BIAP Recommendation 12-8
Audiometric procedures in the first year of life
Part: 12-8.2: Visual Reinforcement Audiometry (VRA)

General foreword

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Recommendation

Starting at the developmental age of 5 to 6 months, the child's spontaneous and un-conditioned reactions to sounds in the Behavioural Observation Audiometry test (BOA, see Part 12-8.1.5) can be expanded to even more reliable and consistent conditioned reactions. The most widely used approach utilises a conditioning scheme of highly attractive visual reinforcers to reward a correct head-turn response to the test sound. Through Visual Reinforcement Audiometry (VRA) an experienced audiologist is able to obtain reliable conditioned hearing reactions of a hearing-impaired child in its second half year of life, within 0 to 10 dB of to its true hearing threshold. For normal-hearing children their hearing threshold reaction in VRA can be expected within 0 to 20 dB_{HL}. The key to an early subjective measurement of the child's hearing threshold is an optimised setting for the VRA.

Under the right conditions, VRA can be used to:

- establish a reliable tone audiogram (air conduction and bone conduction) for each ear, supplementing an already existing frequency-specific ABR threshold or making up for the second ABR usually used for a confirmation of the hearing threshold in the second half year of life.
- evaluate further a conductive hearing loss in case of middle ear problems.
- monitor hearing sensitivity over time.
- provide the frequency-specific basis for the hearing aid-fitting algorithm.
- measure the functional benefit of amplification.
- facilitate the frequency-specific fine-tuning of hearing aids.

The foundations of VRA go back to a publication by Suzuki and Ogiba (1960), and today's VRA procedures are based on a publication by Wilson and Thompson (1984). However, the practical realisation of VRA in different parts of the world have developed differently. This recommendation concentrates on the Anglo-American concept, as evidence shows that it provides a reliable hearing assessment for young children, beginning at the developmental age of 5 to 6 months up to approximately 24 months of age. At this age, many children start to lose some interest in VRA, so for children with a developmental age of more than 24 months it is the aim to teach them the principles of play audiometry.

VRA procedure

The technical set up:

VRA is a sound-detection procedure in which a consistent head-turn response following the presentation of an audible test signal is rewarded by a pleasurable (positive) reinforcer. So a test sound that is otherwise “unattractive” to the child will cue the child that a behavioural response in the form of a unidirectional head-turn will provide them some entertaining reinforcement.

- The reinforcer (visual reward) has to be age-appropriate appealing: for children less than one year of age a colourful, animated, moving, three-dimensional toy is much more attractive than the display of a picture.
- The sound of such an animated toy can make it even more enjoyable (at least for the children who can still hear the sound). Any sound of the toy normally does not interfere with the test procedure, as the toy is only activated after the turn of the child's head in response to the primarily presented test sound. Still some professionals prefer to work with silent reinforcers (toys), so some equipment provides the choice of activating the toy with or without sound.
- The animated toy must be hidden in a box with a smoked Plexiglas front, so that it is only visible to the child when it is activated and illuminated. The vanishing and reappearance of the toy makes it even more attractive to the child. This also helps to prevent the child from searching for the toy during the silent intervals.
- To keep the interest of the child as long as possible it is advisable to use more than one toy reinforcer.
- The box with the toy has to be placed at an angle of 90°, so that the child has to perform a distinct head-turn to watch the reinforcer.
- The box with the toy should be placed next to the speaker that is initially used when starting the test procedure, so that the child’s spontaneous reaction to the first few supra-threshold sounds direct the child automatically to the reinforcer.
- For the primary task of establishing a reliable hearing threshold, a unilateral placement of the reinforcers is sufficient. The child will learn that the correct response to the test sound is the uniform head-turn to one side, which is then rewarded. The conditioned head-turn in the VRA procedure needs just a single decision by the child, whether there is a test sound or no test sound. This should be clearly differentiated from the orientation reaction, where the child has to make a second decision, whether there is a sound and from which side the sound is coming. This second decision can delay and confuse the child’s reactions in a threshold-seeking procedure. Orientation reactions should therefore not be part of the VRA procedure.

