provides a definition of terms.

3. Scope

The document sets out to provide guidelines for testing babies with a minimum developmental age of 5–7 months. The test is suitable for infants who are able to sit unsupported or with minimal support and able to turn their head side to side. It is assumed that the reader of this document is familiar with the principles of VRA. This protocol covers only VRA, including the defining feature of one-sided reinforcement (rather than two-sided reinforcement of the conditioned orientation response test). VRA is the accepted standard audiological assessment method for children that can be conducted with reliability from a developmental age of 8–9 months onwards (Day et al. 2000).

The document covers the technical procedure of carrying out a manual VRA test, equipment/environment considerations, basic interpretation of the results, reporting and patient handling procedures relevant to the test. This document should be read alongside BSA (2008) for guidance on the more technical aspects of sound-field testing, and also BSA (2011a) for air-conduction (AC) and bone-conduction (BC) testing.

The term 'shall' is used in this document to refer to essential practice, and 'should' is used to refer to desirable practice.

4. Competency and skills

Staff engaged in performing VRA testing should have received specific training associated with documented assessment to demonstrate their competency to perform this test. The level of competency should be at least adequate for the role performed (whether supporting or leading the assessment). Those leading the assessment should be competent in briefing/debriefing carers, use of the equipment deployed, and the correct interpretation of results to ensure appropriate recording/reporting of results for use by oneself and others. To ensure correct reporting of results for interpretation by others, it is particularly important that the differences between minimal response levels (MRLs) obtained by VRA and adult normative thresholds are recognised and understood.

5. Facilities and preparation

5.1 Test environment, set-up and equipment

The test should be performed in a room that is of adequate size to accommodate parent(s), child and two testers comfortably. Following BSA (2008), minimum floor dimensions of 6 m × 4 m are advised. Note: this specification assumes that the room is dedicated to the behavioural hearing assessment of children under 3 years of age. The room should have adequate ventilation and air conditioning for patient comfort; babies who are uncomfortable are less likely to respond well to testing. The room should offer minimal distraction to the child. It is advised that diffuse (down) lighting is used to prevent shadows. These lights should be capable of being dimmed, in order to permit enhancement of illuminated visual rewards/reinforcers; this is particularly useful for children who have a visual impairment or for children with other complex additional needs. The table should have a soft, wipeable surface to keep noise down to a minimum when engaging with the child, yet is still compliant with infection control procedures.

It is recognised that a variety of test room arrangements can be employed for VRA. However, the test protocol described here is the preferred test equipment and set-up, using two testers and two rooms, see Figure 1. The two-speaker and two-reinforcement unit arrangement as described is the basis of the test procedure presented below.

Control of stimuli and reward should be operated from a second (observation) room by Tester 1 while Tester 2 engages the child (Figure 1). Such an arrangement allows for discreet communication/instructions to the tester controlling the child's attention, reduces the potential for distraction, and allows for optimum (frontal) observation of the child's behavioural responses. The test and observation room should be separated by a one-way window (or alternative arrangements provided, e.g. image on a monitor screen) such that the child is not distracted, yet allowing the observer (Tester 1) a clear view of the child and ideally of the engager (Tester 2) as well. This arrangement is also more useful for training purposes and for allowing other family members to observe the test discretely. There should also be the facility for the Tester 1 to hear sounds made in the room (for communication and appropriate timing of stimulus). The arrangement also allows Tester 1 to present live speech to the patient through the sound-field speakers, via a microphone with presentation level controlled by the audiometer intensity attenuator.

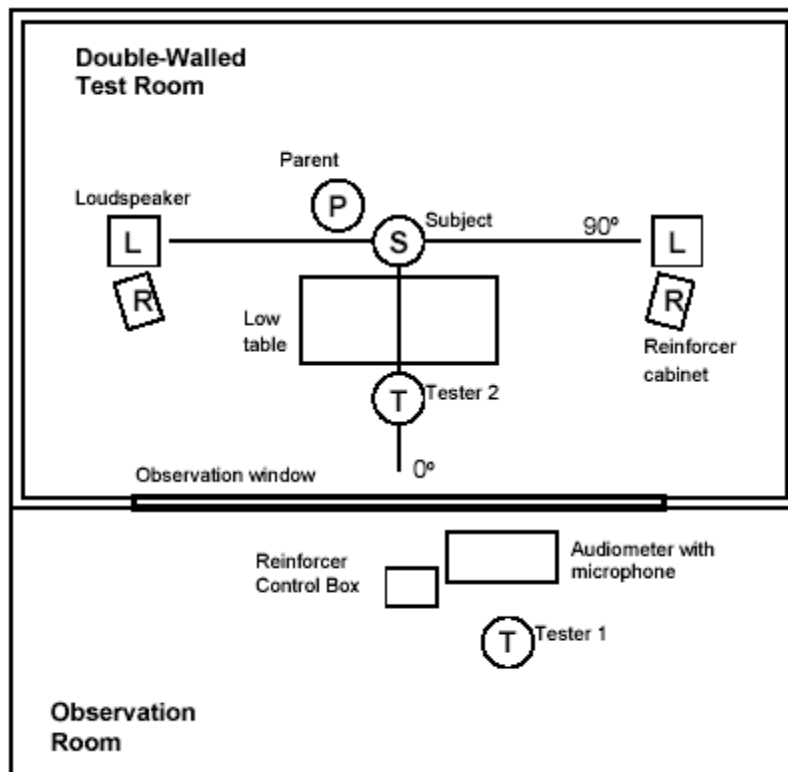


Figure 1

Recommended room layout. Note Tester 1 is positioned to one side of Tester 2 to allow for direct line of sight of the subject. Reinforcer cabinets (and/or reward monitors) should be readily moveable (see Section 5.5).

