Recommended Procedure

Cochlear Microphonic Testing

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General foreword

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

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Declarations of interests

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

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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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Contents

1. Abbreviations

ABR	Auditory Brainstem Response
AC	Air Conduction
ANSD	Auditory Neuropathy Spectrum Disorder
BC	Bone Conduction
BSA	British Society of Audiology
ckABR	Click Auditory Brainstem Response
Con	Condensing (in relation to waveform pressure wave)
CM	Cochlear Microphonic
dBppeSPL	Decibel peak to peak equivalent Sound Pressure Level
ECochG	Electro-cochleography
EPSIG	Electrophysiological Special Interest Group
dBeHL	Decibel estimated Hearing Level (estimated PTA from electrophysiological thresholds)
dBnHL	Decibel normal Hearing Level
NHSP	Newborn Hearing Screening Programme
OAE	Otoacoustic Emission
RA	Response Absent
Rare	Rarefaction (in relation to waveform pressure wave)
RETSPL	Reference Equivalent Threshold Sound Pressure Level
SNHL	Sensorineural hearing loss
tpABR	Tone Pip Auditory Brainstem Response

2. Introduction

2.1 Development of the recommended procedure

This document has been adapted from an earlier document produced by the Clinical Group of the NHSP, entitled 'Guidelines for Cochlear Microphonic Testing' Version 2.0 September 2011. The development of this recommended procedure was undertaken by the members of the Electrophysiology Special Interest Group (EPSIG) and has been developed in accordance with BSA Procedure for Processing Documents (2003).

2.2 Background and aims

The cochlear microphonic (CM) is a pre-neural response from the cochlear outer hair cells which is thought to follow the waveform of the stimulus - it is as though the cochlea is acting as a microphone, hence the term. Like the otoacoustic emission (OAE), when reliably present, it can be taken as evidence of outer hair cell function but cannot be used to estimate hearing threshold.

Auditory Neuropathy Spectrum Disorder (ANSD) is characterised by an absent or abnormal auditory brainstem response (ABR) in the presence of evidence of outer hair cell function (Starr et al. 2001). This is thought to arise when there is a failure to transmit hair cell activity to the auditory nervous system or when there is abnormally poor temporal synchronisation of the signals. For a more complete description of ANSD diagnosis and management refer to the BSA Recommended Procedure for the Assessment and Management of Auditory Neuropathy Spectrum Disorder in Young Infants (BSA 2019). Either an OAE or CM may be taken as evidence of outer hair cell function but note that the presence of one does not guarantee the presence of the other. The presence of a CM using a stimulus at or below a level that does not evoke a recordable ABR, or the presence of an OAE in the absence of any recordable ABR, is usually suggestive of ANSD. A reliably present OAE is evidence of outer hair cell function and CM testing is usually not necessary although having the results of both OAE and CM tests can be helpful benchmarks against which future tests can be compared. An OAE may be absent for a number of reasons (e.g. a conductive component to the hearing loss) so it is important to consider CM testing when the OAE is absent and the ABR is absent or abnormal as defined below. An absent OAE or CM cannot exclude ANSD especially in the presence of a conductive component / unpeaked age appropriate tympanometry. The CM is known to be less vulnerable to the effects of a conductive component than the OAE (since a conductive component affects both the stimulus on the way into the ear and the response on the way out) but a conductive loss sometimes leads to both the OAE and CM being absent. Very occasionally there is a present OAE and an absent CM, which is more difficult to explain and the technical reliability of the OAE should be carefully examined.

It is worth noting that the label ANSD merely indicates the pattern of results, not a single pathology. Accordingly, among these cases will be babies with auditory maturational delay which may resolve, as well as those with a permanent condition.

2.3 Scope

This guidance provides advice on how a CM should be recorded and interpreted and should be read in conjunction with the current version of the BSA document "Guidelines for the Assessment and Management of Auditory Neuropathy Spectrum Disorder in Young Infants", which provides detailed information on other aspects of ANSD, based on the current literature. This CM guidance document has

been written with the newborn population in mind but is also generally applicable to older children and adults, for whom the uncertainty surrounding the level of the stimulus in the newborn occluded ear canal does not apply (see warning, section 7. Calibration).

