Recommended Procedure

Visual Reinforcement Audiometry

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General Foreword

This document presents a Recommended Procedure by the British Society of Audiology (BSA). This Recommended Procedure 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 at the time of publication. Although care has been taken in preparing this information, the BSA does not and cannot guarantee the interpretation and application of it. The BSA cannot be held responsible for any errors or omissions, and the BSA accepts no liability whatsoever for any loss or damage howsoever arising. This document supersedes any previous recommended procedure by the BSA and stands until superseded or withdrawn by the BSA.

This document supersedes the BSA Recommended Procedure: Visual Reinforcement Audiometry (2014)

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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.

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1. Introduction

This document replaces the BSA Recommended Procedure for Visual Reinforcement Audiometry (2014). The content here is guided by published evidence where possible however, where there is insufficient research in this area the recommendations in this document are based on the consensus or reported practice of experienced practitioners in the field. General and research references that have guided the content of this document are provided and specific references have been included where considered helpful. We welcome further research in this area (see Appendix F).

Visual reinforcement audiometry (VRA) is central to completion of the diagnostic process for infants. Accurate diagnosis and paediatric amplification fitting methods rely on solid foundations of hearing measurement. It is hoped that the standardised VRA technique described here will underpin training of Audiologists and be of use in research studies. VRA results should always be interpreted in the context of the patient history, clinical observations and other testing (which may include otoscopy, tympanometry, otoacoustic emissions, auditory brainstem response tests) following the cross-check principle (Norrix, 2015).

Fundamental to accurate VRA are the following elements:

- Audiometers used must be within calibration and have daily (Stage A) checks performed to verify their output before testing commences.
- Room setup/furniture positioning must be as specified at the time of Stage B calibration and maintained during soundfield testing.
- Conditioning must be established before testing can commence. Where conditioning cannot be established Tester 1 must take steps to verify whether this is because the child is not developmentally able to condition or whether the stimulus is inaudible.
- Tester 1 must be able to see the infant's face during testing. Only clear-head turns or prolonged gaze at the reinforcer will be classed as acceptable responses. Eye-flicks, stilling, or other movements should not be accepted. Where the child has motor development problems which prevent them from making head or prolonged gaze turns, alternative testing methods may be required.
- Testers must not bias the test through repeated presentations at low levels, where the infant has already not responded on two occasions. The test must be approached as an unbiased measurement of minimum response levels, rather than testing with the expectation that the child will have normal hearing.

The term 'shall' is used in this document to refer to essential practice, and 'should' is used to refer to desirable practice. The term 'parent' has been used throughout the document but this could be a carer or other adult.

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2. Scope

2.1 Subjects

The document sets out guidelines for testing infants with a minimum developmental age of 6-7 months to around 30 months developmental age (Day et al., 2000; Widen et al., 2005). The test is suitable for infants who are able to sit unsupported or with minimal support and able to turn their head to each side. Once a child can begin to control their own attention focus and does not need their attention set by an adult before each task, they are no longer suitable for VRA as they will be able to inhibit responses, and play audiometry should be considered.

2.2 Procedures

The document covers the technical procedure of carrying out a VRA test, equipment/environment considerations, basic interpretation of the results, reporting and patient handling procedures relevant to the test. This document shall be read alongside BSA 'The Acoustics of Soundfield Audiometry in Clinical Audiological Applications' (2019) for guidance on the more technical aspects of sound-field testing, and also BSA 'Pure-Tone Air-Conduction and Bone-Conduction Audiometry with and without Masking' (2017).

2.3 Competency

Staff performing VRA testing shall receive specific training in performance of the test, with both documented assessment to demonstrate their competency and peer review of their testing skills undertaken at least every two years (British Academy of Audiology, 2022a). In this document the term Tester 1 will be used to refer to the tester responsible for control of stimuli and reward. Tester 2 will refer to the tester who will engage the child. The preferred VRA technique uses two testers, with at least one experienced Audiologist or Clinical Scientist, specialising in paediatric audiology, as Tester 1, and one other experienced audiological professional such as an Audiologist, Assistant Audiologist or Educational Audiologist as Tester 2.

3. Equipment and Test Environment

3.1 Audiometric Equipment

Audiometers and test rooms shall meet the performance and calibration requirements (including soundfield) of the relevant and current BS EN ISO Standards (see Section 6).

3.2 Audiometric Test Environment

The test shall be performed in a room of adequate size to accommodate parent(s), the child, two testers and the VRA equipment comfortably. Following BSA (2019), minimum floor dimensions of 6 m x 4 m, plus a separate control room, are advised. Note: this specification assumes that the room is dedicated to the behavioural hearing assessment of children under 3 years of age. The minimum distance between

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the child's ear and the speaker shall be at least 1 m, with the speaker at the child's head height. The room should have adequate ventilation and air conditioning for patient comfort; children who are uncomfortable are less likely to respond well to testing. The room shall offer minimal distraction to the child. The room 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 could be covered with a wipe-able, soft mat to keep noise down to a minimum when engaging with the child, whilst complying with infection control procedures.

Hearing protection shall be freely available for others present, in the rare case that soundfield stimuli are presented at ≥80 dBHL during testing (see section 7).

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. It is essential that Tester 1 is not visible to the child but can clearly view the child's face.

Figure 1 describes the recommended standard room layout. Where only a single room is available the room should be arranged as depicted in Appendix A. Examples of suitable equipment may be found in Appendix B.

It is important that if there is potential for equipment to be moved between clinics e.g. in community settings, it shall be verified that the equipment is located in the marked positions prior to commencing testing. Following BSA (2019), the test environment shall be clearly documented with a defined layout of furniture, furnishings, equipment and positions for people in the room during testing. Marks shall be made to floors and/or ceilings to ensure that layout and positions remain consistent as any deviation may compromise calibration.

