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British Society of Audiology
Recommended procedure

Pure tone air and bone conduction threshold audiometry with and without masking and determination of uncomfortable loudness levels

1 CONTENTS

2 INTRODUCTION

This document replaces the three British Society of Audiology recommended procedures for pure tone audiometry (1981, 1985, 1986). These have been updated for consistency with BS EN ISO 8253-1 (ISO 8253-1) and as a consequence there are some changes to procedure. This document differs from BS EN ISO 8253-1 in some areas. These include differences in audiogram symbols and minor differences in the method of hearing threshold determination.

This document also includes and updates the procedure on descriptors for pure tone audiograms (1988), the recommended format for audiogram forms (1989) and determination of uncomfortable loudness levels (1987).

3 SCOPE

3.1 Subjects

This document describes procedures suitable for routine clinical use with adults and older children. It may not be appropriate for certain populations e.g. younger children. In these cases some modification of the test method may be required, although this may result in a less accurate measurement of hearing threshold level.

3.2 Procedures

Procedures are described for manual audiometry, using both air and bone conduction testing and masking, and for determining uncomfortable loudness levels. Descriptors of audiograms are given and the recommended format for audiogram forms is shown.

3.3 Recommendations

Recommendations are made for equipment calibration. References are given for the relevant BS EN ISO standards.

4 EQUIPMENT AND TEST ENVIRONMENT

4.1 Audiometric equipment

Audiometers should meet the performance requirements of BS EN 60645-1 (IEC 60645-1) and be calibrated in accordance with the BS EN ISO 389 series (ISO 389 series).

4.2 Audiometric test environment

The subject should be clearly visible to the tester. The subject should not be able to see or hear the tester adjust the audiometer controls. When the test is controlled from outside the audiometric test room, the subject should be monitored through a window or by a closed circuit TV-system. Audible communication with the subject should also be possible.

To enable the accurate testing of normal air and bone conduction hearing threshold levels down to 0 dB HL, ambient sound pressure levels should not exceed any of the levels shown in Tables 1 and 2 respectively (from BS EN ISO 8253-1). To measure minimum hearing threshold down to levels other than 0 dB HL, calculate the maximum permissible ambient sound pressure levels by adding the minimum hearing threshold level required to the values in Tables 1 and 2. For example, to measure down to 10 dB HL, *add* 10 dB to all the values in the table.

In general, the ambient noise should not exceed 35 dB (A). If it is higher than this, it is recommended that audiometry should not proceed.

Table 1: Maximum permissible ambient sound pressure levels for measuring air conduction audiometry (supra-aural earphones) to a minimum hearing level of 0 dB HL between frequencies 250 and 8000 Hz*

Mid-frequency of one-third octave band (Hz)	**dB re 20 µPa**	**Mid-frequency of one-third octave band (Hz)**	**dB re 20 µPa**	**Mid-frequency of one-third octave band (Hz)**	**dB re 20 µPa**
31.5	66	250	19	2000	30
40	62	315	18	2500	32
50	57	400	18	3150	34
63	52	500	18	4000	36
80	48	630	18	5000	35
100	43	800	20	6300	34
125	39	1000	23	8000	33
160	30	1250	25		
200	20	1600	27		

* Adapted from BS EN ISO 8253-1 (ISO, 1989)

Note: Insert earphones (eg Etymotic ER3 and ER5) will not require such stringent ambient noise levels.

Table 2: Maximum permissible ambient sound pressure levels for measuring bone conduction audiometry to a minimum hearing level of 0 dB HL between frequencies 250 and 8000 Hz*

Mid-frequency of one-third octave band (Hz)	**dB re 20 µPa**	**Mid-frequency of one-third octave band (Hz)**	**dB re 20 µPa**	**Mid-frequency of one-third octave band (Hz)**	**dB re 20 µPa**
31.5	63	250	13	2000	8
40	56	315	11	2500	6
50	49	400	9	3150	4
63	44	500	8	4000	2
80	39	630	8	5000	4
100	35	800	7	6300	9
125	28	1000	7	8000	15
160	21	1250	7		
200	15	1600	8		

* Adapted from BS EN ISO 8253-1 (ISO, 1989).

5 PREPARATION FOR TESTING

Before testing, the tester should perform the daily checks as described in Section 12.

5.1 Preparation of test subjects

Audiometry should be preceded by otoscopic examination. Occluding wax may be removed prior to audiometry. If there seems a likelihood of ear canals collapsing with supra-aural earphones in position, this may lead to measurement of a false air-bone gap. To avoid this, an otoadmittance tip (as used for tympanometry) can be inserted into the external auditory meatus. Alternatively, insert earphones (eg Etymotic ER3 and ER5) can be used.

The subject should be asked about any recent noise exposure, which should be noted as a comment on the audiogram form. Recent significant noise exposure (e.g. attendance at a night club within the past 24 hours) prior to audiometric testing should be avoided as this can temporarily elevate thresholds. If possible, re-test the subject at a time when they have had no recent exposure to noise.

Subjects should be asked if they have tinnitus, as this may affect their ability to detect tones in one or both ears, and especially at around the frequency of the tinnitus. Note should be made of the frequencies and ears at which such disturbance may have occurred. Subjects should be asked if they have better hearing in one ear, and if so, testing should commence with that ear. Make an informal assessment of the extent of their hearing loss through general conversation.

If applicable, inform the subject about intercom facilities. After giving the test instructions, remove any hearing aids, also any glasses, headwear or ear-rings that may obstruct the correct placement of the test transducers. Wherever possible, hair should not be allowed to sit between the ear and the transducer.

5.2 Test time

Care should be taken not to fatigue the subject as this can affect the reliability of the test results. If the test time exceeds 20 minutes, subjects may benefit from a short break.

6 AIR CONDUCTION PURE TONE AUDIOMETRY WITHOUT MASKING

6.1 Instructions

Instructions should give clear information about the task. This could be as follows:

"I am going to test your hearing by measuring the quietest sounds that you can hear. As *soon* as you hear a sound (tone), press the button (or raise your finger). Keep it pressed (or raised) for as long as you hear the sound (tone), no matter which ear you hear it in. Release the button (or lower your finger) as soon as you think you no longer hear the sound (tone). Whatever the sound and no matter how faint the sound, press the button (or raise your finger) as soon as you think you hear it, and release it (or lower it) as soon as you think it stops."