3. Order of testing

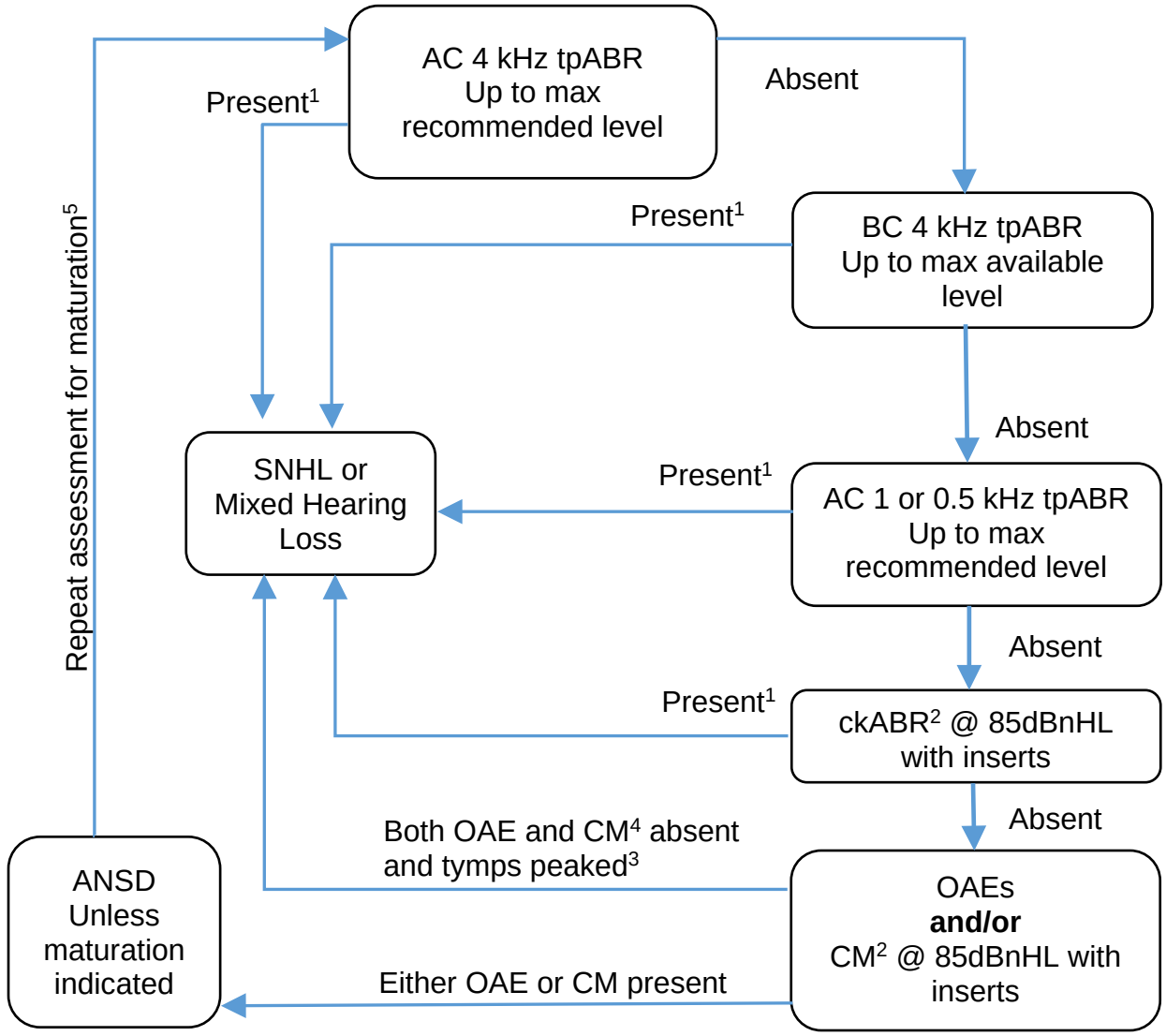
The decision to conduct tests for ANSD should be based on ABR absence at the maximum recommended stimulus level or, in the case of a recordable ABR at or above 75dBeHL having a grossly abnormal ABR morphology (for example no wave V in the presence of wave I or wave III) regardless of stimulus type. Any evidence of a recordable ABR of normal morphology (normal for the stimulus used) makes the likelihood of ANSD very low. Regardless of the presence or absence of ANSD, testing at a lower frequency (e.g. 1 kHz or 500 Hz) will be useful in addition to testing at 4 kHz. This is because absent tpABR responses at 4 kHz cannot exclude an island of better hearing at a lower frequency which could generate an ABR and CM in a "conventional" cochlear hearing loss. It is therefore logical to proceed from air conduction (AC) tpABR[1] at 4 kHz to bone conduction (BC) tpABR at 4 kHz and tpABR at 1 kHz or 0.5 kHz and only if all show absent or abnormal responses (see below) should tests for ANSD be considered.