Where an observation room is not available, another possibility is to use a monitor screen linked to a camera positioned to observe the front of the child and ideally of Tester 2 as well. Tester 1 should be out of view of the child, perhaps behind a screen/curtain (see Appendix C).

In exceptional circumstances, there may be a need to move Tester 2 away (e.g. when the child is shy). In these cases, particular attention must be paid to instructions to parents remaining in the test room with the child.

Recommendations for maximum permissible sound levels are in BSA (2008).

5.2 Type of reinforcement: illuminated and animated toys

Reinforcers should be located within a moveable cabinet obscured by smoked perspex screen such that the toys are not visually attractive without illumination. A switch in the observation room should control animation and bright illumination of the toys. Ideally, at least two independently controllable toys should be provided for each side of testing. Alternatively, a variety of equivalent video images could be used (although these might not be appropriate for some children, Karzon and Banerjee, 2010) and a rotating light would be a useful additional reinforcer.

5.3 Positioning of the loudspeakers

Loudspeakers shall be positioned at 90° azimuth (reference equivalent threshold sound pressure levels, RETSPLs, are only available for these angles of presentation) relative to, and at least 1 m from, the test position to each side (BSA, 2008). The speakers should be approximately level with the child's head; such positioning provides the most efficient means for conditioning the behaviour and establishing MRL.

5.4 Position of reinforcers

Reinforcers should be positioned as close to 90° as possible; 90° azimuth is used in order to elicit the clearest head turn. The reinforcers should be located approximately level with the child's head at a distance of 1–2 m. Close proximity between speaker and reinforcer is preferred in order to aid conditioning when using soundfield stimuli; so in practice adjacent positioning of loudspeaker and reinforcers is recommended. Facility should exist to move the reinforcers closer to the child to enhance reinforcement (if their developmental and/or visual ability requires this) although care should be taken to avoid interfering with the calibrated soundfield of the loudspeaker. Reinforcers positioned to both sides

allows children to be rewarded on their preferred side (e.g. useful when testing through insert earphones or through bone conduction).

5.5 Positioning of child and tester

A younger infant (age 5–12 months) should be seated on the parent's knee, gently supported at the waist and facing forward. In some cases it may be useful for the child to be supported by the parent's hands underneath the arms around the side of the body and facing forward, the thumbs resting on the shoulder blades and the remaining fingers on the child's chest. Here, the parent's hands actively support the upright sitting of the body, thus enabling even the younger infant to spend their effort in turning rather than maintain the body's upright position. Alternatively, the infant may be placed in a secure 'high chair'. An older child can be seated on a low chair, with parent seated on the opposite side to reinforcement, and slightly behind. The child should be at a point determined and marked during calibration of the sound-field. A table is placed in front of the child to provide a surface for the engaging activity. Tester 2 is positioned on the opposite of the table facing the child. She/he has a concealed and plentiful supply of suitable toys close at hand adequate for the duration of the assessment. The table should be at a height comfortable for the child to see (and if required reach). If a child is not developmentally ready for full head turn to a reinforcer at 90°, it may be appropriate to change the angle of position of the reinforcer to achieve a lesser angle (possibly in association with a reduced distance) from the child. Care should be taken to ensure that the calibration position is not compromised when sound-field testing (e.g. avoid moving the reinforcer in front of the speakers).

5.6 Position of tester in observation room

Tester 1 should have a clear view of the child's face and Tester 2's activity. The audiometer, reinforcer control box and recording materials should be within easy reach.

5.7 Communication between testers

Good two-way communication between testers is essential requirement for the test. Communication from Tester 1 to Tester 2 should be direct and discreet so as to avoid auditory distractions for the subject, for example the use of a wire-free system.

5.8 Hearing protection

Regulations stipulate daily personal noise exposure levels beyond which hearing protection should be used (Health and Safety Executive, HSE, 2005). If daily noise exposure is above the first action level of 80 dB(A) but below the second action level of 85 dB(A), hearing protection should be available to the employee. If daily noise exposure is beyond the second action level, or if any peak levels exceed 137 dB SPL then hearing protection must be used. Daily personal noise exposure level can be calculated from knowledge of the level and duration of the stimuli.

Calculations for a VRA system with a maximum output of 115 dB(A) indicate that the second action level could be exceeded when testing one child with severe or profound hearing loss. As well as this, some of the sound levels used may be uncomfortable and for this reason also hearing protection (muffs and /or plugs) shall be available for parents and observers as well as testers. The maximum output at each frequency should be measured and this information used to calculate likely noise exposure levels according to the methods described in the Regulations. This information can be used to specify local hearing protection policy. (See also recommendations for determination of uncomfortable loudness levels BSA, 2011b.)