- If one places reinforcers on both sides (in spite of the above-mentioned considerations), one has to reinforce any correct (test-sound related) head-turn from the middle to either side, irrespective of whether it is the orientation to the speaker from which the test sound came.
- It is necessary to ensure that there are no other distractions in the visual field of the child. To gain the interest of the child in the visual reinforcer more easily during the conditioning process, and to make the visual reinforcer even more impressive, the lighting of the test room should be dimmed.
- The toys should be replaced regularly to surprise the children with a different toy at their next appointment.
- For a very experienced examiner the above-mentioned procedure can be managed by one person, but it is very helpful and therefore recommended to perform the testing with two examiners, even when the examiners and the child are in the same test room. With two examiners the first controls the audiometer and the presentation of the sound, and the second is responsible for orientating the child back to the middle, when the visual reinforcer has stopped, and to maintain the alertness of the child.
  With two examiners it is also easier to observe all the reactions of the child to sounds but also to interfering stimuli, such as visual stimuli, influences from the caretaker, distractions in the room or child-related distractions (such as playing with their own hands, bowel activity ...). After the testing, the two examiner-concept allows an exchange of their observations and judgment about the validity of the measurement.
- Especially with difficult-to-test children it can be very helpful to video-document the child's hearing reactions. Then the hearing reactions can be analyzed a second time after the examination and the video can be also shared with other experienced examiners or the multi-professional team, and can be used in the counselling of the parents.
- Besides optimizing the setting of the VRA procedure, the interest of the child may also depend on the type of the test stimulus. Usually a warble tone or narrow band noise is more interesting for the child than a pure tone.

Alternative visual reinforcers:

- Especially for children older than one year, video clips instead of the animated toys can be used equally successfully, but the video has to be as awesome as possible for this age group:
  - The video screen has to be big enough.
  - Good contrast of light between the video screen and the lighting in the test room has to be ensured. Therefore, it is highly recommended to dim the lights of the room.
  - The video clip itself has to be bright and colourful. It should include some movements and present a short scene of action.
  - The video clip should only last around 5 to 6 seconds.
  - As with the animated toys, playing the sound of the video can make the video even more attractive to the child.
- Especially for some multi-handicapped and visually impaired children, an animated toy or a video clip can be already too complex. For them a brightly flashing light (like

the blue flashing light of a police car or fire engine) might be still very attractive especially when it is presented in a room with dimmed lights.

- Some (very few) children might react anxiously to any unexpected moving object (toy or video clip). For these children it can be very helpful if the illumination and the activation of movement of the toy can be switched on separately, so that the toy can be just illuminated without making any movements.

Alternative use of tactile reinforcers:

- Blind or severely visually impaired children, as well as some severely mentally handicapped or autistic children, cannot be attracted by the above-mentioned visual reinforcers. For them one can try to use a tactile reinforcer such as a short puff of air from a bottle of compressed air or a powerful hairdryer (Air Puff Audiometry).
  The strength of the air puff has to be adjusted to the needs of the individual child. Some children enjoy a stronger air puff and start already smiling in reaction to the test sound anticipating the rewarding air puff. Other children may try to avoid (turn away) from an even softer air puff, when they hear the test sound.
  If these reactions, when anticipating the air puff after hearing the test sound, are consistent, these reactions can also be used to estimate the hearing sensitivity of these children.
  For some of these severely handicapped children their daily environment and their ability to react to their environment can be very limited and dull, therefore the air puff audiometry can be a surprisingly interesting and stimulating experience for them. So it can provide the basis for obtaining any repeatable and consistent reactions over a limited period of time.
- Another tactile approach developed especially for autistic children is the TOUCH procedure, utilizing a vibrating reinforcer (plus some elements of play audiometry), which can give the autistic child the opportunity to have an influence on the progression of the test. For more information, see the publications by Roger Verpoorten, A Touch Procedure: Tactile Auditory Conditioning, Procedure for the Hearing Assessment of Persons with Autism and Mental Retardation.
- For some multi-handicapped children none of the above described procedures is motivating enough to maintain contingent hearing reactions. So the professional in collaboration with the parents has to try to find a creative individual solution utilizing something that the child likes very much, which could be used as a reward (e.g. gentle petting of the child's hand, moistening the child's cheek, providing a favorite food …).