Although ANSD is confirmed only after ckABR and CM/OAE tests have been performed, it is not necessary to conduct both a ckABR and a CM test if the patient does not have ANSD and the two tests do not have to be conducted in a fixed order. The following examples illustrate the two possible test strategies. Assume for the purpose of these examples that AC 4 kHz tpABR, BC 4kHz tpABR and AC 1 kHz tpABR all failed to evoke a response at the recommended maximum stimulus levels and tympanometry was peaked.

Example 1: Where an alternating polarity ckABR is conducted prior to CM testing: if the ckABR shows a clear response of normal morphology (albeit at a high stimulus level, consistent with a severe high frequency sensory neural hearing loss (SNHL) for example) then no CM testing is needed – this is not a case of ANSD. If a ckABR is absent or has a grossly abnormal morphology then CM or OAE testing is needed. This order of testing is illustrated in Figure 1.

Example 2: Where a CM test is conducted prior to ckABR testing: if the CM is absent (and any current or previous OAE testing also shows no evidence of hair cell activity) then there is no evidence of ANSD and a ckABR is not needed. If the CM is present then ckABR testing is needed to interpret the significance of the recorded CM.

[1] Reference to tone pip ABR should be read as also applying to narrow-band CE-Chirps.



Notes:

1. ABR "present" means identifiable characteristic morphology with expected latencies. If ABR presents with abnormal morphology, refer to section 3.3 Recommended Procedure: Assessment and management of Auditory Neuropathy Spectrum Disorder (ANSD) in young infants, for further guidance.
2. An alternative testing order would be to perform the CM prior to the ckABR, as detailed in example 2 above.
3. If there is evidence of middle ear effusion, ANSD cannot be excluded.
4. The absence of OAE and CM does not categorically rule out ANSD, but when both are absent it is reasonable to assume conventional hearing loss. There are anecdotal reports that in some cases of ANSD the OAE and/or CM can "burn out" with time.
5. See Appendix B of the ANSD recommended procedure for advice on repeat assessments.

Figure 1: Flow Chart to illustrate order of testing.

4. Test parameters

When present, the CM is usually easy to record from babies (but less so from adults in whom the CM is often small and less well defined) using the same surface electrodes and methods for recording the more familiar ABR. General BSA / NHSP guidelines for ABR tests (BSA 2019) should therefore be followed although some important differences are required if the CM is to be successfully and efficiently recorded.

SUMMARY OF PARAMETERS FOR CM TESTING

Electrode Location:	Positive Negative Common	High forehead (as close to vertex as possible, avoiding fontanelle) Ipsilateral mastoid Contralateral mastoid
Stimulus:	Separate runs of Rarefaction and Condensation clicks	Rate: high 80s e.g. 87.1/s Level: 85 dBnHL
Earphone:	ER–3A tubal inserts	Clamp tubing for control run
Coupler value for 0dBnHL:	IEC60126[A1] coupler IEC318-4[A2] coupler	26.5 dBppeSPL 35.5 dBppeSPL
Amplifier reject levels:	±3µV to ±10µV	±3µV recommended default
Filters:	Low (high pass) High (low pass)	100 – 300 Hz 3000 Hz – 5000 Hz
Window length:		8 -10ms (starting at -1ms)
Number of sweeps averaged per replication:		Minimum 1500 Typically 2000
Display Scale:	Default: Small or absent CMs: Large CMs:	0.05 - 0.1µV (50 - 100nV) = 1ms 0.025 - 0.05µV (25 - 50nV) = 1ms 0.1 – 0.2µV (100-200nV) = 1ms

- It is not acceptable to use CM test parameters to record the ckABR; use recording parameters as for the 4 kHz tpABR. It is likewise not ideal to derive the CM from the ckABR waveform. Because the recommended time bases for CM and ckABR tests differ considerably it is recommended to plot

them on separate charts to aid interpretation (the size and aspect ratio of the waveforms may then be separately optimised).