6. Stimuli

6.1 Stimulus type

Frequency-modulated (a.k.a. warble) tones and/or narrow-band noise (NBN) or any other stimuli that have reference equivalent threshold sound pressure (AC) or force (BC) levels should be employed (BSA, 2008; Shaw, 2004). If the child is unresponsive to one of the above stimulus types, the use of an alternative should be considered. Important notes when using NBN:

1. NBN for estimating thresholds should be calibrated in dB HL not dB effective masking level (in order to avoid under-estimating hearing loss by 5–10 dB)
2. Reference equivalent threshold sound pressure levels for calibrating NBN in dB HL are available for presentation in the sound-field but not via other transducers
3. Conventional NBN is considerably less frequency specific than warble tones and can lead to the substantial under-estimation of hearing loss in people with steeply sloping hearing loss. Therefore, care should be taken in use of conventional NBN where it is suspected that the patient has a

steep audiometric slope or results suggest this. Alternative NBN that is more frequency specific and provides more accurate estimation of thresholds with steeply sloping hearing loss may be available on some audiometers (Rowan et al, 2012).

6.2 Stimulus delivery

There are advantages and disadvantages/limitations related to each method of stimulus delivery; these will not be explored here but have been described elsewhere (e.g. BSA, 2011a). However, a comprehensive range of transducers should be available for use: supra-aural earphones (e.g. TDH49/50), insert earphones (e.g. EAR3A coupled with immittance tip, foam tip or earmould), speakers for sound-field presentation and a bone vibrator. For children with hearing aids, where available, insert tips should be inserted into the tubing of their ear-moulds, as this will be useful for prescribing amplification.

6.3 Precautions against cross infection

Local procedures should be adhered to. If insert ear phones are used, disposable single-use tips should be used and be available for different ear canal sizes. Manufacturer's guidelines must be followed and local advice be sought regarding best practices for cross-infection control when using supra-aural headphones or bone vibrators.

6.4 Calibration

Stimuli presented through headphones, bone vibrator or insert-earphones shall be calibrated in accordance with the relevant international standards, preferably in dB HL in order to present a unified documentation of the audiogram.

Calibration of stimuli presented in the sound-field by loudspeakers is less straightforward. Sound-field calibration requires a considerable knowledge of the use and limitations of sound level meters and sound-field acoustics. Most test environments do not provide the ideal anechoic condition and a number of measures have to be taken to ensure that the sound level delivered to a child's ear is accurate and stable. It is recommended that expert help be sought from centres with experience in this field. The reader is referred to the specific guidance provided on calibration in BSA (2008) particularly as they relate to use of static systems as employed in VRA.

Whatever the range of stimuli, a daily visual examination and listening checks shall be carried out (Stage A check). The checklist described for pure-tone

audiometry (BSA 2011a) could be used with additional checks of reinforcers and between-room communication systems. Such checks are particularly important for VRA given the variety of stimuli and transducers typically employed and routing of signals between rooms often via additional cable connections.

Aside from the requirement for initial and annual full calibration (Stage B) against the standards, calibration should be carried out when any major changes are made (e.g. to room layout) or changes in external noise levels occur. Following BSA (2008), the test environment should be clearly documented with a defined layout of furniture, furnishings, equipment and positions for people in the room during testing; marks should be provided to floors and ceilings to ensure that layout and positions remain consistent as any deviation may compromise calibration. If sounds other than warble tones and NBN are to be used, a biological calibration will have to be carried out; this is outside the scope of this document.

7. Test procedure

7.1 Subject preparation

Following equipment checks, parent(s) and child are brought into the room, seated and introductions made. History taking provides an opportunity for the child to settle in an unfamiliar environment and for the audiologist to make some preliminary observations about the child. It is advisable to ask at the beginning about the level of alertness of the child and if this is likely to change during the consultation in order to determine the best point of time of testing. If the child is becoming restless it may be appropriate to cut the history short and begin testing.

The test procedure is explained to the parent with suitable cautions about cueing the child to the presence of an auditory stimulus, and the need to minimize distracting noise. Information should be obtained about the child's developmental and visual status before starting the test. If there is any doubt about the child's ability to respond in the desired manner (i.e. with a head-turn) this can be discussed with the parent. If necessary, head control and turning can be checked by having the child visually track an object of interest through an arc of 180°. It is important to advise the parents about the best way to hold / support the child (see Section 5.6).

Any others present are best invited to sit in the observation room (preferred) or directly behind parent and child. Care shall be taken when positioning parent and child to ensure that sound-field calibration (if relevant) is not compromised. Ear protection (e.g. ear muffs / plugs) shall be available for those individuals present in the test room. The transducer should be fitted to the child. The fitting of insert

earphones should be preceded by otoscopy (BSA, 2010) or if it is not done this is on the basis of an assessment of risk and benefit for individual subjects. A flexible headband (e.g. elasticated towelling /neoprene) may be used to position the bone vibrator in place as a more comfortable alternative to a conventional 'Alice band'. There should be due consideration for infection control when using a flexible headband, e.g. washing following each use. If the child is resistant to either method of placement the bone vibrator could be held in place by the parent with clear instruction that the conductor is applied with moderate force. Whatever the means of placement, Tester 2 should be alert to ensure that the conductor remains appropriately placed throughout the test procedure.