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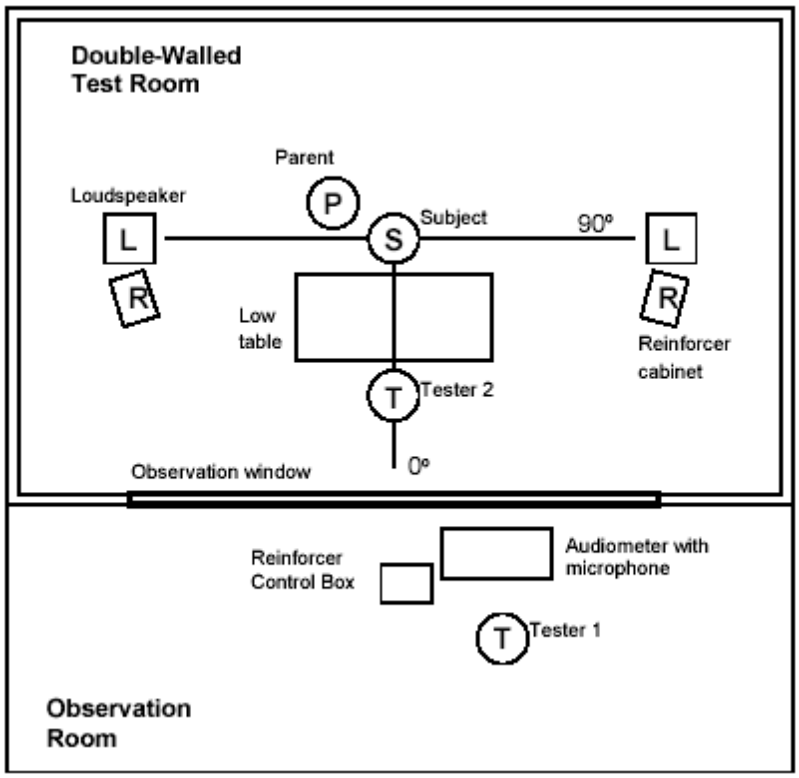

Figure 1. Recommended Room Layout

3.3 Position of Testers

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. Tester 2 is positioned on the opposite side of the table facing the child and shall have a concealed and plentiful supply of suitable toys close at hand adequate for the duration of the assessment. The table shall be at a height comfortable for the child to see the engaging activity.

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 discreetly. There should also be the facility for the Tester 1 to hear sounds made in the room (for communication and appropriate timing of stimulus) and these should be audible to Tester 1. The arrangement also

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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.

Good two-way communication between testers is an essential requirement for the test procedure. Communication from Tester 1 to Tester 2 shall be direct and discreet, for example by the use of remote microphone system, so as to avoid auditory distractions for the subject. Where an observation room is not available Tester 1 shall ensure that they do not give any visual cues to the child but shall be able to view the child's responses.

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. Consider provision of a remote microphone system to enable communication with the parents.

The literature is based upon a two tester testing model however it is acknowledged that in exceptional circumstances practitioners may sometimes carry out single tester VRA. There is less evidence to support the efficacy of single tester VRA therefore this practice is discouraged at this time within recommended practice guidance.

3.4 Position of child

The child's head shall be at the point determined and marked during calibration of the sound-field. The child can be seated on the parent's knee, gently supported by the parent's hands on their waist or under their arms, and facing forward. The parent's hands should 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. Care should be taken to avoid letting the child lean against the parent, in order to maintain alertness and avoid cues from the parent's movement. Alternatively, the infant may be placed in a secure 'high chair'. An older child can be seated on a low chair, with parent seated slightly behind. A table is placed in front of the child to provide a surface for the engaging activity.

Any others present shall be invited to sit in the observation room (preferred) or directly behind parent and child. This arrangement is also more useful for training purposes, and peer review and for allowing other family members to observe the test discreetly.

3.5 Reinforcers

Reinforcers may include toys, video images or rotating lights. Toy reinforcers shall be located within a cabinet obscured by a smoked Perspex screen so that the toys are more visually attractive with illumination. Reinforcer cabinets (and/or reward monitors) shall be secured to the wall or floor to prevent accidental injury should the cabinet be toppled over, however the fixings should also allow for release so the tower can still be moveable for patients requiring this (see Section 5.5).

Tester 1 uses a switch to control the animation and illumination of the visual reward. Ideally, at least two independently controllable rewards should be provided for each side of testing. The literature offers

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mixed and inconclusive evidence as to the relative efficacy of animated toys versus video rewards (Karzon & Banerjee, 2010; Lowery et al., 2009; Schmida et al., 2003) but it is acknowledged that having access to a varied and complex rewards increases the number of responses (Moore et al., 1975; Primus, 1987; Thompson et al., 1992). Some video reward systems allow users to add their own videos (e.g. www.videovra.com). Users can source their own material or use video libraries, for example (https://osf.io/bk6rc/, Hemann et al., 2020). Such personalisation of video rewards may be particularly helpful for children with developmental disabilities and specialist interests, though further research is needed to confirm this (Bonino et al., 2021).

Reinforcers shall be positioned as close to 90° as possible from the test position. 90° azimuth is used in order to elicit the clearest head turn. The reinforcers shall be located approximately level with the child's head. Adjacent positioning of loudspeaker and reinforcers is recommended to aid conditioning to soundfield stimuli. Furthermore co-location of speakers and rewards has been shown to improve response behaviour (Primus, 1992b). Facility shall exist to move the reinforcers closer to the child to enhance reinforcement (if their developmental and/or visual ability requires this) although care shall be taken to avoid interfering with loudspeaker calibration, therefore it may be necessary to use alternative transducers (e.g. insert earphones) if the changed reinforcer position could impact upon the loudspeaker signal. Having 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). This is likely to improve overall response behaviour compared to being limited to using a single reward location (Primus, 1992b).

3.6 Stimuli

Frequency-modulated warble tones shall be employed. If the child is unresponsive Frequency Specific Hearing Threshold (FRESH) noise or Narrow Band Noise (NBN) or any other stimuli that have reference equivalent threshold sound pressure levels (RETSPLs) for air conduction (AC) or force (BC) shall be attempted when available and calibrated in dB HL for threshold measurement (See Appendix C). NBN for estimating thresholds shall be calibrated in dB HL not dB effective masking level (in order to avoid under-estimating hearing loss by 5–10 dB).