- Time base: 8 to 10ms. The CM will end long before 10ms and this short time base allows a rapid stimulus rate to be used and allows the region of interest to be examined in greater detail. It can be advantageous for the time base to begin 1ms before the stimulus. This allows both the stimulus artefact and any CM to be distinguished. The option to show a flat line during the blocking period must not be used; the entire waveform must be displayed for inspection.

- Stimulus repetition rate: typically high 80s for example 87.1/s (the exact rate is not crucial). Being a pre-neural response, the CM (like the OAE) is not subject to neural fatigue and may be recorded as fast as the timebase allows. This reduces acquisition time.

- Low (high pass) filter: 300 Hz (if not available use the highest value available between 100 Hz and 300 Hz); This minimises recorded background myogenic and EEG activity.

- High (low pass) filter: 3 kHz to 5 kHz.

- Data reject (artefact rejection) level: A value of ±3µV is recommended where possible; a value of ±10µV should not be exceeded. The recommended filters allow a strict artefact rejection to be used.

- Display scale: because of the large range of CM amplitudes the aspect ratio used for the display scale may need to be modified beyond that normally used for recording ABR responses. Use the normal ABR scale as the initial default but a more sensitive scale may assist the interpretation of small or absent CMs; a less sensitive scale may be appropriate for large CMs. The scale should be chosen on the basis of most clearly demonstrating the presence or absence of a CM.

- Use a vertex (avoiding the fontanelle in babies) or high forehead electrode for the positive input to the amplifier. The common electrode may be at the contralateral mastoid or lateral forehead.

- Use an ipsilateral mastoid electrode for the negative input to the amplifier rather than a nape of neck electrode which ***cannot*** record a CM. The mastoid electrode should ideally be sited as close to the meatus (and therefore cochlea) as practicable. The BSA recommended procedure for ABR testing in babies (BSA 2019) recommends a low mastoid position to allow room for a mastoid placement of the BC transducer and to maximise the ABR response. Placement of two electrodes, one for ABR and one for CM, is not practical and so it is recommended that the guidance for ABR testing is followed but that the 'low mastoid' position is interpreted as no more than 1cm lower than the meatal level of the ear. In older children and adults, if a CM result is clinically important and no CM is recorded with an ipsilateral mastoid electrode, the use of a "tiptrode" or tympanic membrane ECochG electrode may reveal a small, hitherto undetected, CM.

- Be very careful to gather (or twist) together the electrode leads and physically separate them from the transducer cables and transducer to minimise the extent of stimulus or other electromagnetic artefact.

5. Method

- Tubal insert earphones ***must*** be used. These have a remote transducer coupled by an acoustic tube (e.g. ER-3A) that introduces a time delay (about 0.9ms) between the electrical signal at the transducer and the acoustic stimulus at the ear canal, enabling separation in time of the electromagnetic stimulus artefact from the cochlear microphonic. If conventional supra-aural earphones were to be used the CM and stimulus artefact would occur almost simultaneously and would therefore be difficult to distinguish. Tubal insert earphones have a further important advantage: the acoustic stimulus can be easily blocked during a control run by clamping the tube between the transducer and the ear tip. This forms an important element of the test procedure since in this condition the electrical artefact remains whilst the stimulus is effectively withdrawn, thus allowing a possible CM response to be validated or rejected as artefact.

- The recommended method is to use separate runs of condensation and rarefaction polarity clicks at 85 dBnHL[2]. Waveforms should be replicated (at least two runs). In order to avoid uncertainties relating to stimulus level in a baby's ear canal, it is recommended that both the ckABR and the CM test are conducted at the same stimulus level with the same (insert) transducer. This is not an issue for older children and adults, whose occluded ear canal volumes are larger and less variable, with correspondingly less uncertainty in effective stimulus level. If the ckABR at 85dBnHL is present but grossly abnormal then the highest level at which ckABR is absent should be determined and the CM then performed at that level, the aim being to perform the CM test with a stimulus for which the ABR is absent. This tactic can be used with a stimulus down to around 70dBnHL but at lower levels the likelihood of recording a CM diminishes, particularly in the presence of a conductive element.