VRA clinical test protocol

As the attention span of a child is limited, it is the goal to find as quickly as possible an optimum (lowest) start level for the initiation of the threshold search. On the basis of data by Tharpe, Ashmead and Widen, 1993, Judith Gravel suggests starting with a 500 Hz stimulus at 30 dB_{HL} in a free-field condition. If that leads to a head-turn to the loudspeaker, this head-turn is reinforced by a second stimulus of the same intensity. If that leads again to a prompt head-turn, it is reinforced and the threshold search can begin.

If no response occurs after the two stimulus presentations of 30 dB_{HL} the signal level is increased in 20 dB steps until the child shows a head-turn to the loudspeaker, which is rewarded by the reinforcer. After two correct reactions at the same level the threshold search is started. In the initial threshold search with very young children it is recommended to use

10 dB steps for the up and down threshold search procedure. Whenever possible sound field thresholds between 500 Hz and 4000 Hz should be obtained.

For a child under good stimulus control in the VRA procedure (showing contingent response behaviour) in the free field, the same procedure can also be used for a bone conduction measurement and a threshold search with insert earphones. If there are no contraindications, the measurement with insert earphones should start with the ear closest to the visual reinforcer.

In case the child does not react to a maximum free-field stimulus of 80 dB_{HL}, it is necessary to teach the infant the head-turn through a classical conditioning approach with a bone conductor and narrow band noise of 250 or 500 Hz, which is loud enough for the child to feel the vibration.

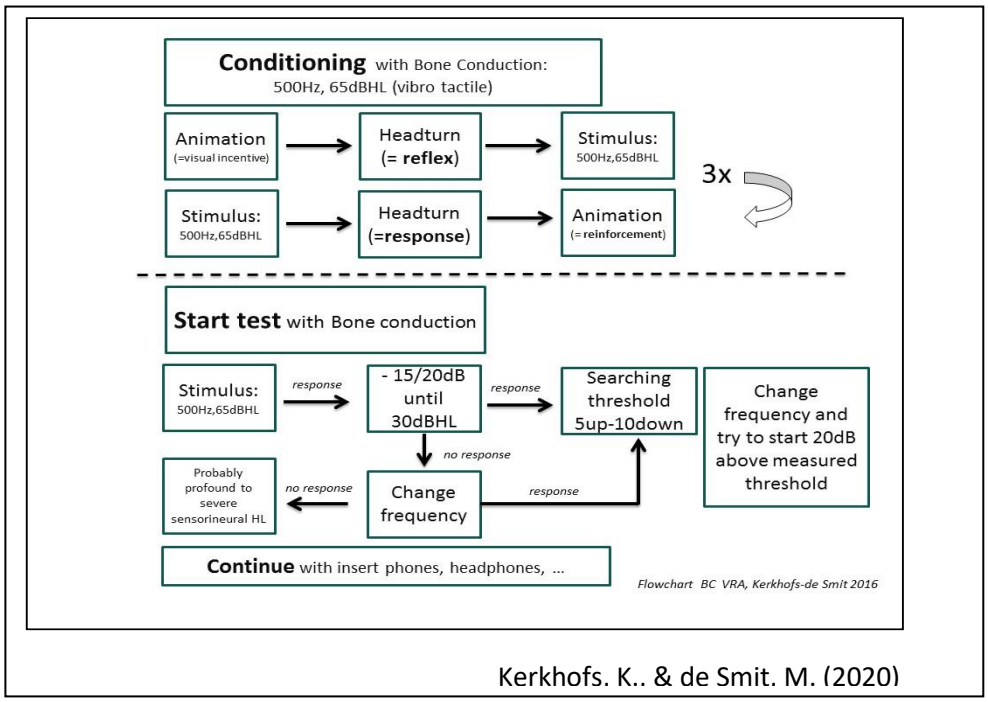
In later audiological appointments the hearing threshold can be confirmed by measurements with a smaller step size of 5 dB.

If the child is reliably reacting to the VRA procedure ("being under good stimulus control") it is also possible to introduce masking. The infants can learn that the continuous, and not a changing, broadband masking noise is not the intended trigger for a head turn, and that they are still obliged to react to a single-frequency test stimulus, and be rewarded for it.