3.7 Stimulus delivery

Full assessment of the type and extent of hearing loss in each ear requires different transducers to be used. Supra-aural earphones (e.g. Telephonics TDH39), insert earphones (e.g. Etymotic ER3) coupled with foam tip or earmould, speakers for sound-field presentation and a bone vibrator are used to define the extent and type of hearing in each ear. The tester should ask whether the child has a programmable ventriculo-peritoneal (PVP) shunt prior to testing, to check for any contraindications to using transducers (BSA, 2021). For children with hearing aids, where available, insert tips shall be inserted directly into the tubing of their ear-moulds, as this is useful for prescribing amplification.

In the absence of contraindications, insert earphones are the preferred transducers for ear-specific air conduction testing. Insert earphones have several advantages over supra-aural earphones for this test method, including reduced acoustic crossover (increased inter-aural attenuation), decreased likelihood

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of collapsed external ear canals, accurate location of sound delivery, increased comfort and reduced interference with head-turn response (Scollie et al., 2019). Older infants may also give more responses with insert earphones than supra-aural headphones (Weiss et al., 2016). In addition, frequency specific correction factors to convert minimum response levels to hearing thresholds are only available for insert earphones therefore where test results may be used to fit hearing aids, testing with insert earphones and the child's earmoulds is preferable. Using insert earphones is also complementary to using real-ear-to-coupler-difference measures for hearing aid verification, rather than reliance upon normative values if supra-aural headphones are used (real-ear-dial-difference required instead).

3.8 Precautions against cross infection

Local procedures to avoid cross-infection shall be adhered to, including cleaning of all surfaces in patient contact and toys. If insert ear phones are used, disposable single-use tips shall be used (unless using the child's own ear-mould). Manufacturer's guidelines must be followed and local advice sought regarding best practices for infection control when using supra-aural headphones or bone vibrators.

4. Test Procedure

4.1 Preparation

During history taking information shall 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 make a head-turn this can be checked by having the child visually track an object of interest through an arc of 180°. Tester 2 may use the history-taking time to engage with the child and help them feel settled. If the child is becoming restless it may be appropriate to return to history taking later in the appointment and begin testing.

Explain the test to the parent, request and document consent. Instruct the parent regarding sitting in the test position and, if the child is to be held on their lap, how to support the child appropriately (See Section 3.4). Ask the parent to remain as quiet as possible and not respond to any of the stimuli to prevent cueing the child. Both testers shall be aware of potential cueing by parents throughout the test and if a parent is giving cues they must be made aware of their behaviour and asked to stop. If this is ineffective then hearing protection (ear plugs/muffs) could be used to assist in preventing the parent /carer from hearing the presentations and thus not giving cues.

If required, the transducer shall be fitted to the child. The fitting of insert earphones shall be preceded by otoscopy (BSA, 2022). The use of an adjustable metal headband is recommended for the bone conductor. Where this is not possible or cannot be tolerated, a flexible headband is a possible alternative. There shall be due consideration for infection control when using a flexible headband. Results obtained when using a flexible headband shall be interpreted cautiously as the force applied cannot be assured. The practice of parents holding the bone conductor on the mastoid should be avoided when possible as it may result in inconsistent placement and force. Whatever the means of placement, Tester 2 shall be alert to ensure that the bone conductor remains appropriately placed throughout the test procedure.

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4.2 Procedure for measurement of minimum response levels

4.2.1 Minimum response level (MRL)

The minimum response level (MRL) is the lowest intensity level at which reliable repeatable responses are obtained, for a given sound stimulus. MRLs are distinct from equivalent adult thresholds due to the sensory and nonsensory factors raising the level at which a response can be elicited in an infant (Nozza, 1995; Nozza and Henson, 1999). To ensure correct reporting of results for interpretation by others, it is particularly important that the differences between MRLs obtained by VRA and adult normative thresholds are recognised and understood. 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.

4.2.2 Initiation of test

Tester 2 will choose a suitable table-top activity (e.g. playing quietly with small toys). The toys selected and manner employed will be the minimum necessary to encourage the child to adopt a midline forward position and maintain alertness. Tester 2 shall provide no change in activity linked to stimulus presentation as this could serve as a cue for signal presentation (e.g. distinct and rhythmical phasing shall be avoided). Tester 2 shall avoid noisy play, so as not to mask the signal. The play shall be conducted at a low table rather than at eye level, so that the child's gaze is forwards and slightly down, to assist in producing a clear head-turn when looking for the reinforcer. It may be suitable to allow the child to hold or play with a simple toy if this keeps the child settled, provided that they do not become too engrossed in this activity and maintain an appropriate test state.

4.2.3 Familiarisation and conditioning

Conditioning must be established before testing can begin. The following sequence is suggested:

1. A 1 or 2-kHz warble stimulus is presented unilaterally at a level judged to be adequately supra-threshold. Where no previous information about the child's thresholds is known the default starting level of 65 dB HL is recommended in soundfield testing to align with the 20 dB step sizes to descend to near threshold in a small number of responses. For insert testing, the default starting level should be 60 dB HL unless previous results suggest this would be ineffective or unnecessary. Consideration shall be given to the type and degree of hearing impairment if that can be 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).
2. Initially stimulus and reward are presented simultaneously, or with a 1-2 second delay, and if necessary Tester 2 shall direct the child's attention towards the reward. When a head turn response is reliably elicited 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

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consistently responding to sound alone (minimum of two consecutive responses) testing can begin.

3. Multiple presentations may be required to establish conditioning, however, if the child does not condition within the first 3-4 presentations the tester shall take action to increase the likelihood of conditioning being established, rather than continuing to present the same (possibly inaudible) stimulus and reward.