- Many ABR systems have a facility whereby the responses evoked by rarefaction and condensation stimuli using an alternating polarity stimulus can be displayed simultaneously. This alternative approach is acceptable but note the next point, below, regarding the number of sweeps.

- Sweeps per waveform: typically 2000 (minimum 1500). If alternating polarity with simultaneous collection of responses to condensation and rarefaction stimuli is used then typically 4000 sweeps should be averaged, so that typically 2000 are averaged for each stimulus polarity. If the artefact rejection level is relaxed to above ±3μV then a greater number of sweeps may need to be collected.

- If a CM is considered to be present it is important to verify that it is not a stimulus artefact. Perform replicated additional control runs (of either polarity; it is not necessary to obtain both) at the same stimulus level but with the tubing clamped. An alternative to clamping the tubing is to temporarily disconnect the tubing from the transducer. If the potential is clearly eliminated, it is a true biological potential. If the measured potential remains, it is due to a stimulus artefact: separate the transducer

[2] In babies up to 84 days (12 weeks or 3 months) corrected age the stimulus level (clicks, the maximum for 4 kHz is the same) must be limited to 85 dBnHL. This can be exceeded in older babies (90 dBnHL from 85 to 168 days, 95 dBnHL over 168 days), children and adults but caution is advised in the 3-12 month range because there is little data on how the insert calibration error changes with age.

and electrodes as much as possible and retest. Carry out further replications of any test where there is any doubt over the presence of a cochlear microphonic or artefact.

- If no CM is evident and the level of residual noise is very low it is not necessary to perform a control run (with the tubing clamped). Note however that if an independent peer review were to cast doubt on CM presence, the availability of a control run (especially in non-ideal test conditions) would be valuable in resolving any uncertainty. Testers should therefore obtain control runs except where the absence of a CM is beyond doubt.

- When clamping the insert tube care must be taken not to move the transducer or its leads since this would change any stimulus artefact, introducing uncertainty into the interpretation of the presence of a CM. The initial positioning of the insert transducer therefore needs to allow the tubing to be clamped. In practice this is achieved by allowing the tubing to form a loop or curve rather than being straight. Nevertheless, the transducer should not be placed close to the mastoid electrode or its lead.

- As with all insert measurements if a clear recording is not obtained check that the sound has been delivered to the ear canal at the desired level i.e. that the insert or tubing has not become blocked.

Since the CM is a “near field response” there is no requirement to mask the non-test ear during CM testing, even if masking is needed when recording the ABR.

6. Interpretation

The replicated waveforms should be superimposed and the separate polarities displayed immediately above and below each other without overlapping (Figure 2 provides an example) to look for the following characteristic features of the cochlear microphonic:

- A sinusoidal segment that has mirror image (inverts) in the two stimulus polarity waveforms, beginning within 1ms of stimulus and possibly lasting up to 5 or 6ms. If the polarity of the measured potential reverses with click polarity, this is consistent with a cochlear microphonic basis for the potential. Note that tests using *alternating* clicks would yield a flat line if the potential was a genuine cochlear microphonic (due to cancellation of the response). If a repeatable portion of the waveform does not reverse with changes in stimulus polarity and the response persists using alternating clicks, this is consistent with a ***neural*** (ABR) basis for the potential or the summating potential. For a CM to be regarded as “clear” its size should be substantially greater than the residual noise (as judged from the average gap between the superimposed replicates), preferably with a signal to noise ≥3:1. As with ABR testing, residual noise can be reduced by using more sweeps or performing weighted addition of sub-averages.

- If the potential is clearly eliminated when the insert tubing is clamped / disconnected, it is a true biological potential.