Alternative wording is acceptable providing the same points of instruction are included. The provision of an abbreviated printed version of these instructions may be advantageous. The subject should be asked if they understand the instructions. They should also be told that they may interrupt the testing in case of discomfort. Subjects with tinnitus present at the time of the test should be asked to ignore their tinnitus as much as possible and to respond to the test tones. They should be instructed to inform the tester if they experience difficulty in discriminating between their tinnitus and the test tones. A note to that effect should be made on the audiogram form.

6.2 Subject's response

The subject's response to the test tone should clearly indicate when the test tone is heard and when it is no longer heard.

The subject response system should be inaudible. Common examples include pressing and releasing a response button or raising and lowering the finger or hand. Arm raising, a vocal "yes" or tapping the table are to be avoided as they are methods that create sound or cannot be extended for the duration of the stimulus.

6.3 Earphones

There are three main types of transducers that can be used for air conduction audiometry: supra-aural, circum-aural and insert earphones. Supra-aural earphones (eg Telephonics TDH39 and TDH49) rest on the ear and have traditionally been used for air conduction audiometry. Circum-aural earphones surround and cover the entire ear and can also be used for audiometry. However both supra- and circum-aural earphones can be cumbersome, particularly when masking bone conduction thresholds and may cause the ear canal to collapse. Insert earphones (eg Etymotic ER3 and ER5) typically use a disposable foam tip for directing the sound straight into the ear canal and therefore prevent the ear canal from collapsing. Insert earphones also have a greater transcranial transmission loss than supra-aural earphones so reduce the need for masking. However, insert earphones may not be appropriate in ears with infections, obstructions or other abnormalities.

The tester should fit the earphones and the subject should be instructed not to hold or move them, after checking with the subject that there is no discomfort. The sound opening of a supra- or circum-aural earphone should be aligned with the ear canal entrance. The appropriately sized ear tip of an insert-earphone should be inserted, so the outer end is flush with the entrance to the ear canal. Partial insertion of the ear tip may invalidate calibration and provide less immunity to the effect of ambient noise.

Vibrotactile perception can occur at frequencies of 500 Hz and below, and at high intensity levels. The tester should be aware of the possibility that thresholds at these frequencies and levels may be vibrotactile. (See section 7.6 for more detail).

6.4 Test order

Start with the better-hearing ear (according to the subject's account) and at a frequency of 1000 Hz. Next, test 2000, 4000, 8000, 500 and 250 Hz in that order. For the first ear only, retest at 1000 Hz. If the retest value is more than 5 dB more acute than the original value, retest the next frequency and so on. Take the more sensitive threshold as the final value. Where needed and practicable, test also at intermediate frequencies 750, 1500, 3000 and 6000 Hz (3000 and 6000 Hz may be required in cases of high-frequency hearing loss, especially 3000 Hz for compensation assessment). Test the opposite ear in the same order. The retest at 1000 Hz is normally not required in the second ear to be tested unless tests in the first ear revealed significant variability (but see Section 6.8).

6.5 Test stimuli

The duration of the presented tone should be varied between 1 and 3 seconds. The interval between the tones should be varied between 1 and 3 seconds. The tester must ensure that the timing of each tone is not predictable.

6.6 Initial familiarisation

To ensure the subject is familiar with the task, present a tone of 1000 Hz that is clearly audible (e.g. at 40 dB HL for a normally hearing subject or approximately 30 dB above the estimated threshold for a subject with a hearing impairment, but never more than 80 dB HL). If there is no response at this level, increase the level of the tone in 20 dB steps until a response occurs. If the tone is still inaudible at 80 dB HL, increase the level of the tone in 5 dB steps until a response occurs, taking care to monitor the subject for discomfort.

If the responses are consistent with the tone presentation, i.e. onset and offset, the subject is familiarised with the task. If not, repeat. If after this repeat, their responses are unsatisfactory, re-instruct the subject.

6.7 Method for finding threshold

1. Following a satisfactory positive response, reduce the level of the tone in 10 dB steps until no further response occurs.
2. Increase the level of the tone in 5 dB steps until a response occurs.
3. After the response, decrease the level by 10 dB and begin another ascending 5 dB series until the subject responds again.
4. Continue to decrease the level by 10 dB and increase by 5 dB until the subject responds at the same level on two out of two, three or four (i.e. 50% or more) responses on the ascent. This is the hearing threshold level. Threshold is defined arbitrarily as the lowest level at which responses occur in at least half of a series of ascending trials with a minimum of two responses required at that level. Where greater precision is necessary (for example in research studies or in medico-legal compensation cases) three out of three, four or five ascents are recommended.
5. Proceed to the next frequency, starting at a clearly audible level (e.g. 30 dB above the previous threshold, but see 6.6 above) and use a 10 dB down, 5 dB up sequence until the threshold criterion is satisfied. Repeat familiarisation if necessary.

6.8 Variations in method

Subjects being tested for medico-legal or pension assessment purposes should have their hearing thresholds re-tested at those frequencies used in the calculation of disability (often 1, 2 & 3 kHz) as described by King et al (1992).

If non-organic behaviour is observed or where there is reason to suspect that the hearing thresholds are exaggerated, published variations in technique may help reduce the extent of non-organic overlay (e.g. Cooper & Lightfoot, 2000). When used, an appropriate note citing the method should be added to the audiogram.

7 BONE CONDUCTION PURE TONE AUDIOMETRY WITHOUT MASKING

Without masking, it is not possible to determine which ear is responding to bone conduction testing. Calibration standards for bone conduction apply only to monaural hearing and were derived using approximately 35 dB SL of masking noise in the non-test ear. When testing without masking, thresholds may appear more acute by about 5 dB. See Section 8 for masking in pure tone audiometry.