Difficulties Establishing Conditioning

1. 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 (although it may be necessary to return the reinforcer to the calibrated position once conditioning has been established to avoid affecting the soundfield stimulus). Tester 2 shall also be enthusiastic in drawing the child's attention to the reinforcer.
2. 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 shall 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, Fresh Noise, band filtered stimuli) or changing the frequency of the stimulus.
3. If the child continues to show no response to the combined stimulus/reward the tester shall establish whether the child is developmentally able to condition by using a vibrotactile stimulus generated from the bone vibrator (such as 40 dB HL at 250 Hz). Reconditioning using vibrotactile stimulus and paired presentation should show a response if the child is developmentally ready to perform the task. If the child is unable to condition with the vibrotactile stimulus 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.
4. If the child has been deemed developmentally ready for the test i.e., was able to condition to a vibrotactile stimulus, the tester shall return again to using sound as the stimulus. If the sound stimulus still elicits no response, 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). It may be necessary to change from soundfield to insert earphone testing to allow for presentation of high stimuli levels, depending upon the maximum output of the soundfield speakers and being mindful of the need for hearing protection for others in the room.

4.2.4 Testing

When conditioning is secure (at least two consecutive responses), Tester 1 will proceed to the test trials proper. Here sound only will be presented for approximately 2–3 seconds. If Tester 1 judges that the child has turned in response to the sound, then visual reinforcement will be presented for

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approximately 2 seconds, with overlap of the stimulus in order to continue a clear association between the two. Excessively long reward durations shall be avoided. Long rewards durations (4 seconds) have been shown to lead to faster habitation than shorter (0.5-1.5 seconds) durations (Culpepper and Thompson, 1994). Shorter duration rewards may be particularly useful to help older children remain engaged with glimpses of the reward.

Prolonged stimuli presentation shall be avoided due to the increased likelihood of false responses during the presentation. True responses are most likely to occur with 4 seconds of stimulus onset (Primus, 1992a). Testers shall also avoid rhythmical presentation to avoid false positive responses.

Tester 1 must judge when to present based upon the attention of the child. Engaging with the child is encouraged but tester 1 shall avoid presenting when the child is overly engrossed in distraction e.g., when a new toy has just been revealed. Testers need to communicate whether to raise or lower the engagement level.

During testing the stimulus level should initially be dropped in 20-dB steps as long as responses are still observed to reach threshold levels in the fewest number of responses. However, around the estimated minimum response level (MRL), a '10-dB down, 5-dB up' rule (BSA, 2018) should be adopted. The criterion for MRL will be the lowest level at which a response occurs on at least 2 out of 3 presentations (i.e., >50 %).

Testing which follows the principles of adult pure tone audiometry would only include ascending responses as valid, however it is recognised that in VRA sometimes it is acceptable to take one descending response alongside an ascending response at the same level in the interest of test duration and fatiguing interest on the part of the child. For similar purposes, larger step sizes may be beneficial in these circumstances (e.g., 20-dB down, 10-dB up). Such deviations shall be recorded in the test comments and testers shall be aware of the potential limitations of such methods in terms of accuracy and precision of results.

The minimum test intensities which correspond to satisfactory hearing will be 25 dB HL in the soundfield and 20 dB HL when presented via inserts, headphones or bone conduction (see Section 5). For time-efficiency and to maximise responses obtained it is appropriate to test to these levels, rather than determine a threshold which is within satisfactory range, unless a threshold is specifically needed e.g., for the purposes of hearing aid fitting or threshold monitoring. If testing below 20 dB HL the tester must be mindful to ensure that the ambient noise levels meet the relevant requirements (BS EN ISO 8253-1, BS EN ISO 8253-2).

Throughout testing the tester will need to demonstrate dynamic decision making regarding the order of frequencies tested and which transducer to use. The tester shall be mindful that the child may lose interest at any point and therefore Tester 1 needs to plan their test strategy to maximise the relevance of information obtained. The 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

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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.

When testing children with profound hearing loss where responses appear to be absent at the maximum output, before the result is recorded at e.g., >120 dB HL the tester shall, if possible, return to a frequency where there is measurable hearing and present a supra-threshold, or vibrotactile stimulus in order to validate that that child is still conditioned and that their lack of response was not due to loss of interest. (See Section 7 regarding hearing protection for others in the room).

4.2.5 Acceptable Responses

The desired response is a clear head-turn to view the reinforcer. In a child who will not turn their head, but will respond by a prolonged turn in their gaze toward the reinforcer, this shall be interpreted with more caution and reported as such. Due to the risk of misinterpretation, other responses such as eye glances / flicks, small movements and stilling shall not be deemed a response. Where the child has motor development problems which prevent them from making head or prolonged gaze turns, alternative testing methods may be required.

If the child looks to the reinforcer on the opposite side to that of the signal presentation because they were conditioned to this side originally, this is acceptable provided that the responses are consistent. Any clear head-turn in response to a signal must be reinforced, as lateralisation ability is not being tested. If the child then gives sporadic turns to the other reinforcer, these shall not be accepted.

It is recognised that determination of individual clearly observed MRLs that meet the criterion (see Section 4.2.3) 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 must be clearly recorded/labelled as such pending confirmation through reliable assessment and shall not be displayed alongside confirmed responses. The tester shall be mindful that it is preferable to have accurate results, albeit at limited frequencies, rather than estimated values across multiple frequencies/transducers.

4.2.6 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, rewarding through simple illumination rather than animation is an option, or switching to alternative toys. With parental consent, it may be possible to continue testing whilst the child is upset if they are still responding with clear head turns. Consideration should be made, however, of the likelihood of the child requiring further

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testing in future as it is important that the child is not so upset that they are upset or anxious about future appointments.

- To extend interest in responding, switch reward toys and/or use in combination. Also be prepared to switch testers or take a break from testing and return to complete the assessment (a 10 minute break has been shown to significantly increase the number of responses obtainable after initial habituation (Thompson et al., 1992)). The interest of older children in particular may be extended by praise/encouragement of correct head turn, provided by Tester 2.
- If it is uncertain whether the child is looking backwards towards the parent or to the reward, it may be helpful to ask the parent to slightly lean to the opposite side of the test direction.
- Avoid long stimulus presentations (4 seconds or over) due to the likelihood of false positive responses, and long reward presentations (4 seconds or over) due to the increased likelihood of habituation to the reward.
- 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.