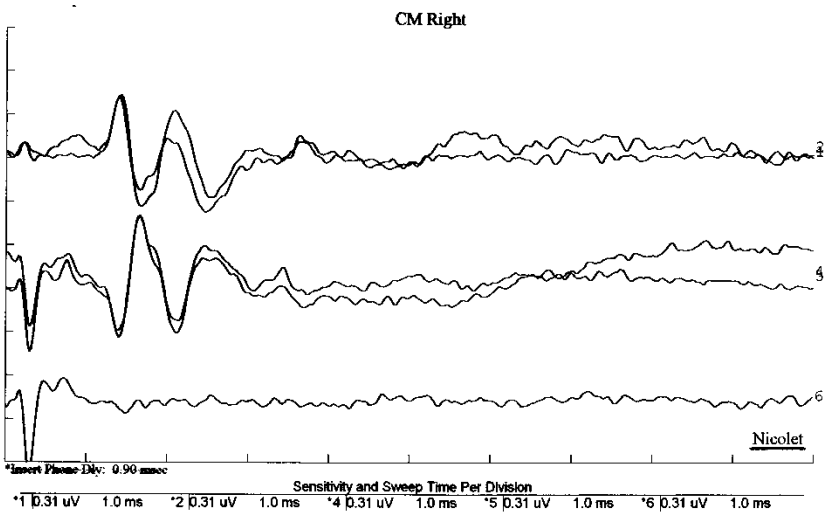


Figure 2: A clear and large (about 0.8µV) CM in a case of a baby with ANSD. Top: Rarefaction click (two runs, superimposed). Centre: Condensation click (two runs, superimposed). Bottom: Condensation click, with tube clamped. Note that the initial deflection in the condensation waveforms is the stimulus artefact. The CM is not present in the clamped waveform. Ideally the clamped waveform should have been replicated but in such an obvious case the lack of replication does not introduce uncertainty. Because of the large size of this CM a display scale beyond that recommended for ABR has been used.

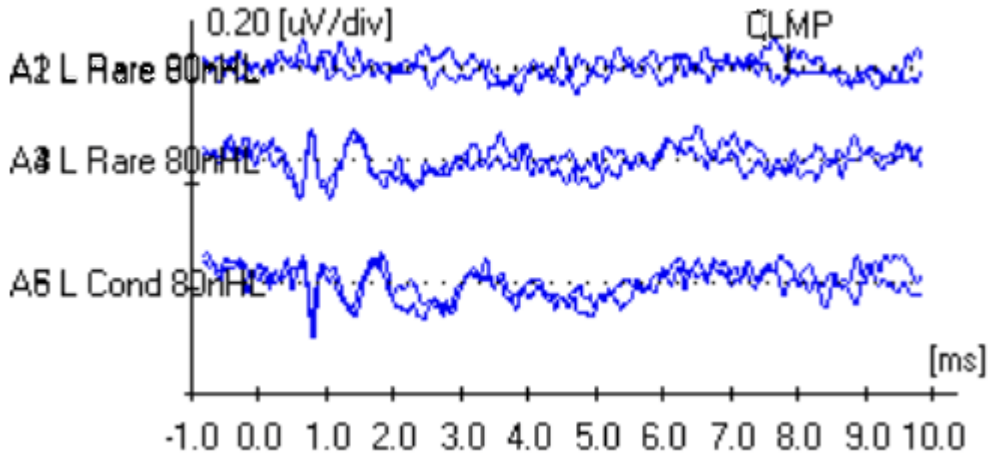


Figure 3: An example of a small but clear CM in the centre and bottom waveforms, which is not evident in the clamped waveforms at the top. As with conventional ABR recordings, the superimposition of replicated waveforms provides an estimation of the residual noise thus allowing the significance of waveform features to be assessed. Note that the time base begins 1ms before the stimulus. The display scale falls within the range normally used for ABR work.

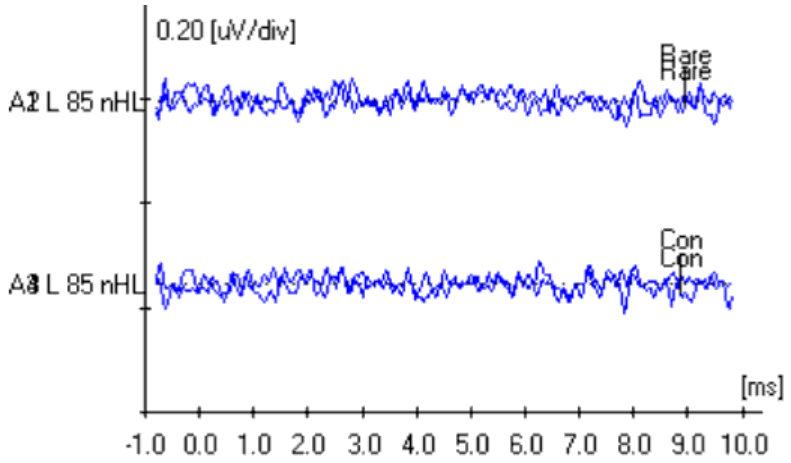


Figure 4: An example of an absent CM. The low level of residual noise (as judged from the average gap between replicates) confirms that recording conditions were good. There is no feature in the waveforms with the characteristics of a CM so no clamped waveforms were necessary.