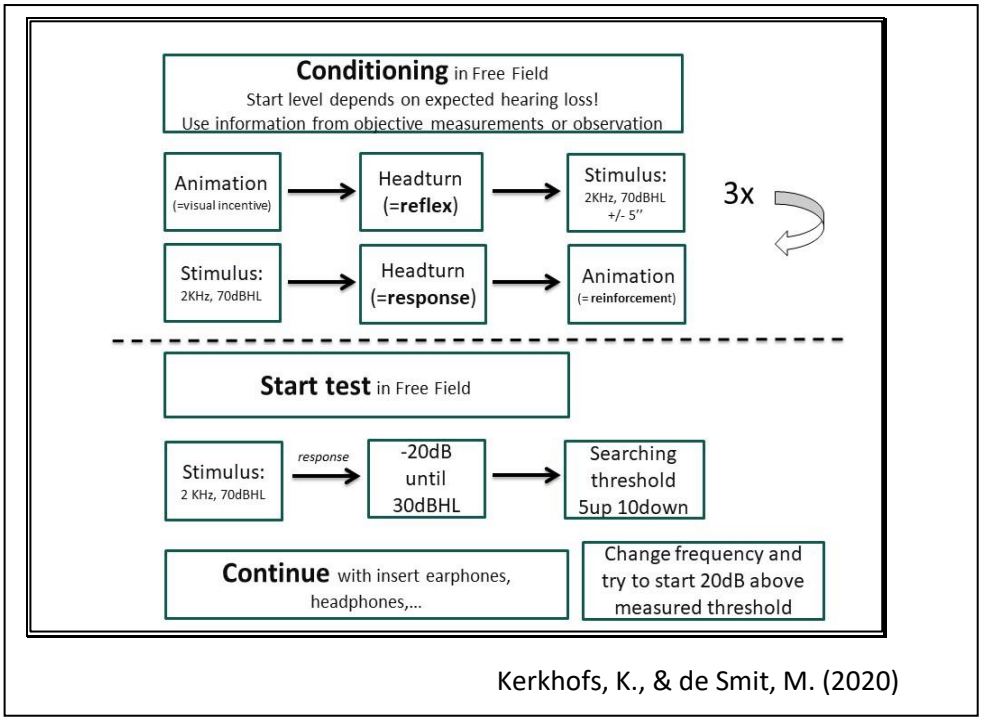
Another approach, which is used in some European countries, is to start from a stimulus that will certainly be perceived by the child. To find this starting sound pressure level, which is well audible to the child, it is necessary to have prior information from other measurements (such as ABR) and observations on hearing reactions in daily life. If no information is available, which sound pressure levels should be clearly audible to the child, one has to start with bone conduction on a vibrotactile level such as 65 dB_{HL} at 500 Hz. Starting with bone conduction is anyway an interesting option, as bone conduction results will not be affected by middle ear ventilation problems but will reflect directly the hearing by the inner ear. After the bone conduction measurement one should have enough information to continue with the measurement with insert earphones or headphones, which will provide ear-specific, air conduction threshold data. For this approach a test protocol could be (see also the flowchart below):

1. Activate the visual reinforcer, expecting a spontaneous head-turn of the child to the visual reinforcer, then turn on a well audible 2 kHz test-sound (see considerations above), so that the child may get a first idea that the visual reinforcer and the test sound are connected. To familiarise the child with the visual reinforcer and the test sound, one can also present them simultaneously. Repeat this conditioning circle three times.
2. Then present the test-sound first and activate the visual reinforcer after the child has shown the head-turn. If the child reacts consistently, you can proceed with the measurement.
3. To introduce the threshold searching procedure, reduce the level of the test sound in 20 dB steps until the child no longer demonstrates the head-turn or you have reached 30 dB. At 30 dB continue with the 5 dB-up and 10 dB-down protocol to specify the threshold.
4. After establishing the procedure for one frequency under free-field conditions, try to proceed with headphones (preferable with insert phones).
5. If you want to or have to start with the bone conduction measurement you can follow the same principles (see the bone conduction flowchart).
6. In case the child refuses any contact with a bone conductor or a headphone, it will be necessary to measure the hearing threshold in different frequencies under free-field conditions. Free-field conditions also allow the measurement of the hearing threshold

with a hearing aid or a cochlear implant and determining the functional gain of the devices.