7.2 Procedure for measurement of minimum response levels

7.2.1 Initiation of test and role of Tester 2

Tester 2 will choose a suitable table-top activity (e.g. playing with small toys). The toys selected and manner employed will be the minimum necessary to encourage the child to adopt a midline forward position (for head position in relation to the calibrated sound-field system) and maintain alertness (in order to be ready to respond when the acoustic signal is presented). Importantly for children with object permanence (Piaget and Inhelder, 2000; Anderson 1955) Tester 2 shall provide no change in activity linked to stimulus presentation that could serve as a cue for signal presentation (e.g. distinct and rhythmical phasing shall be avoided). Very young children who have not yet reached the developmental level of object permanence should therefore require coverage of the object. Tester 2 should avoid noisy play, so as not to mask the signal, and refrain from engaging with the child too fully, particularly direct eye contact as this can override the response to hearing the signal, save for praising a correct response.

7.2.2 Familiarisation and conditioning

Before testing it is essential to establish conditioning. Some children will give a clear and repeatable head-turn to an auditory stimulus without any formal conditioning while others will require a number of conditioning trials.

The following sequence is suggested:

1. A 2-kHz stimulus is presented at a level judged adequately supra-threshold. (As a guide, 60–70 dB HL is suitable for routine purposes, although consideration should be given to the type and degree of hearing impairment anticipated.) Also, a different frequency may be selected if it is judged that the child is likely to be more responsive (e.g. a lower initial

frequency would be appropriate if there is suspicion that the child has a high-frequency hearing loss). See Section 7.6.

If the child gives a clear head turn within 2–3 seconds of the stimulus presentation then visual reinforcement is provided in combination with the sound for a further 2–3 seconds. If repeatable, conditioning can be considered to be established and the test sequence begins.

2. If the child does not respond spontaneously with a head turn, a more formal conditioning procedure is needed. Initially stimulus and reward are presented simultaneously and if necessary the child's attention directed towards the reward. A number of such paired presentations may be required. When a head turn response is reliably elicited to the combined stimulus conditioning is checked by presenting the auditory signal alone and presenting the visual stimulus as a reward after the head turn response. Once the child is responding to sound alone testing can begin.
3. If the child responds to the combined stimulus/reward but fails to demonstrate a response to the stimulus alone it may be that the stimulus is insufficiently interesting or is not audible. The assumption should be that it is not audible and the presentation level increased (e.g. by 10 dB). If no response is observed at this higher level then differentiation between interest/inaudibility can be assessed by changing the stimulus type (e.g. to NBN, although see Section 6.1) or changing the frequency of the stimulus. Using a vibrotactile stimulus generated from the bone vibrator (such as around 40 dB HL at 250 Hz) with reconditioning using the paired presentation should show a response even in a deaf child. If the tone is still inaudible at 80 dB HL, then care shall be taken to increase the level of the tone in 5-dB steps until a response is observed, while continuing to monitor the child for discomfort (e.g. blinking, crying).
4. If the child is not responding to the stimulus/reward combination it may be that the reward is insufficiently visible or interesting. This may be remedied by lowering the room lighting, changing the reward, using two or more rewards in combination or moving the visual reward closer to the child. Alternatively it may be that the child is not developmentally ready for the procedure or is not sufficiently motivated by the reward in which case other test procedures will be required.

7.2.3 Testing

When conditioning is secure (at least two consecutive correct responses), Tester 1 will proceed to the test trials proper. Here sound only will be presented for 2–3 seconds. If Tester 1 judges that the child has turned in response to the sound, then visual reinforcement will be presented for 1–2 seconds, with overlap of the stimulus in order to continue a clear association between the two. The

desired response is a clear head-turn to view the reinforcer. Eye glances or small movements should be interpreted with more caution and be reported as such.

False 'checking' responses will be managed by using variable inter-trial intervals, some of long duration, and additionally use of deliberate no-sound control trials may be employed. Withholding the visual reinforcer for a moment or two after the child turns also may help to distinguish checking glances, which are often short-lived, from real responses.

Once responses have been established to the initial high level, the level should be dropped as rapidly as possible (e.g. 20-dB steps) as long as responses are still observed. Tester 1 should determine presentation level based upon age of the child, attention state, and other factors concerned with time. However, around the estimated MRL, a '10-dB down, 5-dB up' rule (BSA 2011a) should be adopted. The criterion for minimal response level will be the lowest level at which a response occurs at least 2 out of 3 of ascending trials (i.e. >50 %). False positive responses should be discounted from judgment against the criterion defining a MRL. Minimum response level at one frequency should be defined before moving to another frequency where possible.

The initial and subsequent test frequencies will vary for each patient, depending on the information obtained by previous methods and the need to acquire further information. When changing stimulus frequency, present the initial stimulus at a level judged to be at or above threshold. It may also be helpful to present clear supra-threshold stimuli or re-condition a child who has become distracted. For a child who is restless or bored, various techniques can be used to maintain interest, e.g. changing stimulus type and choice or reward. Where ear-specific information is sought, insert ear phones should be used. This could be achieved for one or more frequencies in each ear following sound-field VRA. In instances where the child rejects the inserts, or has reduced interest/awareness, the child's localisation ability for NBN or voice (supra-threshold, up to 30 dB above the minimal response level) may be assessed, using both low and high frequency NBN. It may be necessary to recondition the child using loudspeakers on both sides. Difficulty with localisation may indicate an asymmetric hearing loss, and may warrant the need for testing each ear individually using insert earphones. An ability to localise successfully, however does not exclude the possibility of an asymmetric loss. Therefore, where medical or parental history indicates the need to investigate for an asymmetric hearing loss, then ear-specific information should be the goal.