7.1 Bone vibrator

The bone vibrator is normally placed over the mastoid prominence of the worse hearing ear (as defined by the air conduction thresholds averaged between 500 and 4000 Hz), with the required area of the vibrator in contact with the skull. It should be placed as near as possible behind the pinna without touching it and without resting on hair, and should be held firmly in place by means of a headband. If a single audiogram form is used, the side on which the vibrator was placed should be noted on the audiogram form. See Section 11.2 for details of the use of symbols. An alternative placement of the bone vibrator is on the forehead but this site requires a set of correction values, which are available in BS EN ISO 389-3 (ISO 389-3).

7.2 Test order

This is similar to that used in air conduction audiometry except that bone conduction should only be performed in the frequency range 500 to 4000 Hz. No retest is required at 1000 Hz. See Section 7.7 for comments on limitations of bone vibrators, the need to use ear plugs and for test frequencies outside this range.

7.3 Test stimuli

The requirements for timing of the test stimuli are the same as for air conduction audiometry. See Section 6.5.

7.4 Instructions

Instructions are the same as for air conduction pure tone audiometry, as described in Section 6.1. However, emphasise that the subject should respond regardless of the side on which the sound (tone) is heard.

7.5 Methods for finding threshold

Ear specific bone conduction audiometry requires masking of the non-test ear. Where an ear specific measure is not required, bone conduction audiometry may be undertaken without masking. The ear being tested by bone conduction should not be occluded, except as described in Section 7.7. If it is occluded, it should be noted on the audiogram form.

Determine hearing threshold level, as described in Section 6.7.

7.6 Vibrotactile threshold

For mastoid location of the bone vibrator, vibrotactile threshold may be as low as 25 dB at 250 Hz, 55 dB at 500 Hz and 70 dB at 1000 Hz. (Boothroyd and Cawkwell, 1970). However, large variations may occur. Care must be taken not to misinterpret vibrotactile perceptions as hearing. Any threshold considered to be vibrotactile should be noted on the audiogram form.

7.7 Limitations of bone vibrators

Bone vibrators tend to emit more sound than vibration at frequencies above 2000 Hz (Lightfoot, 1979; Bell et al, 1980; Shipton et al, 1980). If testing at 3000 and 4000 Hz it is preferable to insert an ear plug (eg E.A.R. plug as used for hearing protection purposes) into the test ear canal or cover the test ear with a supra-aural earphone. This attenuates the air borne radiation from the bone vibrator to a satisfactory degree. Failure to occlude the ear canal at high test frequencies is likely to lead to inaccurately acute bone conduction thresholds, resulting in a false air-bone gap in the audiometric results. The canal must not be occluded at test frequencies below 3000 Hz since this may produce the “occlusion effect” in which bone conduction thresholds are improved.

The standard bone vibrator used in audiometry (Radioear B71) has poor distortion performance at low frequencies (Lightfoot, 2000). Testing is not recommended at frequencies below 500 Hz because the subject’s threshold may relate to hearing at the second or third harmonic rather than the fundamental. Bone conduction tests at 6000 Hz and above are also problematic due to transducer limitations and should be avoided (Lightfoot and Hughes, 1993). However, there may be exceptional circumstances when tests at the lower and higher frequencies are required, depending on the investigation performed. A check must be made that these frequencies have been included in periodic objective calibration tests, and caution is advised in the interpretation of the results.

8 MASKING IN PURE TONE AUDIOMETRY

8.1 Cross-hearing and its prevention by masking

Although earphones allow sound to be presented to one ear at a time, it is not always certain that the intended (test) ear is the one actually detecting the sound. When the hearing acuity of the ears is very different it is possible that, when testing the worse ear, the better (non-test) ear detects the test signals more easily despite the fact that the signals reaching it are attenuated.

This inter-aural attenuation, sometimes referred to as ‘transcranial transmission loss’ varies considerably from person to person. It is also earphone dependent. It varies from 40-80 dB when using conventional supra-aural audiometric earphones. When using insert earphones, the inter-aural attenuation is higher, with a minimum attenuation of 55 dB (Munro and Agnew, 1999). The situation with bone conduction is very much worse, with little or no transcranial transmission loss being afforded by the head.

When the difference in the thresholds of the two ears is greater than the transcranial transmission loss, cross-hearing may occur and the apparent threshold of the worse ear is in fact a ‘shadow’ of the better ear.

Reliance should not be placed on the subject to make an accurate report of the ear in which the sounds were heard, since many people are unable to make such judgements easily and the sound may not be fully lateralised to one ear.

8.2 The principles of masking

The problems of cross-hearing can usually be overcome by temporarily elevating the hearing threshold of the non-test ear by a known amount so as to enable an accurate assessment of the test ear threshold to be made. This may be achieved by presenting a masking noise into the non-test ear of the appropriate intensity to prevent it from detecting the test signals, and at the same time measuring the apparent threshold of the test ear with the test signals. There is approximately a 1:1 relationship between the increase in masking noise and the elevation of the masked threshold of the non-test ear.

The term not-masked is used to describe measurements made without masking, rather than the term unmasked which refers to a different psychophysical phenomenon.

8.3 Masking noise

Narrow band masking noise of the type specified in BS EN ISO 389-4 (ISO 389-4) should be used, where the geometric centre frequency coincides with that of the test tone and the bandwidth of the noise is between one-third and one-half of an octave.

8.4 Effective masking level

Masking noise should be calibrated in terms of *effective masking level* according to BS EN ISO 389-4 (ISO 389-4). This is the level of masking noise that is equal to the hearing level of a pure tone at the same frequency. The pure tone threshold of hearing at that frequency will be raised by the effective masking level of the masking noise. It is not necessary to measure the subject’s subjective hearing level for the masking noise.

However, when masking noise is not calibrated in terms of effective masking level, the masking threshold (M) must be measured. The effective masking level may be considered to be equivalent to M+10.

8.5 Measuring the masking threshold (M)

The threshold of masking (M) indicates the sound level in dB (relative to an arbitrary zero) of a masking noise at its own threshold of audibility for a given ear. Masking noise levels are then expressed as M + 10, M + 20 dB etc, i.e. as 10 dB and 20 dB above M.

The same method as used for pure tone threshold determination should be used to determine M. The procedure should be repeated for each narrow band noise corresponding to the frequencies of the pure tones to be masked.