Kerkhofs. K.. & de Smit. M. (2020)



Kerkhofs, K., & de Smit, M. (2020)

VRA and the fitting of hearing instruments

Reliable hearing threshold results fromVRA in the second half year of life provide the opportunity to fill in missing threshold values for each ear across the speech frequency range that were not obtained by the ABR measurement in the beginning of the hearing

assessment. To acquire data that closely approximate the actual sound pressure level at the infant's eardrum, it is highly recommended to use insert earphones. In most cases the insert earphones are also less irritating and therefore better accepted by the child, especially if they can be attached to the child's individual earmoulds, as the child is already accustomed to wearing the earmoulds with its hearing aids. Some infants may also tolerate the measurement with insert phones better when they are allowed to keep on their hearing aid on the contralateral side, so that the child stays acoustically connected to the world around.

The threshold data obtained with insert earphones can easily be used within the child-specific prescriptive hearing aid fitting procedures such as DSL. [See also BIAP Rec 06-11 Hearing aids for children in the first year of life + Annex 1: Insert Earphones + Annex 2: RECD measurements and the SPLogram.]

A well-established cooperation of the infant in the VRA procedure also provides the opportunity to monitor the hearing development over time and to document the hearing aid benefit for soft sounds through an aided threshold. The aided threshold can be also a valuable tool to demonstrate the hearing aid benefit to parents and caregivers. But the aided threshold alone is not sufficient to validate or verify an appropriate hearing aid fitting. For the verification process a percentile measurement or SPLogram is necessary to ensure the audibility of the speech spectrum [see above the reference to BIAP Rec 06-11].

VRA potential pitfalls

To prevent an invalid test result due to false positive responding is the biggest challenge in using the VRA procedure. After some experience, it may be easy to teach an infant the head-turn, but the hard part is teaching the baby when not to turn.

To limit the number of head-turns that are not related to the test sound, it is necessary to present the test sounds with variable silent intervals in between. The test sound should never be presented in a rhythmic fashion, otherwise the child can follow this rhythm without the need of detecting the test sound. In addition to varying the silent intervals between the test sounds, one must also insert silent "control-trials" (instead of audible stimulus). The control-trials should comprise up to 25% of the overall trials.
One should also keep in mind that the individual response time, which a child needs to react to an acoustic stimulus, can vary, especially for children with additional disabilities.

To control the validity of the measurement, ideally, a record of responses to each trial (with the stimulus and without a stimulus) should be documented, so that a false alarm rate can be calculated. A false alarm rate of more than 30% should raise suspicion and one exceeding 45% is indicative of an unreliable test and the test should be discarded. When a test session has to be considered unreliable, the infant should be given a short break until another attempt is made to establish a contingent response.
The examiners have to take any precautions to identify, reduce or eliminate sources of examiner bias and avoid any subtle hints (such as facial expressions, gestures) that might cue the child to show a reaction. The examiners should also be on alert to ensure that the parents not involuntarily prompt the child to show some reactions that are desired by the parents.

VRA as part of an oddball-paradigm measuring the detection and discrimination of speech sounds

The VRA procedure not only offers the key to measuring a reliable hearing threshold but, like hearing threshold testing with masking, it also provides the opportunity to use more sophisticated measuring algorithms such as an oddball-paradigm. In this case the infant

learns not to react to a constantly repeating background stimulus but to react to a seldom occurring deviant stimulus, as in the A§E® (auditory speech sound evaluation) procedure. With such a procedure it is possible to test reliably the detection and discrimination of speech sounds under clinical conditions for children older than 9 months.

The Delaroche-protocol (an alternative to the Anglo-American VRA approach)

Besides the Anglo-American VRA approach outlined above, a different approach is used in the francophone audiological community to assess the hearing threshold of babies and toddlers.

This protocol was developed in the 1980s by Monique Delaroche, in the Department of Paediatric Audiology of the University Hospital Centre of Bordeaux (France).