The selection of transducer to use will not be covered in depth in this Recommended Procedure; as with selection of frequencies for testing, this will depend upon the profile of information previously obtained on the child and that required for further management. However, use of insert earphones is strongly

preferred for those suspected or known to have a permanent hearing loss, in order to obtain reliable ear-specific information.

7.3 Tips for effective VRA testing

- The procedure relies on continued cooperation of the child, in particular their ability to stay in the required test position and to maintain interest; time will therefore be limited. To avoid delay/disruptions ensure that all required equipment is checked in advance (Stage A calibration checks are completed, reward system operating and communications equipment ready for immediate use).
- Some children may be upset by certain animated toys. If so, reward through simple illumination rather than animation or switch to alternative toys.
- To extend interest in responding, switch reward toys and/or use in combination. Also be prepared to take a break from testing and return to complete the assessment, or switch testers. The interest of older children in particular may be extended by praise/encouragement of correct head turn, provided by Tester 2.
- Towards the end of the test procedure, return to the first frequency tested and present at MRL (or 5 dB above that dial level); does the child still respond? This information will help the tester judge validity of later responses.

7.4 The most common pitfalls of VRA testing

- Inadequate test set-up and communication between testers
- Attempting conditioning to sub-threshold stimuli
- Not establishing clear responses at supra-threshold levels before descending to threshold
- Incorrect scoring as true responses i.e. scoring of movement other than a clear head-turn, or false positive (checking) responses
- Distinct and/or rhythmical phasing of attention by Tester 2 such that response cues are given to the patient
- Use of toys or behaviour by Tester 2 (or parent) that provides too little or too much engagement for the child and therefore inhibit responses

- Overemphasis on quantity of results (number of MRLs obtained) rather than quality (reliability) of those MRLs obtained
- Not using time efficiently, often spending too long at high intensities
- Inaccurate interpretation and reporting of results due to inadequate consideration of differences in infant MRLs compared to adult normative (threshold) values (see Section 8.1)
- Obtaining MRLs with speakers on right and left and interpreting these as providing ear-specific information (which they do not)
- Cues from parents (e.g. parents moving when sound is presented)
- Tester response bias (e.g. tester believing or wishing that child's hearing is normal) leading to lack of objective interpretation of turns vs. checks.

7.5 Testing children with vision disorders, with other disabilities or at an early age

Visual disability may interfere with conditioning and responses. Consider bringing the reward closer to the child. Alternatively use of more visually contrasting rewards (e.g. bright flashing light), or removal of the smoked Perspex cover to the reinforcer unit should be considered. Dimming the room lights will also increase the contrast. For the more severely visually impaired, or children with complex needs, use of other sensory reinforcement such as air puffs, vibratory stimulation or music may be needed to bring children under stimulus control.

General developmental delay may not necessarily interfere with VRA. However, motor difficulties may obscure head-turn responses. A more flexible approach to response reward and interpretation may be appropriate. However, any deviations from the standard approach should be described when reporting.

Although VRA is generally reliable in assessment of normally developing children from age 30 weeks (corrected age), some infants may be testable at younger ages, from age approximately 20–26 weeks. Testing at this age may be required because of parental or professional concern and is of particular value to early diagnosis and habilitation. However, when testing younger children who have not yet achieved object permanence in their developmental stage (Piaget and Inhelder, 2000), it might be required to stop and cover/hide the engagement activity. The child will otherwise be unable to respond to a different stimulus (e.g. the acoustic signal presented) due to their inability to switch attention. It should be recognised that a sequence of test appointments may be required to

incrementally gain the information required (e.g. a series of frequency and ear-specific MRLs).

For children with disabilities or where VRA is used speculatively at an early age, a realistic appraisal of the likelihood of test success should be presented to parents/carers before testing. Testers should also seek the advice of parents/carers in advance of assessment to determine the appropriate test strategy. For more detailed information on conducting VRA for children with disabilities, clinicians are advised to refer to Coninx and Lancioni (1995).

7.6 Sequence and objectives of assessment

The sequence of assessment should be adapted depending on the objectives of the Audiologist and the status of the child. However, the testers must be aware that the cooperation/interest of the child may fail at any time and this should be reflected in the sequence of assessment: the clinically more important information should be obtained first. As a guide the following sequences are suggested for an initial formal behavioural assessment commencing with stimuli presented in the sound-field:

2 kHz → 500 Hz → 4 kHz → 1 kHz or

1 kHz → 4 kHz → 500 Hz → 2 kHz

Sound-field testing could be followed by delivery of stimuli through insert earphones where ear specific information will be of use (e.g. where the possibility of significant asymmetry is indicated by the history) or where results will be used to guide amplification. Likewise, BC testing may be indicated, albeit with awareness of increased likelihood of vibrotactile responses at the lower frequencies compared to adults (see BSA, 2011a). If ear-specific MRLs are desired and use of insert earphones is contra-indicated (e.g. due to wax) circumaural headphones could be considered (on headband or held over the ear). The timescale for acquisition of MRLs should be considered carefully. On the basis that quality of results takes prominence over quantity (of MRLs) consideration should be given to arranging a sequence of appointments. This is particularly important where a large quantity of information is required and/or where the child is only just at sufficient developmental age or has relevant disabilities. A duration of 30 minutes would be typical for an assessment appointment that included sound-field VRA.