4.2.7 Common mistakes in 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)

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- Tester response bias e.g. tester believing that the child's hearing is satisfactory leading to lack of objective interpretation of turns vs. checks, or repeated presentations at lower levels which have already been excluded as meeting criteria for MRLs.

4.2.8 Reliability

The overall reliability of the test shall be commented upon on the results sheet/report (e.g. good, fair, poor). Test reliability shall be assessed by both a subjective judgement of response repeatability, and by the use of 'no sound' trials. A 'no sound' trial is a point in time during hearing assessment when a sound would have been presented, but instead the child's reaction is observed without sound presentation. This is in order to evaluate the probability/likelihood of the child producing false-positive responses. The outcome of no-sound trials shall be recorded on the tick-sheet. Where an infant responds to a no-sound trial, another no-sound trial should be presented before continuing with the test. For test results to be considered valid, the overall number of false positive responses to no sound trials throughout the whole test should not exceed 30%, which has been shown to be an appropriate cut-off for test validity (Norrix, 2015; Widen et al., 2000). The tick sheet or recording materials shall be kept as part of the child's record as a measure of validity and for the purposes of peer review (see Appendix D for examples).

4.3 Minimum Response Levels

4.3.1 MRLs for Inserts

For insert earphones, the frequency-specific correction factors are derived from studies using children with normal hearing, examples of which are presented in Table 1. Parry et al (2003) employed a VRA protocol similar to that described here, and the study was conducted on 8–12 month old infants with normal hearing. Nozza (1995) and Nozza and Henson (1999) studies were conducted on infants aged 6–11 months.

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 (2003)	16.4 (5.9)	13.3 (6.1)	7.1 (5.5)	6.4 (6.2)
Recommended correction value	15	15	5	5

Table 1 Comparison of MRLs in infants for insert earphone VRA studies, in children with normal hearing.

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The normative values presented in Table 1 may be used as correction factors by subtracting these values from the MRLs to provide the estimated PTA hearing threshold levels. 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. These studies have only been carried out on infants with normal hearing, therefore it is possible that the correction factors may differ for children with sensorineural hearing impairment or older children. Further research in this area is encouraged (see Appendix F).

4.3.2 MRLs for Other Transducers

No studies have been identified that provide reliable 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.

It has been estimated that normally hearing infants (<12 months) present mean threshold at approximately +10dB relative to adult thresholds (from 0.5-4KHz) when tested using VRA in the soundfield. Review of the literature, however, has not provided an evidence-base for this widely accepted value. Based upon this +10dB value, 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 in at least the better hearing ear. Testing to 25 dB HL, rather than 30 dB HL, allows for uncertainty regarding the +10dB value and ensures that the MRL is within the range of normal hearing thresholds, rather than at the limit of normal. Such guidance should not discourage testing down to lower levels, ambient noise permitting. Those professionals interpreting and reporting results shall be mindful that sound-field assessment only indicates the hearing status of the better hearing ear at each test frequency.

4.3.3 Masking

The use of masking requires the tester to know the effective masking level of the non-test ear. This is equal to the tonal threshold of that ear at that frequency (BSA, 2018). When testing with VRA we are measuring the MRL, rather than threshold. As studies on conversion factors between MRL to thresholds for using inserts in normal hearing children have only been conducted with children up to 12 months old there are many children for whom there is no agreed conversion factor. Using the MRL rather than the threshold as the starting level for masking could lead to erroneous results. There is also indication that transcranial transmission for children may occur at lower levels than that expected in adults when testing with insert earphones (Young and Milchard, 2022). Due to these ambiguities, it is advised that masked VRA is only attempted by experienced testers who understand these potential factors. If a plateau is achieved by masking, the results may be informative but must be interpreted with caution. Where a plateau is not found, cross-masking may be occurring, therefore the tester must not assume that an increasing response level is indicative of a sensorineural hearing loss.

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5. Interpretation of Results

Typically MRLs are not corrected when they are used for calculation of hearing aid prescription formulae. Correction of raw MRLs obtained by insert earphone VRA could be applied at the clinician's discretion however further research is required to determine whether this should be standard practice (see Appendix F).

5.1 Recording and Reporting

Reporting of the results shall 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 shall be taken in reporting results to other professionals who may be more familiar with interpreting thresholds rather than MRLs.

The records and reporting of results shall 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 shall indicate whether recorded levels are MRL or corrected to provide estimated adult thresholds.

Other factors that may have impacted on the reliability of the test shall be recorded/reported e.g. the alertness state of the child (drowsy /sleepy, overactive/overexcited, vocalising). The reader is directed to 'Uncertainty of Measurement in Audiology' (British Academy of Audiology, 2022b) for further consideration of reporting reliability of results and considerations to minimise variability in test measurements.

Recommended symbols for recording the results of sound-field testing are given in Appendix E. Symbols for inserts or headphones shall follow the BSA (2018) procedure for recording PTA, with clear indication of which transducer was used on the audiogram. For not-masked results where 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 such audiogram symbols are not available, an alternative is to refer to minimum levels tested in the narrative directly accompanying the audiogram.

Where recorded results represent the MRLs, this shall always be clearly indicated in the comments/report 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) shall be indicated. Consideration shall also be given to

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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.

Finally, guidance on the matter of MRL to adult threshold corrections may change with the outcome of further research. The use of this (standardised) protocol in further research studies about VRA would allow for research results to be collated and compared (see Appendix F).

6. Calibration

Stimuli presented through headphones, bone vibrator or insert-earphones shall be calibrated in accordance with the relevant international standards (BS EN ISO 8253-1, BS EN ISO 8253-2), in dB HL in order to present unified documentation of the audiogram.