The protocol by Monique Delaroche become the primarily used method in francophone centres. The method has been the subject of evaluations, international publications and a 7-hour audio-visual montage for teaching (for more details see also the literature references below).

Specific features of "Delaroche-protocol":

I. Diagnostic objectives.

II. Test setup: positioning the baby and nature of the reactions.

III. Testing: Stimulation strategy and Reinforcement.

I – Diagnostic objectives:

1. First, to measure hearing thresholds by bone conduction. The advantage of the bone conductor is that the function of the auditory nervous system can be examined directly, bypassing the outer and middle ear, which are frequently affected in young children and which might mask the real extent of hearing impairment.
   Owing to the transcranial passage, only one bone conduction (BC) is needed to confirm the integrity of the auditory nervous system of at least one ear or the deterioration of both. Therefore, despite limitations in intensity (45 dB at 250 Hz, 60 dB at 500 Hz and 70 dB at 1000, 2000 and 4000 Hz), measurement of hearing by bone conduction is the key stage of the diagnosis.
   In cases of severe and profound hearing loss, the vibro-tactile stimuli (generated by the BC-transducer at a frequency of 500 Hz at 60 dB or 250 Hz at 45 dB) make it possible to awaken the reactions of the baby and to trigger the conditioning process.
2. The protocol allows the hearing thresholds to be measured in each ear by using headphones over the whole range of hearing frequencies (from 250 to 8000 Hz). Moreover, by using the headphones, it is possible to deliver stimulations of up to 120/130 dB, values unattainable for sound field stimulations. Well-adjusted insert earphones can also be used.
3. To compare bone and air conduction (BC/AC) in order to specify the type of hearing impairment: sensorineural hearing loss, middle or mixed ear impairment.

II – Test setup: positioning the baby and nature of the reactions

<table>
<tr><td>Developmental age</td><td colspan="2">< 5/6 months</td><td>> 6 months</td></tr>
<tr><td>Position of the baby</td><td colspan="2">In the arms of a parent,
or in a lounger,
or laid on a small mattress or…

Baby in drowsiness:

Eyelids are still fluttering between opening and closure.

Baby awake:

No third person is allowed to distract, catch attention of or interfere with the baby`s visual field.

Only a motionless object is placed in front of the baby to channel the vision in a given direction.</td><td>Sitting on the knees of a parent.

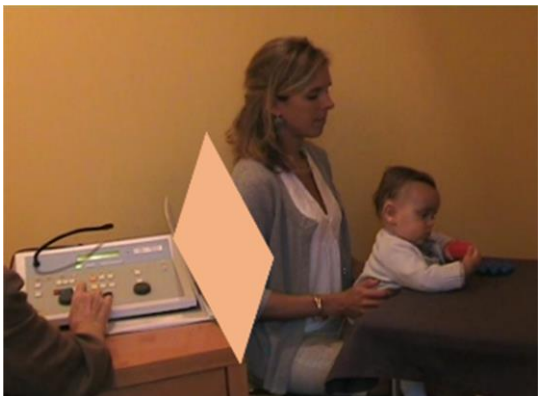
Must not be “on the watch” or in a state of passive expectation. So he is encouraged to play with two or three silent small toys made of foam or soft plastic, arranged in front of him on a felt-covered table.

He must be left to play alone, without the intervention of the parents or a third person.

The toys maintain the child’s vigilance, induce certain stability and channel his vision in a given direction.</td></tr>
<tr><td>Observable reactions</td><td>Various multiform reflex reactions: opening eyes, changes in sucking, in respiratory rhythm…</td><td>Various reflex Reactions, especially

modification in direction of gaze…</td><td>The perception of an unexpected stimulation captures the child’s involuntary attention, leads to a “surprise reaction” and an orientation reflex.</td></tr>
</table>

The baby is laid on a small mattress and no third person is allowed to distract, catch attention of or interfere within the baby`s visual field.



The examiner sits in the cabin where the baby is, but on the side, out of the baby's field of vision and in front of the audiometer. A small screen conceals his manipulations.

When the examiner detects a reaction, he appears in the baby’s visual field and sets up a pleasant interaction.

First test performed in sound field to detect the level of reaction in two frequency ranges:
baby in a booth, examiner in other booth separated by a one-way mirror.