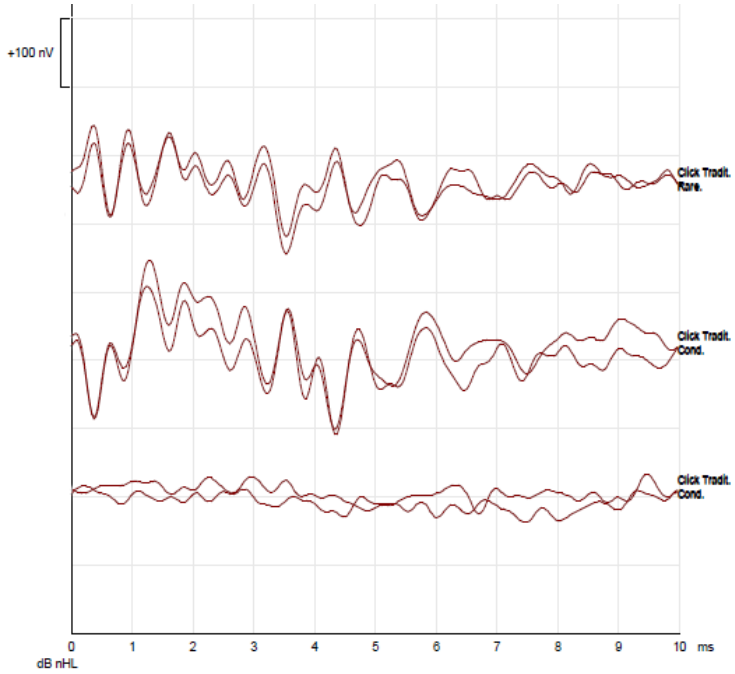


Figure 5: An example of a "ringing CM" where the CM exhibits several cycles. The mechanism is uncertain but may be related to a wide frequency region of intact hair cells on the basilar membrane. Top: rarefaction; centre: condensation; bottom: clamped condensation.

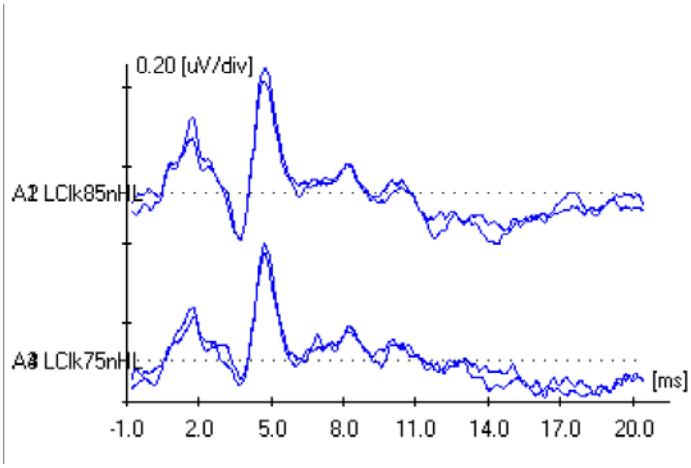


Figure 6: An example of an "abnormal" but recordable ABR waveform. Waves I (2ms) and III (5ms) appear to be present but there is only a vestigial wave V (8ms). Lower stimulus levels should be used to find the highest level the ckABR is "Response Absent" (RA). In such a case a CM test should be conducted, but at the level of the ckABR RA and it may be worth performing OAE testing. Careful consideration of the patient's medical history and other clinical findings are important to help identify whether this pattern relates to a known neurological condition. See the ANSD guidance for further advice.