Loudspeakers shall be positioned at 90° azimuth relative to, and at least 1 m from, the test position to each side (BSA, 2019). The speakers shall be approximately level with the child's head, to maintain calibration and for efficient conditioning of the head turn behaviour.

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 by loudspeakers is accurate and stable. The reader is referred to the specific guidance provided on calibration and ambient noise in BSA (2019) particularly in relation to the use of static systems as employed in VRA.

Daily visual examination and listening checks shall be carried out and documented (Stage A check). The checklist described for pure-tone audiometry (BSA 2018) shall be used with additional checks of reinforcers and between-room communication systems. These 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.

In addition to annual full calibration (Stage B) against the standards, calibration shall be carried out when any major changes are made (e.g. to room layout) or when changes in external noise levels occur. Following BSA (2019), the test environment shall be clearly documented with a defined layout of furniture, furnishings, equipment and positions for people in the room during testing. Marks shall be made to floors and/or ceilings to ensure that layout and positions remain consistent as any deviation may compromise calibration. It must be clear to all testers whether narrowband noise stimuli on any given system has been calibrated for threshold testing (dB HL) or for masking, and testers do not use stimuli that have been calibrated for masking (see Appendix C).

7. Hearing Protection

Regulations stipulate daily personal noise exposure levels beyond which hearing protection shall be used (Health and Safety Executive, HSE, 2019). 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 shall be available to the employee and parents/guardian. If daily noise exposure is beyond the second action level, or if any peak levels

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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. Hearing protection (muffs and /or plugs) shall be available for parents and observers as well as testers. The maximum output at each frequency shall 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.

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Appendix A: Suggested Single Room Layout

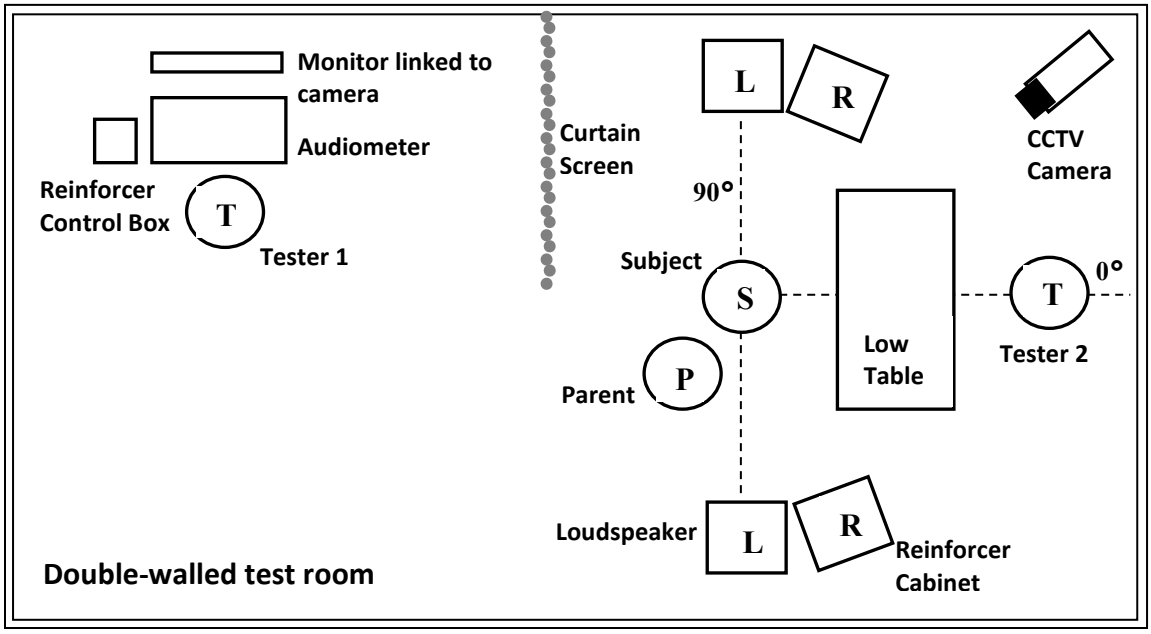

Figure A1: *Recommended layout of test area if using single-room format.*

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Appendix B: Useful Equipment

With all seating the tester must consider the calibration height of the speakers if performing soundfield testing. The child's head must be at the calibration position, otherwise the alternative seating can only be used if testing with transducers i.e. not for soundfield testing. These are just a summary of potential equipment and are not to be seen as an endorsement or recommendation of a particular manufacturer. If a child is not seated on the parents knee care shall be taken to ensure that they are able to sit in a chair safely without risk of falling off.

Height Adjustable Horseshoe Classroom Table

Horseshoe Chair

Chair with Adjustable Arms

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Highchair

NB Reflective surfaces should be kept to a minimum. For example tray tables on high chairs should be removed and high backs (extending above the patient's head) should be avoided.

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Appendix C: Test Adaptations

Narrow Band Noise (NBN)

Important notes when using NBN:

- NBN for estimating thresholds shall be calibrated in dB HL not dB effective masking level (in order to avoid under-estimating hearing loss by 5–10 dB)
- 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
- 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. FRESH noise that is more frequency specific and hence provides more accurate estimation of thresholds with steeply sloping hearing loss may be available on some audiometers.
- There shall be a clear note on the test sheet as to which stimulus has been used if warble tones have not been used.

Non-traditional sounds

Non-traditional and band filtered sound files can be used as an alternative to warble tones in the conditioning phase of VRA, as they may be useful for children that prove difficult to obtain results from using conventional methods.

Interesting or familiar sounds such as nursery rhymes may attract a child's attention for longer, resulting in more success in conditioning and testing children with complex needs (Young, 2020). Anecdotally using familiar rhymes as a stimulus, possibly associated with a matching reinforcer, makes the hearing assessment less intimidating and stressful for the child.