III – Testing: Stimulation strategy and Reinforcement

<table>
<tr><td colspan="2">1. First test performed in sound field to detect the level of reaction in two frequency ranges</td></tr>
<tr><td>< 5/6 months</td><td>> 6 months</td></tr>
<tr><td>Baby and examiner in the same audiometric booth.

In preparation of the real testing the examiner observes the baby’s reactions to 1 or 2 sound-making toys limited to a high frequencies (such as a mini-bell or a maraca).

When reaction/age are abnormal, the examiner estimates the reaction to a toy making a low frequency sound (such as a gong).

The reaction level is estimated by correlating it with distance and intensity.</td><td>Baby in a booth, examiner in another booth separated by a one-way mirror.

The examiner observes the reactions of the child to specific vocal stimulations and records the intensity emitted by loudspeakers:

1. A two-tone whistle corresponding to 2000/2500 Hz
or the onomatopoeic tch-tch corresponding to 3000/6000 Hz.

2. Interjections of a coucou corresponding to 250/750 Hz).</td></tr>
<tr><td>Reinforcement of response

- Baby in drowsiness: no reinforcement.

In case of a startle, stroke the baby to reassure him.

- Baby awake: when the examiner detects a reaction, he enters the baby's visual field, shows him the sound-making toy. This is accompanied by words, gestures, suitable facial expression and touches.

Then he disappears from his visual field and is forgotten before delivering another stimulation.</td><td>Reinforcement of response

When the baby reacts, the tester, who is hiding behind the one-way mirror, pops up, flashes a light and attracts the child’s attention with a facial expression and gestures.

After this interaction the tester disappears until the next reaction giving rise to a new warm interaction.

Thus the conditioning is established.</td></tr>
<tr><td colspan="2">2. Measure Bone Conduction hearing thresholds (BC)</td></tr>
<tr><td colspan="2">The examiner sits in the cabin where the baby is, but on the side, out of the baby's field of vision and in front of the audiometer. A small screen conceals his manipulations.

His position very close to the baby allows him to recognise a good moment for presenting the test sound, to detect even the smallest reaction and to ensure an immediate reinforcement.

- Stimulations used: bi-tonal sounds composed of two pure tones that are half an octave apart. The musical and rhythmic nature of these stimulations makes them very response-inducing.

- Warble or manually pulsed tones can be also used.

- First investigate the high frequency responses: 2000/3000 Hz, 3000/4000 Hz, then 1000, 500, 250 Hz.

- Starting with intensity of 20 dB and increase in 10 dB steps, never increase the volume continuously.

- The presentation of the sound must be short like a "sound pulse".

- If a profound hearing loss is suspected, start with vibro-tactile stimulation: 250 Hz at 45 dB or 500 Hz at 65 dB.</td></tr>
</table>

Reinforcement of response

When the examiner detects a reaction, he appears in the baby's visual field and sets up a pleasant interaction.

This interaction involves exchanges of glances and suitable facial expressions, thus providing the child with a symbolic meaning of the stimulation. For example, the tester may begin to nod his head gently, or make some form of gestural and/or verbal expression in accordance with the type of the stimulus.

This personalised form of reinforcement gives meaning to the perception by triggering a multi-faceted type of communication. The conditioning is thus based on a highly dynamic interplay, which stimulates the child's vigilance.

3. Measure Air Conduction hearing thresholds (AC)

1. First perform a binaural air conduction (the bi-tonal sound being given simultaneously in both ears via headphones)
   - Stimulations used: as for BC.
   - Choice of frequencies and intensities according to the results obtained with BC, in free field, with ABR or ASSR or both.
   - Search thresholds in ascending mode. Increase in 10 dB steps, never increase the volume continuously.
2. Secondly, measure thresholds of each ear separately as soon as possible.

Masking can be introduced, with a suitable procedure, from the age of 14/15 months with a child very well-conditioned by the previous tests.

Same Reinforcement as for the measure of bone conduction hearing thresholds.

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This recommendation was created and approved in multidisciplinary cooperation between professionals of all audiophonologic disciplines, which are medicine, pedagogy, speech therapy, psychology and hearing instrument audiology.

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