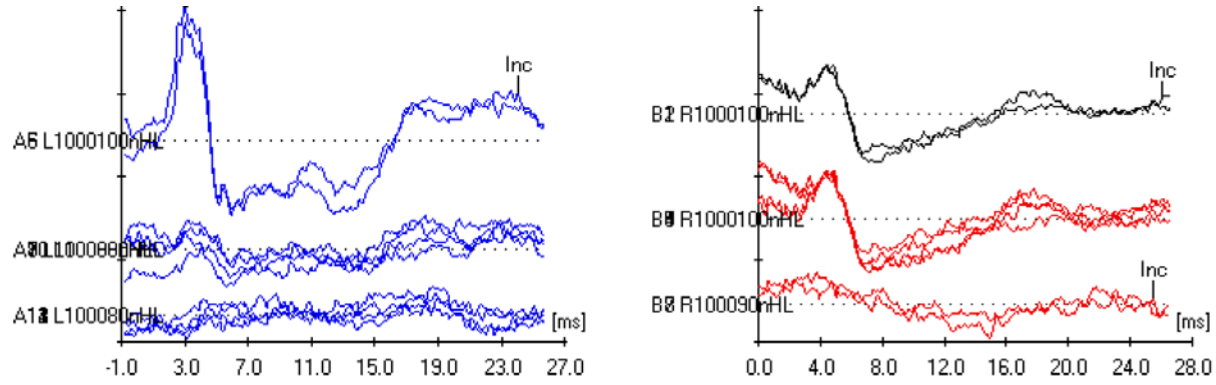


Figure 7: An example of a "short latency component" in response to high-level 1 kHz tone pip stimuli at 100dBnHL. This pattern is sometimes seen in potential cochlear implant candidates where high level stimuli are used. There is no recognisable ABR; the deflection around 3 ms is thought to be of vestibular origin. There is a positivity at around 18 ms but it is not possible to identify its origin. This pattern does not exclude ANSD so testing for ANSD would be appropriate. B3 to B6 were used to create the summed average B1 and B2. The CM test in this case should be conducted at 85dBnHL (the default level suggested earlier in the guidance), as should the ckABR. A click stimulus at 85dBnHL is unlikely to evoke this short latency component, so does not alter the decision to test for ANSD in such a case. If a click stimulus at 85dBnHL does evoke a short latency component then follow the advice given in Figure 6 above.

NOTES

- The CM threshold level is ***not*** a useful predictor of behavioural threshold, as even in normally hearing infants it cannot be reliably measured at levels below 50 – 60 dBnHL with surface electrodes.

- Figure 2 shows a very large (about 0.75µV) CM. This is sometimes seen in ANSD and may be associated with abnormal efferent inhibition of hair cell activity. There have been anecdotal reports of similarly large OAE responses in some cases of ANSD. However large CM and OAE responses are not always seen in ANSD.

- Although not relevant to distinguishing between ANSD and SNHL, as with ABR testing, make a note of any behavioural response to the CM stimulus.

- The flow chart in Figure 1 suggests that if an ABR to low-frequency tone pip stimuli is recorded the interpretation leads towards SNHL or a mixed hearing loss. Some clinicians believe it is possible to have features of both ANSD and SNHL and that management should include monitoring for evidence of poor speech discrimination. See the BSA / NHSP guidance on ANSD for more details.

7. Calibration

The international standard (ISO 2007) gives the reference equivalent threshold sound pressure level (RETSPL) for clicks and tone bursts/pips The reference levels for clicks and insert earphones are:

Earphone	Coupler	dBppe RETSPL
ER-3A	IEC60126 $(2cc)^3$	**26.5**
ER-3A	IEC318-4[4]	**35.5**

ppe = peak to peak equivalent

The ER-3A earphone RETSPL values are recommended for the two respective couplers. It is recommended that expert help is sought if you are not familiar with the measurement of peak to peak equivalent values.

Warning: The above values were derived from normal adults. When inserts are used on neonates, the smaller canal volume has the effect of increasing the actual SPL of the stimulus by around 10dB - 20dB. This is the reason for limiting the stimulus level to 85dBnHL – a neonate may actually receive 100-105 dBnHL and higher stimulus levels are likely to risk cochlear damage. A stimulus level of 85dBnHL can be

exceeded in older babies, children and adults but caution is advised in the 3-12 month range because there is little data on how the insert calibration error changes with age.

8. References

BRITISH SOCIETY OF AUDIOLOGY (2019) Recommended Procedure Auditory Brainstem Response (ABR) Testing in Babies [Online]. Available from: https://www.thebsa.org.uk/resources/.

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