8.6 Rules for masking

The rules given below are to be applied independently at each frequency. Note that words such as *better*, *worse*, etc describe hearing as measured by air conduction. The *test ear* is always the ear whose hearing threshold is being sought. It is the ear receiving the pure tone test signal directly. The *non-test ear* is the ear which may have to be masked to prevent detection of the test signal.

It is preferable to mask two or three frequencies properly, rather than incorrectly or hurriedly masking all frequencies in audiometry. It is not necessary to mask in the order that the rules are given below, eg the rules may be applied in the order: 1, 3, 2.

Rule 1: Air conduction audiometry

Masking is needed at any frequency where the difference between the left and right not-masked air conduction thresholds is 40 dB or more when using supra or circum-aural earphones or 55 dB or more if insert-earphones are used.

Rule 2: Bone conduction audiometry

Masking is needed at any frequency where the not-masked bone conduction threshold is more acute than the air conduction threshold by 10 dB or more. The worse ear (by air conduction) would then be the test ear and the better ear would be the non-test ear to be masked. Although this rule may frequently indicate the need for masking, there will be occasions where this is not warranted, depending on the purpose of the investigation.

Note: If the bone conduction threshold with masking remains the same or only increases by 5 or 10 dB, it is possible that the not-masked bone conduction result was from the ear with the worse air conduction threshold, and it may be necessary to test the better ear whilst applying masking to the worse ear. This will establish the true bone conduction threshold of the ear with the better air conduction.

Rule 3: Air conduction audiometry

Masking will be needed additionally where Rule 1 has not been applied, but where the bone conduction threshold of the better ear is more acute by 40 dB (if supra or circum-aural earphones have been used) or 55 dB (if insert earphones have been used) or more than the not-masked air conduction threshold attributed to the worse ear. The worse ear would then be the test ear and the better ear would be the non-test ear, to be masked.

Note: Rule 3 is necessary because an air conduction frequency that does not require masking under Rule 1, may need to be masked if the bone conduction results show that the non-test ear has a conductive element. Note that it is the sensitivity of the non-test cochlea (as indicated by the bone conduction threshold) that is the important factor in cross-hearing, and that Rule 1 is merely a convenient way of anticipating the need to mask in many cases.

Note: At frequencies where no bone conduction thresholds have been measured, doubt may exist regarding the possible effect of Rule 3. If there is a possibility that air conduction thresholds at these frequencies (including 250 and 8k Hz) are not the true thresholds, they should be marked accordingly on the audiogram form.

8.7 Instructions for masking

Suitable instructions would be:

"In this next test, you will hear the sounds (tones) again, just as before. I would like you to press the button as soon as you hear the sound (tone) start and release it as soon as it disappears. Do this even for the very faint sounds (tones), and no matter which side you seem to hear the sounds (tones).

For some of the time, you will also hear a steady rushing noise, but I want you to ignore it and press the button only when you hear the sounds (tones). This steady rushing noise will get louder at times. Let me know if you find it difficult to tell the difference between the two.

I want you to tell me if any of the sounds become uncomfortably loud, or if you would like me to explain the test again."

The subject must not be told to expect to hear the pure tone signals in the test ear. The very fact that masking noise is required means that it is not known which ear is picking up the signals.

8.8 Procedure for masking

This procedure is called the plateau-seeking method for masking. It is appropriate for both air and bone conduction testing.

1. Re-establish threshold in the test ear without masking noise to remind the subject what to listen for. This is always necessary for bone conduction because the occluded not-masked hearing threshold level is required. It may not always be necessary for air conduction if M has not been measured.
2. Present masking noise to the non-test ear. The level of masking noise should be presented at an effective masking level equal to the tonal hearing threshold level of the non-test ear at that frequency (or at M+10 dB). Wait a few seconds for any erroneous response to occur (a response at this stage may require brief re-instruction).
3. Re-measure the hearing threshold level in the test ear in the presence of masking noise (an abbreviated technique is sufficient). Take this tone level as the pure tone threshold at that level of masking. Increase the level of masking noise by 10 dB.
4. Re-measure the hearing threshold level in the test ear. Take this tone level as the pure tone threshold at that level of masking. Increase the level of masking noise by 10 dB.
5. Continue repeating step 4, using 10 dB increases in masking noise, until you have at least 4 measurements, (ie up to at least M+40), and until three successive levels of masking, 10 dB apart yield the same tonal threshold (or within 5 dB) *or* until the level of the audiometer is reached *or* until the subject finds the masking noise level uncomfortable.
6. When a third successive level of masking yields the same tonal threshold (or within 5 dB), this is the "plateau". This masking level – the level above which no further increase in tone level is required for it to be heard – is the correct masking level. Withdraw the masking noise and plot the

hearing threshold level on the audiogram. Note the maximum masking level that produced the correct hearing threshold level for that frequency on the audiogram form.

The use of a masking chart to plot the relationship between the masking noise level and pure tone threshold can be helpful for interpreting difficult cases. Both axes of the masking chart are marked in dB from –10 to 120 and the aspect ratio is 1:1. See Figure 1 for an example.

Note: It may be appropriate on occasions to use different step sizes when increasing the masking noise.

8.9 Bone conduction masking

An insert earphone should ideally be used to deliver masking noise to the non-test ear for bone conduction testing, for subject comfort and for the advantages of increased inter-aural attenuation with insert earphones. If the insert earphone is not of the type Etymotic ER3 or ER5 and has not been calibrated to effective masking level, then it will be necessary to measure the threshold of masking (M). Use a supra-aural earphone if there is no alternative.

Step1 of the masking function (which involves the re-determination of the not-masking tonal threshold, but with the non-test ear occluded by an insert earphone) may lead to an improvement of the measured threshold. This is due to the occlusion effect which is more pronounced at the lower frequencies. If an improvement in threshold is noted, the original not-masked threshold value on the audiogram should not be altered although the new value should be used on the masking chart.

8.10 Interpretation of the masking function

In the interpretation of the masking results, it is worth remembering that all measurements are subject to a degree of variability. Consequently, the measured masking function may not exactly match the idealised pattern and a "best fit" approach should be adopted. Points (i) and (ii) describe and explain the idealised masking functions.