While passing sounds through a band pass filter can restrict the sound energy to a narrow frequency range, the final frequency specificity of the sounds will depend on the exact filters and software in use. Furthermore, the dynamic nature of the signals precludes a straightforward calibration based on existing RETSPLs, and further research is needed to define optimum calibration procedures and how to interpret threshold measurements based on such dynamic signals (see Appendix F). In addition, different sound stimuli will have meaningful content in different frequency bands, which may mean that under certain filtering conditions the stimuli are no longer recognisable, hence losing the benefit that might have been obtained with a wider-band stimulus. With that in mind, this document recommends that non-traditional and band pass filtered sounds are used for **conditioning only**, and not for MRL measurement unless all other approaches to use standard sounds have been exhausted. Strategies such as switching engagement toys, having a variety of reinforcers, enough breaks during testing, using praise and encouragement, can help the clinician transition to standard stimuli.

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Where it has not been possible to transition the child to standard test stimuli for MRL testing, the tester may choose to pursue MRL testing with non-standard sounds. Such results may help guide management but must always be interpreted with caution until further evidence is available, including standardisation of filtering procedures. Results using non-standard sounds should not be the sole basis of significant management decisions such as the decision to discharge a patient. When responses to band filtered sounds are obtained, the following wording is suggested when reporting the results:

"Responses were obtained to familiar tunes at quiet (change as appropriate) levels today; however, this result is not able to give us any detailed frequency or ear-specific information in relation to (insert child's name) hearing."

With further research it may be possible to use filtered stimuli for frequency-specific threshold estimation, using defined filtering and checking procedures, and reporting results with given confidence limits.

The Ling 6 sounds may be used for testing where available and may be useful for assessing aided functional hearing. Results should be interpreted with particular caution, since there are limitations to the availability of dB HL calibrated versions of the sounds (Glista et al., 2014, Scollie et al., 2012).

Use of Localisation

Whilst formal testing of localisation should not be used as a substitute for ear specific testing, testers may incidentally notice that a child has difficulty localising during the course of the test.
This 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.

Adaptations for partially-sighted patients

- Bring reward closer to the child. (Whilst being mindful that changes of the furniture may affect the soundfield calibration. It would be preferable to condition and test with ear-level transducers to avoid soundfield calibration inaccuracies.) Use contrasting visuals e.g. contrasting coloured objects (black toy on yellow background). Dim room lights.

- Use a stronger reinforcer such as a flashing light.

Adaptations for severely visually impaired patients

- Use alternative sensory reinforcement (i.e: air puffs / vibrotactile)

- Use sensory toys to engage / distract the child (i.e: plasticine, water)

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Adaptations for Patients with Autism

- Each individual with autism will have their own preferences and tolerances, therefore adaptations need to be patient-centered. Finding out this information in advance of the appointment may help the clinicians to prepare a more suitable testing environment for the patient.
- Use a social story (i.e. pictures of otoscope, transducers) to help the child understand what to expect sequentially e.g. what is happening 'now' and 'next'.
- Find out in advance what is interesting to the child, and what distresses the child, and where possible tailor distraction and rewards appropriately.
- Find out in advance whether the child has any hypersensitivity to sounds. Consider lower conditioning intensities for these children and it may be appropriate to drop quickly to minimum test intensities once conditioning has been established.
- Children with autism may habituate quickly, therefore try a range of stimuli. It may be necessary to "jump" between frequencies to keep their attention.
- Try to have a range of seating options to identify what is most suitable (this may help with sensory integration) providing that the child's head is still positioned at the calibration point.. during soundfield testing
- A range of sensory toys may be helpful to calm and engage the child e.g. fidget spinners. Many children will settle whilst watching a phone or tablet device. If this is used the sound shall be turned off. The tester needs to use their judgement with regards to using the device to settle the child versus the upset it may cause if the child becomes too engrossed and the toy or device must be removed. With individuals who prove to be challenging to test, the clinician should be prepared to be flexible and deviate from standard procedure, whilst understanding the limitations of doing so. This is recommended for experienced clinicians only. Where there has been a deviation from standard procedure this shall be noted on the test form

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Appendix D: Response recording materials

Example Tick Sheet

Visual Reinforcement Audiometry Results Form

Patient Name: **Hospital No:** **Date:**
Tester 1:
Tester 2:
Test condition: Aided/Unaided
Comments on reliability and/or any deviation from BSA protocol:

Key:
Y = response (full head turn towards reinforcer unless otherwise indicated) X = no response ? = uncertain C = Conditioning SF = Sound field BC = Bone Conduction
R = Right insert/headphone L = Left insert/headphone

Freq (Hz)	500				1000				2000				4000				
Transducer	SF	R	L	BC	SF	R	L	BC	SF	R	L	BC	SF	R	L	BC	
0																	0
5																	5
10																	10
15																	15
20																	20
25																	25
30																	30
35																	35
40																	40
45																	45
50																	50
55																	55
60																	60
65																	65
70																	70
75																	75
80																	80
85																	85
90																	90
95																	95
100																	100
105																	105
110																	110
115																	115
120																	120
Minimum Response Level (dBHL)																	

No Sound Trial	1	2	3	4	5	6	7	8	9	10		Total X	
Response												% X / Total Trials	

No sound trial criteria: "stimulus presentations" (e.g. pretending to press button) should occur during testing at appropriate times (i.e. when infant/child is well settled and would normally present stimulus). Record Y/X responses. For test results to be considered valid the child should not respond on at least 70% of the 'no sound' trials (i.e. % X/Total Trials should be ≥70%). Additional columns can be added as required.