8. Interpretation of results

The process described above provides calibration to adult norms for a conventional audiometric technique. There are no specific international standards on the RETSPL values for stimuli used for VRA. Audiologists should be mindful of the influence of age of subject and the test method employed when interpreting and reporting results. Consideration should also be given to the use of MRL information, whether to inform others (e.g. ENT medical colleagues) of hearing status or for use by the Audiologist to guide effective amplification to a prescriptive target.

There are numerous factors contributing to the known difference between infant VRA MRLs and adult normative thresholds. These include sensory and non-sensory factors (including ear canal size) and other factors such as the effects of subject generated noise. The effect of these contributory elements is complex and not fully understood. However, the sum of these effects is that normally hearing infants performing VRA require a higher intensity stimulus to induce a response (e.g. a head turn) than that required for normally hearing adults performing pure-tone audiometry. Although some studies have investigated and reported on the difference between MRLs obtained by VRA in infants and adult threshold normative data, the data set (relating to test frequency, age of subject and type of transducer) is far from complete. Further studies are required to confirm and build upon this knowledge base before we can endorse a series of specific correction factors for VRA (as is the case for auditory brainstem response testing of newborn babies). With due consideration of the above, the materials presented below (and in the references) represent current information on the scale of infant-adult correction factors based upon the mode of stimulus delivery, stimulus type and age. Consequently, the correction values indicated are provisional at this time.

8.1 Sound-field

Information available on the relationship between adult thresholds and MRLs for sound-field VRA, indicate that normally hearing infants (ages 7–12 months) present mean thresholds at approximately +10 dB relative to adult thresholds (from 0.5–4 kHz). An infant with an MRL at 45 dB HL, for example could be considered to have equivalent hearing to an adult responding at 35 dB HL. Therefore, it is suggested that when testing infants by VRA in the sound-field, hearing should be tested down to at least 25 dB HL (equivalent to adult 15 dB HL) and that responses at this level are accepted as indicative of hearing within normal limits. Such guidance should not discourage testing down to lower levels, for example in older children, and ambient noise permitting. Those professionals

interpreting and reporting results should be mindful that sound-field assessment only indicates the hearing status of the better hearing ear at each test frequency.

8.2 Insert earphones

For insert earphones, the frequency-specific correction factors are equivalent to the MRLs measured in studies on normally hearing children, examples of which are presented in Table 1. The Parry et al (2002) study employed a VRA protocol similar to that described here and was conducted on 8–12 month old infants with normal hearing. The Nozza et al (1995, 1999) studies were conducted on infants in the age range of 6–11 months.

Table 1

Comparison of MRLs in infants for insert earphone VRA studies, in children with normal hearing.

| Studies | Infant mean MRLs, dB HL (standard deviation) | | | |
|-------------------------------|--|------------|-----------|-----------|
| | 500 Hz | 1000 Hz | 2000 Hz | 4000 Hz |
| Nozza (1995) | | 14.1 | | |
| Nozza and Henson (1999) | 17.2 | | 6.8 | |
| Parry et al (2002) | 16.4 (5.9) | 13.3 (6.1) | 7.1 (5.5) | 6.4 (6.2) |
| Recommended provisional value | 15 | 15 | 5 | 5 |

The normative values presented above may be used as correction factors by subtracting these values from the MRLs to provide the estimated PTA hearing threshold levels. The resulting values may therefore be more comparable to an adult audiogram and as such suitable for interpretation by non-audiological colleagues.

For example, when an infant obtains an MRL of 30 dB HL at 500 Hz using inserts, the conversion to an adult hearing threshold level would be $30 - 15 = 15$ dB HL. For an MRL of 30 dB at 2 kHz, the conversion to an adult hearing threshold would be $30 - 5 = 25$ dB HL. However, as such studies have only been carried out on normally hearing infants, it is possible that these correction factors do not apply to children with sensorineural hearing impairment. In addition,

clinicians should be aware that there are no studies that investigate such MRLs in older children.

Correction of raw MRLs obtained by insert earphone VRA may also be appropriate when estimating the audiometric profile, for inputting to hearing aid prescription formulae.

8.3 Bone conduction

No studies have been identified that provide correction factors between bone conduction VRA MRLs and sound-field thresholds in dB HL. In view of this, it is important to label results appropriately where BC MRLs are presented alongside corrected AC MRLs.

9. Recording and reporting of results

Reporting of the results should fulfil two purposes: firstly to give the final result of the MRLs for the frequencies tested and secondly to provide the information relevant to subsequent interpretation and to guide further assessment. Additionally, given the concept of MRLs, care should be taken in reporting results to other professionals who may be more familiar with interpreting thresholds rather than MRLs. It may be useful to retain the recording form for audit purposes.

The records and reporting of results should be clearly accompanied by a description of the type of transducer, and any comments on the reliability of responses or factors preventing completion of the test. Also each audiogram record should indicate whether recorded levels are MRL or corrected to provide estimated adult thresholds.