(i) When cross-hearing is not present

This is when the original not-masked threshold measurement represents the true threshold of the test ear, even though there was a risk of cross-hearing. It is most often manifest by the measured tone thresholds at the last three masking levels being within 5 dB of the not-masked tonal threshold. An example is shown in Figure 1.

(ii) When cross-hearing is present

Cross-hearing occurs when the original not-masked threshold was a "shadow" of the non-test ear, with the test ear threshold being at a higher level. A typical masking function is illustrated in Figure 2 and usually takes the form of a short (and sometimes absent) initial horizontal line originating from the not-masked threshold (a), followed by a sloping section (b), and then by a horizontal section (c). Additional sections (d) and (e) may also occur.

In Figure 2,

(a) represents an initial condition where the masking noise though audible does not have a masking effect. Low masking levels (up to effective masking level +10dB or M +20 dB) are typical for this condition. Both tone and masking noise are heard in the non-test ear.

(b) represents direct peripheral masking where the threshold of the non-test ear is being raised by the presence of the noise but not enough to prevent it from detecting tones more easily than the test ear.

Again, both tone and masking noise are heard in the non-test ear. Note that the slope of this part of the function is always 1 dB per dB (i.e. 45 degrees assuming the recommended chart with aspect ratio 1:1). In cases where this 1 dB per dB slope continues to the audiometer's tonal or masking maximum output limit, the true test ear threshold has not been found and the appropriate audiometric symbol with a downward pointing arrow should be drawn on the audiogram at the last employed (highest) pure tone intensity. Such symbols indicate that the true threshold is at or beyond that level and lines should not be drawn to connect it with adjacent symbols on the audiogram.

(c) represents the true threshold of the test ear. At these levels the masking noise has raised the threshold of the non-test ear to the extent that the intensity of the test tone is sufficient to be just audible in this test ear. Note that the function is horizontal at this point – the "plateau". At the start of the plateau the subject may hear the tones in the test ear for the first time or may hear the tones centrally and will sometimes report this to the tester. At higher masking intensities, the subject should hear the tone and masking noise in the ears to which they are being presented.

8.10 Central masking

This refers to the inability of the brain to distinguish sounds of very different loudness, even when they are heard in opposite ears. This effect is most commonly apparent at the higher masking levels and may be evident as an upward slope of the masking function of less than 1 dB per dB, i.e. between 5 and 35 degrees, which may lead to an inability to determine the plateau. Line (d) in Figure 2 is an example of central masking. If a 5 dB increase in threshold is seen at the third point of an otherwise possible plateau, it is wise to go on to mask at higher levels in order to evaluate the slope and so aid interpretation of the masking function.

8.11 Cross-masking

Once masking levels corresponding to the beginning of the plateau at a particular masking function have been reached, additional increases in masking level further raise the threshold of the non-test ear. This may not be apparent initially, since the test ear pure tone threshold has been reached and may not be adversely affected by the noise (apart from any central masking effects). However if at some stage the masking level becomes sufficiently high, it may be capable of providing a masking effect in the test cochlea itself even though the noise is attenuated by transcranial attenuation. This is known as cross-masking.

Since cross-masking is of peripheral origin, this may be evident as a second 1 dB per dB slope (45 degrees) of the masking function, as illustrated by line (e) in Figure 2. Even though the masking noise is reaching the test ear, the subject will hear only the tone on that side since the noise will be much louder in the non-test ear.

Cross-masking can become a serious problem when the non-test ear has a conductive loss. The noise must be elevated by an amount corresponding to this loss before it begins to affect the non-test cochlea. This higher level is likely to lead to a cross-masking effect at an earlier stage in the masking function than would otherwise be the case. In cases of substantial conductive loss, there may be no discernible plateau on the masking function at all, making it impossible to measure the true test ear threshold. It may be impossible to accurately mask a bilateral conductive hearing loss. There is less risk of cross-masking with insert earphones.

In general terms, the greater the conductive element in the non-test ear the more likely the risk of cross-masking. Some caution should be exercised when introducing masking noise into an ear with a conductive element greater than about 30 dB. Furthermore, cross-masking may occur even when the non-test ear has no conductive loss; for example when the test ear has a large conductive element (bone conduction normal) and the non-test ear has a moderate sensorineural hearing loss.

In cases when the potential for cross-masking is apparent, increment the masking level in 5 dB steps in order to help correctly identify a shortened plateau.

8.12 Caution

Care needs to be taken when using masking at high intensity levels, particularly when used for several frequencies, as it can present a risk to the subject. See section 10.7.

In subjects with tinnitus, extra care should be taken when using high-levels of masking noise, as this can exacerbate the tinnitus. In some cases, it may be appropriate not to perform masking.

9 AUDIOMETRIC DESCRIPTORS

The hearing threshold levels of an individual ear are often described in general terms rather than in terms of the actual numbers at different frequencies on a pure tone audiogram. Recommendations are made below to associate particular descriptors with bands of average hearing impairment.

Four audiometric descriptors are given below. These are based on the average of the pure tone hearing threshold levels at 250, 500, 1000, 2000 and 4000 Hz. Averages do not imply any particular configuration of hearing loss and do not exclude additional terms, e.g. profound high-frequency hearing loss, being used.

Audiometric descriptor	*HTL (dB)*
Mild hearing loss	20-40
Moderate hearing loss	41-70
Severe hearing loss	71-95
Profound hearing loss	In excess of 95

Average hearing threshold levels of less than 20 dB do not necessarily imply normal hearing. The audiometric descriptors above do not imply any other classification of function, educational attainment or potential. They should not be taken directly as a measure of disability or handicap.

For the purposes of this document in determining the five-frequency average value of hearing loss: if at any frequency no response is obtained due to the severity of the loss, this reading shall be given a value of 130 dB HL. Any hearing level better than 0 dB shall be given the value 0 dB.

Anomalies may occur in calculating the average hearing loss if an audiometer with insufficient output is used in the measurement of severe and profound hearing loss.