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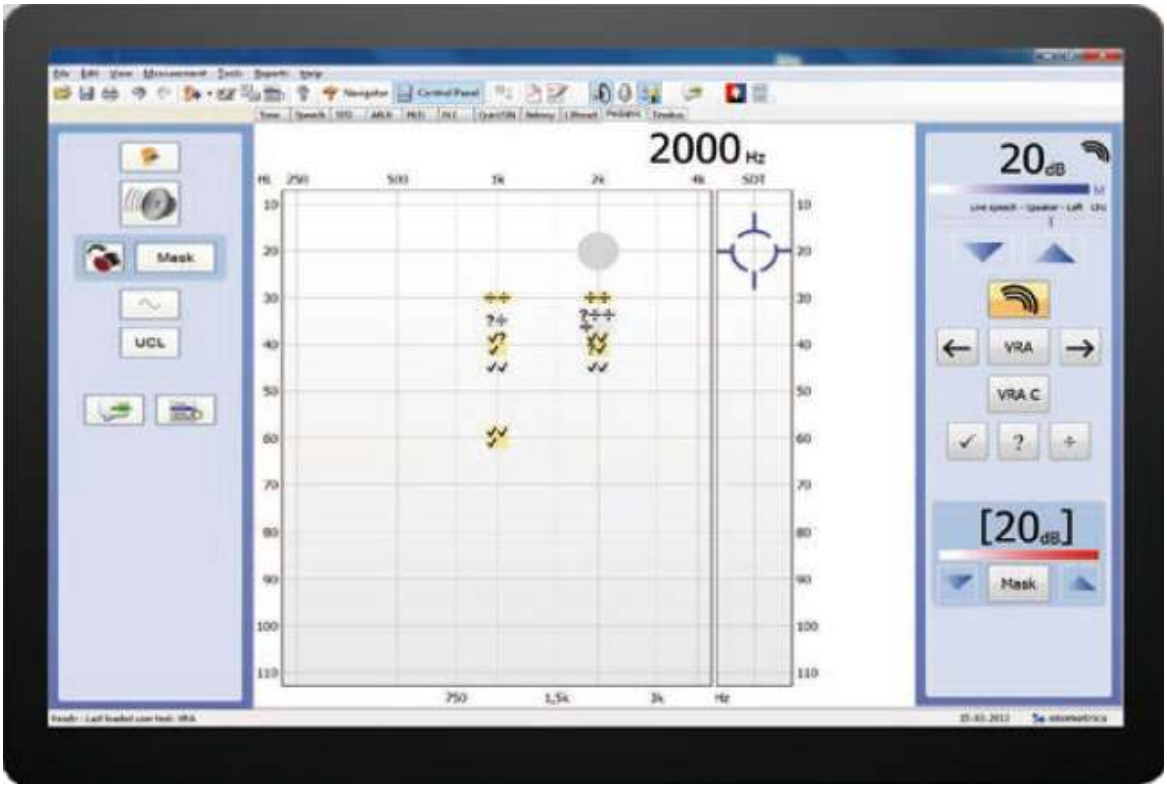
Automated tick sheet



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Appendix E. 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 binaural. Unaided monaural results shall only be measured using ear-specific transducers rather than occluding the non-test ear and continuing to present stimuli in the soundfield. In the case of aided 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 shall 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
Binaural soundfield, unaided	S
Monaural, left ear aided	
Monaural, right ear aided	
Aided – record in comments whether this is monaural or binaural aiding and aid type.	A

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.

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Appendix F: Summary of Recommendations for Further Research

MRL correction factors

Recommended correction factors for insert phone MRL to estimated adult hearing threshold come from a limited number of studies on infants with normal hearing. Further research could expand upon estimated correction factors for infants with sensorineural hearing loss, and at a variety of ages, and for different transducers. This may in the future affect the recommended minimum test intensity to correspond to satisfactory hearing, which is currently given as 20 dB HL (for 0.5-4 kHz) when presented via inserts, headphones, or bone conduction. Furthermore, evidence as to whether absolute or corrected hearing thresholds are most appropriate for treatment and management of infant hearing loss is needed.

Reliable evidence could not be found to support specific correction factors for sound field testing. Such evidence would be of value, for example to support the assertion that 25 dB HL in the sound field corresponds to satisfactory hearing. However the challenges of testing infants in an environment that is suitable for sound field testing at very low levels is acknowledged. I.e. such testing would typically take place in a soundproof and anechoic chamber. Participant generated noise is difficult to control, as is VRA testing in such an environment. Expected sound field correction factors could be modelled based on known factors about ear canal acoustics, bilateral listening advantage, and the research available on MRL correction factors using inserts.

Use of non-standard acoustic stimuli

Anecdotal evidence supports the benefits of using non-standard acoustic stimuli such as filtered TV theme tunes / nursery rhymes to help engage infants in VRA testing when testing with standard signals has been unsuccessful. However, further research is needed to better understand in what cases such deviations from protocol are most beneficial. Furthermore, research is needed to define the optimum filtering and calibration procedures in order to be able to glean useful diagnostic information (i.e. to confirm satisfactory hearing or estimate thresholds for hearing aid prescription) from these non-standard tests. Research in the particular types of sounds that are suitable for VRA testing across different frequencies is also warranted, including whether personalisation of the content (e.g. using a parent's voice) is valuable.

Different types of (visual) rewards

It is not clear from the evidence base what types of visual reward (predominantly lighted mechanical toys versus videos) are the most successful for obtaining reliable VRA responses, though it is clear that variety and complexity of reward help to increase response behaviour. Further research to more clearly understand what features of visual rewards are most beneficial in different populations could be of benefit. This could also include whether personalisation (e.g. a parent's face) is beneficial.

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Complex needs

There is minimal literature comparing the benefits of specific VRA adaptations for patients with complex needs. This is an area that would benefit from further research and sharing of best-practice.

Peer Review

Peer review is an essential tool for ensuring quality and accuracy of VRA testing, but there is currently limited evidence regarding the most effective and feasible methods for this process. This is a further area which would benefit from research and sharing of best-practice.

Masking

Reliable procedures for masking in VRA have not been described in detail. Further work could determine all the factors that would affect this type of testing, and the implications for testing (e.g. access to calibrated masking stimuli, determination of effective masking level, implications of variable transcranial transmission in infants with different transducers, potential impact on attention).

Replication of previous findings

Some of the evidence reported about benefits of certain techniques in VRA (e.g. effect of duration of signals and reinforcers) is based on only limited or single studies, often from some time ago. Further research to investigate such optimised test characteristics and response characteristics would also be valuable.

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