The criterion to determine an MRL should be responses to > 50 % of presentations with at least two positive responses at the MRL. Occasional false positive responses (checking responses; where the child turns without a sound presentation) are quite common to VRA testing. However if excessive they may have the impact of lengthening the time taken to secure reliable MRLs, possibly preventing completion of the assessment. Excessive false positive responses should be reported for future reference.

Other factors that may have impacted on the reliability of the test should be recorded/reported: the alertness state of the child can range from drowsy /sleepy to overactive/overexcited, noisy breathing may mask the sound presented and/or the observed responses may be less distinct than a full head turn towards the reinforcer.

Recommended symbols for recording the results of sound-field testing are given in Appendix D. Symbols for inserts or headphones shall follow the BSA (2012) procedure for recording PTA, with clear indication of which transducer was used on the audiogram. When masking has not been used, and there is a risk of cross-hearing, this shall be clearly indicated on the audiogram.

If a child responds reliably to the lowest sound levels tested at a particular frequency, the result shall be reported as less than or equal that level, e.g. tested down to 25 dB HL, but not below this level is reported as ' ≤ 25 dB HL'. To indicate this on an audiogram the following symbol shall be used: an arrow pointing diagonally to the right top away from the test level. However, this symbol level shall NOT be connected with a line to any neighbouring symbol (of whatever type).

Where recorded results represent the MRLs (dial settings), this should always be clearly indicated in the narrative associated with each audiogram or reported numeric results. Similarly, the nature of any MRL threshold corrections applied (to guide interpretation or to provide an estimated audiogram for the purpose of prescription for amplification) should be indicated.

It is recognised that determination of individual clearly observed MRLs that meet the criterion (see Section 6.2.3) may not always be secured, often associated with a paucity of other information to guide patient management. In such circumstances estimations may be required based on incomplete data. Such estimated MRLs/thresholds must be clearly recorded/labelled as such pending confirmation through reliable assessment.

The Audiologist leading the VRA procedure should be responsible for ensuring that results are appropriately documented and reported.

Finally, guidance on the matter of MRL to adult threshold corrections may change with the outcome of further research. The use of this (standardised) VRA protocol in further research studies around VRA MRLs is encouraged in order to enable the transfer of outcomes of research across test, and collaboration between, centres.

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Appendix A. Authors and acknowledgments

This is a revised version of a document written by a small group (John Day editor, Roger Green, Kevin Munro, Georgina Parry, Paul Shaw, Sally Wood, Ed Brown and Graham Sutton, 2008), which built on an earlier document with contributions by John Bamford and Marianne Gliddon; the previous documents were approved by the NHS Newborn Hearing Screening Programme (England) Clinical Group. The ongoing review of the document was handed over to the BSA in 2011, the current document being the first BSA version of the document. It was revised and processed by the Professional Practice Committee, in collaboration with BSA's Paediatric Interest Group and with John Day, between May 2011 and March 2014, in accordance with BSA Procedure for Processing Documents (2003). The PPC thanks all involved with previous versions of this document and all who contributed to the current review and consultation (Spring 2012). An electronic copy of the anonymised comments received during this consultation, and the responses to these by the authors, is available from BSA on request.

Appendix B. Definitions

Azimuth. Direction of a sound source measured in angular degrees in a horizontal plane in relationship to the listener. For example, 0° azimuth is directly in front of the listener and 180° is directly behind.

Corrected age. Used to describe the age of children under 2 years old who were born preterm and represents the age of the child from their expected date of birth. For example, a 36-week-old who was born at 28 weeks gestation (i.e. 12 weeks early) has a corrected age of 24 weeks.

Chronological age. Usually referred to as 'age'; time since birth.

Developmental age. The age level at which the child is functioning relative to her/his developmental abilities. This can be above or below the chronological age.

Distractor. This term should be avoided and 'engager' be used instead. This is because the aim of this role is to maintain the attention of the child towards the front, without being too engrossed.

Engager. The tester in the room in front of the child who keeps the child engaged and keeps the child's interest on the table in between them.

Minimal response level (MRL). The criterion for the MRL is the lowest level at which a child responds in at least 2 out of 3 of ascending trials (i.e. >50 %) at that level for a given stimulus and method of presentation. While this criterion is similar to that used for 'hearing threshold' on pure-tone audiometry (BSA, 2011a), the interpretation may not be. The MRL may only be the lowest level at which the auditory signal was sufficiently strong to overcome the child's attention to the engagement activity.

No-sound control trial. A point in time during hearing assessment that is designated to observe the child's reaction without sound presentation and with all other parameters exactly the same. This is in order to evaluate the probability/likelihood of the child producing false-positive responses.

Object permanence. A stage in child development when the child is aware that an object continues to exist even though it can no longer be observed. For example, when an object falls off the table such that the child can no longer see or hear it, the stage of object permanence has been reached if the child is aware that the object must still be in existence.