10 UNCOMFORTABLE LOUDNESS LEVELS

10.1 Terminology

The terms loudness discomfort level (LDL) and uncomfortable loudness level (ULL) are sometimes used synonymously. The preferred term is uncomfortable loudness level.

10.2 When to perform the test

The objective of ULL testing is to measure the lowest intensity level that is judged to be uncomfortably loud to the subject, when applied monaurally for a specified signal. This information is generally helpful for hearing aid fitting, although most hearing aid fitting software contains normative ULL values that may be used instead. ULL testing should only be performed when the audiological professional considers the information will be clinically useful.

10.3 Limitations of the test

The pure tone signal used in ULL testing does not necessarily reflect the signal from which a hearing aid user may experience discomfort. ULL testing is also a subjective test and may have poor test–retest repeatability.

10.4 Contraindications

The main contraindication to performing this test is significant tinnitus, which can sometimes be exacerbated by ULL testing. Care should be taken with all subjects with significant tinnitus and also with any individual reporting unusual distress from noise and thus exhibiting symptoms of hyperacusis.

10.5 Instructions

The exact instructions given have a considerable effect on the outcome of the test. It is also important that clear and accurate instructions are given.

Instructions should be given verbally. Written instructions may be provided, especially if there is doubt that the subject has understood exactly what is required. The following instructions or equivalent should be used:

> "I will gradually make the sound louder in your ear, and you must tell me (by pressing the button/raising your hand) as soon as the sound becomes uncomfortable (loud). This is not a test to find the loudest sound you can tolerate; it is a test to find what level of sound you find uncomfortable. You should press the button only when the sound becomes uncomfortable– but make sure you press it as soon as the sound reaches that level."

Check that the subject has understood the instructions.

10.6 Procedure

1. For this test it does not matter if the subject can see what the tester is doing, and this may actually be helpful. The tester should certainly be observing the subject's face at all times.
2. Starting at a level predicted from the audiogram to be comfortable, present tone pulses for a 1 second duration followed by *at least* a 1 second quiet period. Ascend in 5 dB steps until the subject indicates that the uncomfortable level has been reached.
3. If the subject shows any distress or flinching during the test, stop immediately.

Note: It is important to adhere to this procedure in order to avoid the use of unnecessarily high stimulus levels.

10.7 Stimuli

It is the responsibility of the audiological professional to consider the Noise Risk Criteria set by the Physical Agents Directive and balance this for each individual subject against the clinical benefits obtained from ULL measurements. Noise exposure from other audiometric testing (e.g. masking in pure tone audiometry, real ear measures, acoustic reflex testing) should also be considered. (See Physical Agents Noise Directive, 2003/10/EC).

Testing at two frequencies may be sufficient for some subjects, such as a low and high frequency e.g. 500 and 2000 Hz.

Because the precise effect of high-intensity pure tone signals on the ear is not fully understood, it is also recommended that intensities above 110 dB HL should not be used by a student or less experienced tester without supervision from a suitably qualified or experienced person.

10.8 Recording of results

Record the ULL as the hearing level reached as described above. If the limits of the audiometer are reached without the subject reporting discomfort, report the ULL as “greater than x”, where x is the maximum available hearing level at the particular frequency. See Section 11 for the recommended symbols.

11 RECOMMENDED FORMAT FOR AUDIOGRAM FORMS

11.1 Audiogram form

Hearing threshold level can be plotted graphically on an audiogram form. The recommended format is shown in Figure 3. The aspect ratio should be fixed at 20 dB:1 octave.

11.2 Symbols

Symbols are shown in Figure 3. Air conduction symbols should be connected with continuous straight lines; bone conduction symbols may be joined with broken lines.

For not-masked bone conduction, the mastoid on which the bone vibrator was placed can affect the results. For this reason, the mastoid on which the bone vibrator was placed should be noted on the audiogram form. If two audiogram forms are used (one for each ear), the not-masked bone conduction threshold results should be plotted on the form corresponding to the ear on which the bone vibrator was placed, even though those sounds may have been heard in the opposite ear.

If no response occurs at the maximum output level of the audiometer, a downward arrow should be drawn, attached to the corner of the appropriate symbol, see Figure 4. These symbols should not be connected with the line to symbols representing measured thresholds.

Note: Some aspects of the symbols used in audiological software packages may differ to those recommended here.

11. 3 Working audiograms

Working audiograms may be useful for some purposes, especially training, and they may use shaded symbols for air conduction to indicate possible shadow points, which have not been masked. Open symbols should be used to indicate the true hearing threshold, which have been masked if necessary. Figure 4 is an example of a working audiogram.

11.4 Masking levels

The highest level of masking noise used to produce the correct hearing threshold level at a particular frequency should be noted on the audiogram form in the table provided. This may help for training or audit purposes particularly when masking charts are not used.

11.5 Notes

Results obtained from screening audiometry should be clearly indicated as such. The tester's name, signature and date of test should be noted on the audiogram. For electronic copies of the audiogram, the tester's name without signature is acceptable. A note should also be made of the audiometer used, including the type of earphones and bone vibrator used, and the date of the last objective calibration.

12 CALIBRATION

For reliable test results, it is essential that audiometers are regularly calibrated in accordance with BS EN 60645-1 (IEC 60645-1) and the relevant BS EN ISO 389 (ISO 389) series standards.

The following three-stage calibration programme is recommended.

12.1 Stage A: Routine checking and subjective tests

In order to check the audiometer is functioning across the range, checks should be performed by an operator with preferably good hearing or alternatively known hearing thresholds. They should be carried out in the normal test room, with the equipment set up as installed.

Tests 1 to 7 should be carried out daily.

1. Clean and examine the audiometer and all accessories. Check earphone cushions, plugs, main leads and accessory leads for signs of wear or damage. Any badly worn or damaged parts should be replaced, and the audiometer should then undergo a stage B check.
2. Switch on equipment and leave for the recommended warm-up time. (If no warm-up period is quoted by the manufacturer, allow 5 minutes for circuits to stabilise.) Carry out any setting-up adjustments as specified by the manufacturer. On battery-powered equipment, check battery state using the specified method. Check that earphone and bone vibrator serial numbers tally with the instrument serial number.
3. Check that the audiometer output is approximately correct on both air and bone conduction by sweeping through at a hearing level of “just audible” tones (e.g. 10 or 15 dB HL). This test should be performed at all appropriate frequencies and for both earphones and the bone vibrator.
4. Perform a high-level listening check on air and bone conduction at all frequencies used, on all appropriate functions and on both earphones (e.g. 60 dB for air conduction, 40 dB for bone conduction). Listen for proper functioning, absence of distortion, freedom from clicks when presenting the tone etc.
5. Check all earphones (supra-aural and insert phones) and the bone vibrator for absence of distortion and intermittency; check plugs and leads for intermittency.
6. Check that all the switches are secure and that lights and indicators work correctly.
7. Check that the subject response button works correctly.

Tests 8 to 11 should be carried out weekly.

8. Listen at low levels for any sign of noise or hum, for unwanted sounds or for any change in tone quality as masking is introduced. Check that attenuators do attenuate the signals over their full range and that attenuators which are intended to be operated while a tone is being delivered are free from electrical or mechanical noise. Check that interrupter keys operate silently and that no noise radiated from the instrument is audible at the subject’s position.
9. Check subject communication speech circuits.
10. Check tension of headset headband and bone vibrator headband. Ensure that swivel joints are free to return without being excessively slack. Check headbands and swivel joints for signs of wear strain or metal fatigue.
11. Perform an audiogram on a known subject, and check for significant deviation from previous audiograms (e.g. 10 dB or greater).

12.2 Stage B: Periodic objective tests

Stage B checks are objective tests which ideally should be performed every 3 months, although this period can be extended provided the Stage A checks are regularly and carefully applied and it can be shown that the equipment is stable and reliable. The maximum interval between checks should not exceed 12 months. They should preferably be carried out in the normal test room, with the equipment set up as installed, particularly if inter-connecting leads are used through a booth wall.

Measure and compare with the appropriate standards:

1. Frequencies of test signals
2. Sound pressure levels in an acoustic coupler or artificial ear from earphones
3. Vibratory force levels on a mechanical coupler from bone vibrators
4. Levels of masking noise
5. Attenuator steps over a significant part of the range
6. Harmonic distortion

12.3 Stage C: Basic calibration tests

Stage C checks need not be employed on a routine basis if stage A and B checks are regularly performed. They will only be required when a serious error or fault occurs, or when, after a long period of time, it is suspected that the equipment may no longer be performing fully to specifications. It may be advisable to submit equipment for a Stage C check after, for example, five years' use if it has not received such a test in that time in the course of repair.

Stage C checks should be such that after the audiometric equipment has been submitted for a basic calibration, it shall meet the relevant requirements given in BS EN 60645-1 (IEC 60645-1). A suggested minimum requirement for a Stage C check would include all items covered at Stage B plus:

1. Rise and fall times of test tones
2. Interrupter effectiveness
3. Cross-talk between transducers and channels
4. Masking noise spectra
5. Distortion of speech and other external input systems

Note: If insert earphones are used, separate measurements at all three stages must be made for them. On some equipment it is possible to store two sets of calibration values, however for others it may be necessary to use correction factors for the second set of earphones.

13 REFERENCES

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14 STANDARDS RELEVANT TO AUDIOMETRY

BS EN ISO 8253-1:1998 Acoustics. Audiometric test methods – Part 1: Basic pure tone air and bone conduction threshold audiometry *identical to* ISO 8253-1: 1989.

BS EN ISO 389-1: 2000 Acoustics. Reference zero for the calibration of audiometric equipment – Part 1: Reference equivalent threshold sound pressure levels for pure tones and supra-aural earphones *identical to* ISO 389-1: 1998.

BS EN ISO 389-2: 1997 Acoustics. Reference zero for the calibration of audiometric equipment – Part 2: Reference equivalent threshold sound pressure levels for pure tones and insert earphones *identical to*
ISO 389-2: 1994.

BS EN ISO 389-3: 1999 Acoustics. Reference zero for the calibration of audiometric equipment – Part 3: Reference equivalent threshold force levels for pure tones and bone vibrators *identical to* ISO 389-3: 1994.

BS EN ISO 389-4: 1999 Acoustics. Reference zero for the calibration of audiometric equipment – Part 4: Reference levels for narrow-band masking noise *identical to* ISO 389-4: 1994.

BS EN ISO 389-5: 2001 Acoustics. Reference zero for the calibration of audiometric equipment – Part 5: Reference equivalent threshold sound pressure levels for pure tones in the frequency range 8 kHz to 16 kHz *identical to* ISO/TR 389-5: 1998.

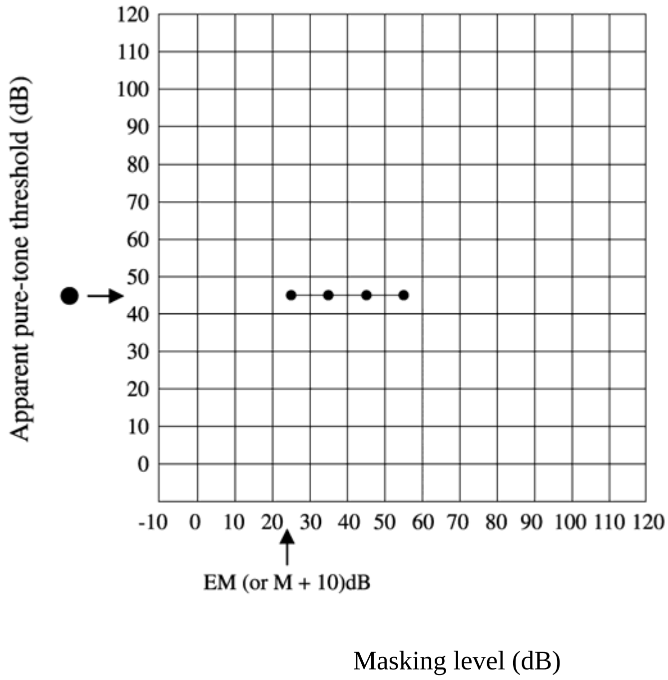
BS EN ISO 7029: 2000 Acoustics - Statistical distribution of hearing thresholds as a function of age *identical to* ISO 7029: 2000.