Appendix C. Suggested single-room layout

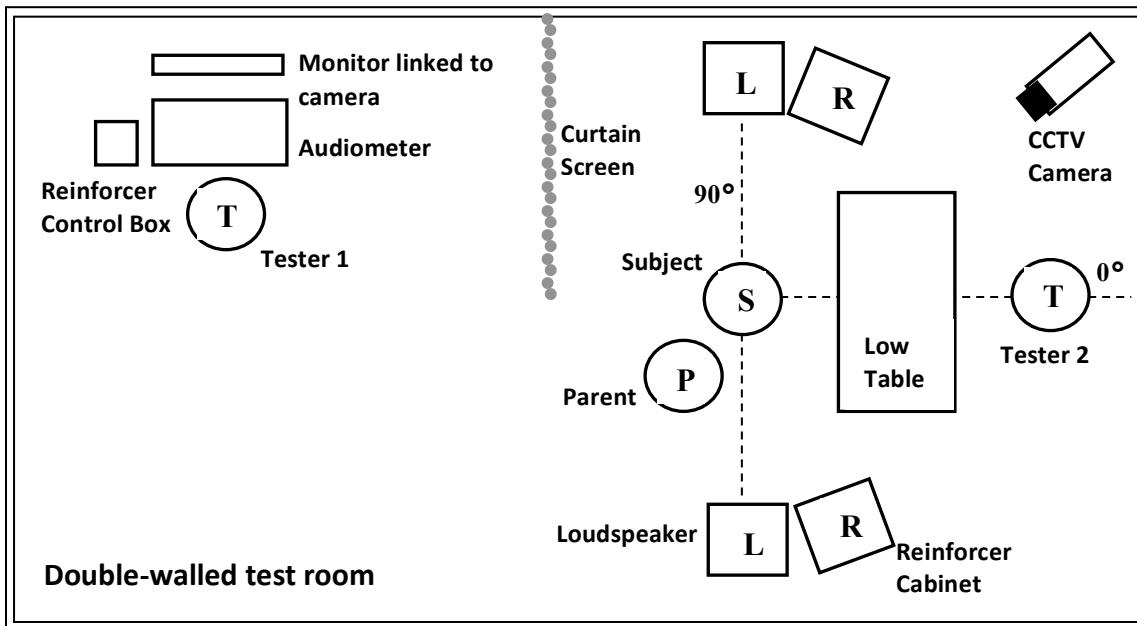


Figure 2

Recommended layout of test area if using single-room format.

Appendix D. Symbols

Table 2 presents the symbols suggested for recording the results of sound-field testing on the audiogram (from ISO 8253-2). In the case of sound-field testing, MRLs will usually be bilateral. In the case of monaural results, it shall be noted with the audiogram how this was achieved (e.g. by occluding contralateral ear and with what occlusion). It is important to remember that any form of occlusion of the non-test ear has only limited attenuation and that this attenuation is probably unknown for child ears. Consequently, responses to sounds presented to the test ear can therefore reflect hearing from the occluded, non-test ear if the level of the sound is sufficiently high, similarly to cross-hearing with PTA. It should always be noted on the audiogram form whether symbols represent thresholds or minimal response levels.

Table 2

Recommended audiogram symbols for sound-field. 'Monaural' results indicate that the possible involvement non-test ear has been reduced, such as by occluding it; the specific method used to achieve this shall be noted with the audiogram.

| Test condition | Symbol |
|---------------------------|---------------|
| Monaural, left ear | X |
| Monaural, right ear | O |
| Bilateral | B |
| Monaural, left ear aided | ◇X |
| Monaural, right ear aided | ◇O |
| Bilateral, aided | ◇B |

An example of sound-field results plotted on an audiogram form is given in Figure 3. In this example, the responses are assumed to reflect the right ear, such as by occluding the left ear and the method of occlusion would be recorded with the audiogram. If there is reason to doubt that assumption (i.e. if it is unclear which ear is involved in the response), such as with the unaided results above 500 Hz, then the results would instead be indicated by a 'B' symbol on the audiogram. Note that if computer-generated audiograms are being produced, these symbols may not be available; a key shall therefore be provided that clearly identifies the meaning of all symbols used.

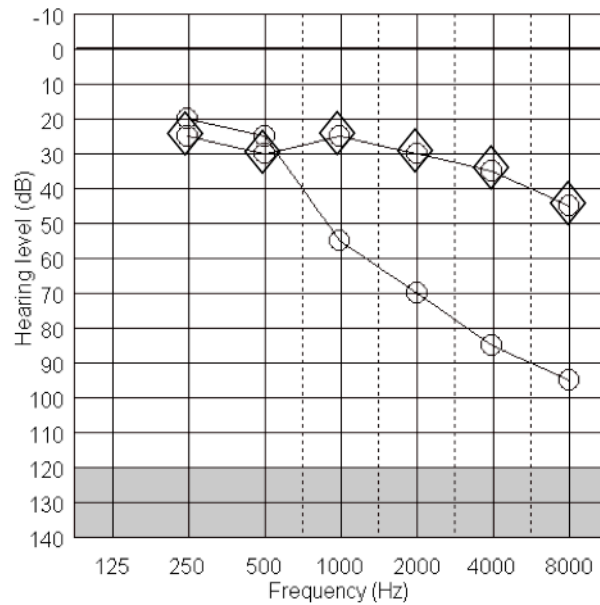


Figure 3

Example of sound-field symbols plotted on the audiogram. It also should also be noted how monaural testing of the right was achieved (e.g. using an ear plug in the left, and which type of plug). The symbol B would be used if it were unclear which ear was involved in the responses.