BS EN 60645-1: 1995 Electroacoustics - Audiological Equipment - Part 1: Pure-Tone Audiometers *identical to* IEC 60645-1: 2001.

BS EN 60645-4: 1995 Audiometers – Part 4: Equipment for extended high-frequency audiometry *identical to* IEC 60645-4: 1994.

Further information relevant to audiometric standards, together with details of the BSA Standards Forum can be found on the following website:
http://www.npl.co.uk/acoustics/techguides/audiometry/standards/

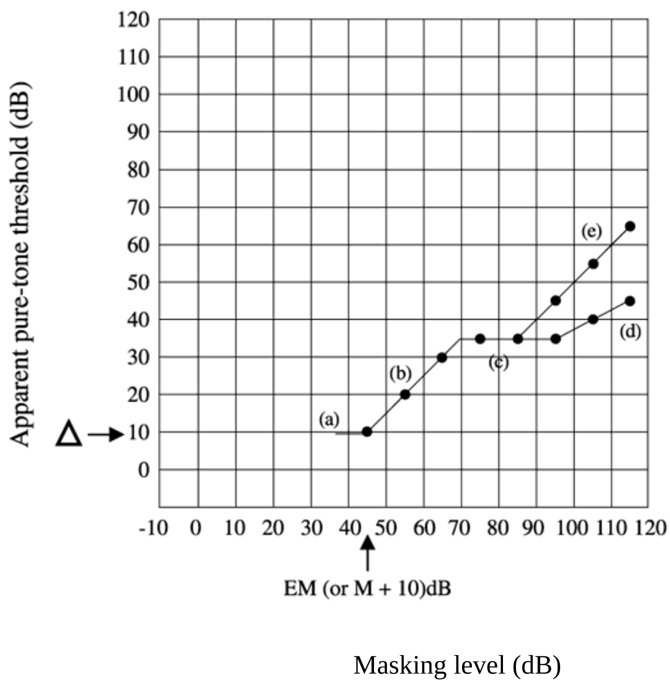
Figure 1. Recommended design of masking chart (reduced in size) and example of masking function derived in a case where cross-hearing is not present.



Test frequency: 2000 Hz
Test ear: R/L
Test mode: AC/BC

Pure tone threshold =45 dB

Figure 2. Recommended design of masking chart (reduced in size) and example of masking function illustrating cross-hearing and the presence of central and cross-masking.



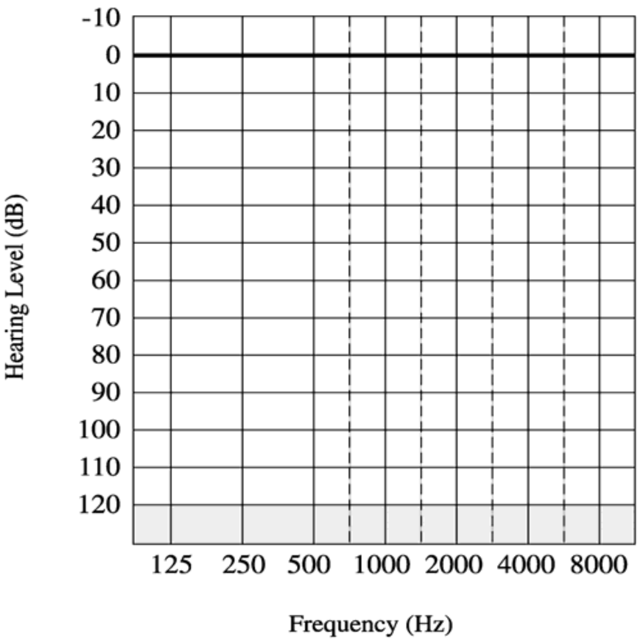
Test frequency: 500 Hz
Test ear: R/L
Test mode: AC/BC

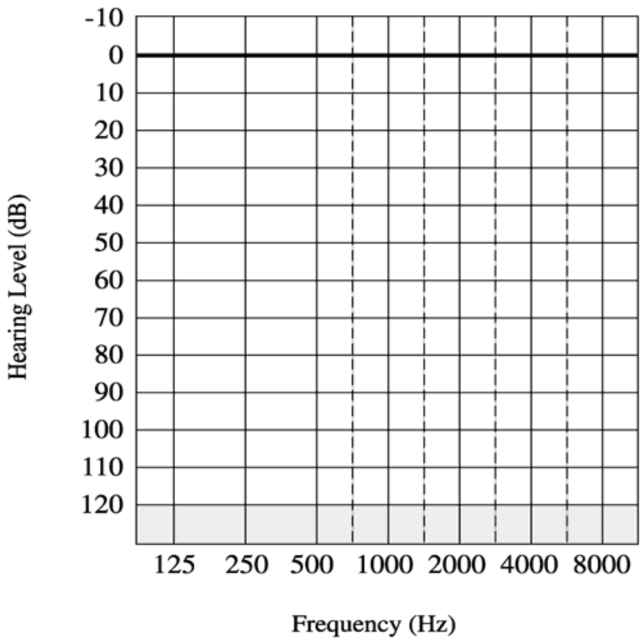
Pure tone threshold =35 dB

Figure 3. Recommended format for audiogram forms.

Pure tone audiogram

Name: **Age:**
Date: **Case No:**





Maximum level of masking noise used in non-test ear

	125	250	500	1000	2000	4000	8000
AC							
BC							

125	250	500	1000	2000	4000	8000

	Right		Left
Air conduction, masked if necessary	○		×
Bone conduction, not masked		△	
Bone conduction, masked	[		]
Uncomfortable loudness level	└		┘

Audiometer type:______________________________

Earphone type:__________________________ Bone vibrator type:_________________________

Date of last objective calibration:______________________________

Tester:_________________________________ Signature:

Comments:____

Figure 4. Illustration of a working audiogram. The application of masking in the testing of the right a-c thresholds revealed shadows at 250 and 500Hz but not at 1k Hz and 2k Hz. (These latter two symbols could have been half-filled in for training or audit purposes.)