British Society of Audiology

Recommended Procedure

Pure-tone air-conduction and bone-conduction threshold audiometry with and without masking

Date: 9th September 2011

Minor amendments: 6th February 2012

Date for review: September 2018

General foreword

This document presents a Recommended Procedure by the British Society of Audiology (BSA). A Recommended Procedure provides a reference standard for the conduct of an audiological intervention that represents, to the best knowledge of the BSA, the evidence-base and consensus on good practice given the stated methodology and scope of the document and at the time of publication.

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 This document supersedes any previous recommended procedure by the BSA and stands until superseded or withdrawn by the BSA.

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Published by the British Society of Audiology

1. Contents

2. Introduction

This document replaces British Society of Audiology (2004). Its purpose is to describe standard procedure and recommendations for effective pure-tone audiometry carried out in most audiological contexts. It also includes descriptors for pure-tone audiograms and the recommended format for audiogram forms. This document is not intended to provide guidance on specific circumstances or on interpretation of results. It is important that the competent person carrying out, or responsible for, the test (the 'tester') uses professional judgement when deciding on the particular approach to be used with each person being tested (the 'subject'), given the specific circumstances and the purposes of the test, and the tester's level of competency. Recommendations for the determination of uncomfortable loudness levels are now given in BSA (2011).

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

Unless stated otherwise, this document represents the consensus of expert opinion and evidence as interpreted by the Professional Practice Committee of the British Society of Audiology (BSA) in consultation with its stakeholders (Appendix A). The document was developed in accordance with BSA (2003).

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. adults with learning difficulties and 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 levels.

3.2 Procedures

Procedures are described for manual audiometry, using both air-conduction (a-c) and bone-conduction (b-c) testing, with and without masking. The document does not cover high-frequency audiometry (>8000 Hz), screening audiometry, use of short-duration tone bursts, self-recording audiometry or sound-field audiometry.

4. Equipment and test environment

4.1 Audiometric equipment

The audiometer, transducers and response button shall be clean. Audiometers shall meet the performance and calibration requirements of the relevant and current BS EN ISO standards, see Section 11 and Appendix B.

4.2 Audiometric test environment

The subject's face shall be clearly visible to the tester. The subject shall 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 shall be monitored through a window or by a closed-circuit TV-system. Audible communication with the subject should also be possible.

Excessive ambient noise will affect the test results, and ambient noise should not exceed the levels set out in the BS EN ISO standards (see Appendix C for further comments and details of the permitted ambient noise). The problems caused by ambient noise are greater when testing by b-c as there are no earphones in place to reduce the noise reaching the ears. Testers should also be alert to the problems of intermittent or transient noise during the test.

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

5. Preparation for testing

5.1 Preparation of test subjects

The tester shall adopt an effective communication strategy with the subject throughout. This must take account of the subject's age, hearing, language skills and any other possible communication difficulties. Any significant communication problems shall be recorded as these may affect the subject's performance.

Audiometry shall be preceded by otoscopic examination (see BSA, 2010) and the findings recorded, including the presence of wax.

Occluding wax may be removed prior to audiometry but if wax is removed the procedure shall only be undertaken by someone who is qualified and competent to do so.

If there is a likelihood of ear canals collapsing with supra-aural earphones in position this shall be recorded as it may lead to measurement of a false air-bone gap. In some cases the use of insert earphones (e.g. Etymotic ER3 and ER5) will avoid this problem (see Section 6.3).

The subject shall be asked about any exposure to loud noise during the previous 24 hours, as this can cause a temporary hearing loss. If the answer is yes then more details should be obtained regarding the exposure and results recorded. 'Loud' can be determined by having to shout or use a raised voice to communicate at a distance of 1 metre or 3 feet. If the results may have been affected by recent noise exposure then it may be necessary to re-test the subject at a time when they have had no recent exposure to noise.

Subjects shall be asked if they have tinnitus, as this may affect their ability to detect tones in one or both ears (see Section 6.8). Subjects shall be asked if they have better hearing in one ear; if so testing should commence with that ear, otherwise testing can start in either ear.

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 transducers, cause discomfort or affect sound transmission. Wherever possible, hair, scarves etc, 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 audiometry without masking

6.1 Instructions

Instructions shall 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. Keep it pressed for as long as you hear the sound (tone), no matter which ear you hear it in. Release the button as soon as you no longer hear the sound (tone). Whatever the sound and no matter how faint the sound, press the button as soon as you think you hear it, and release 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 should sit quietly during the procedure and 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, including which frequencies were affected (see also Section 6.8).

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 response system should be inaudible, with a response button connected to a signal light the preferred method. When testing younger children, adults with learning difficulties or subjects with attention difficulties a more engaging response method may be required, and if so this shall be recorded.

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 (e.g. Telephonics TDH39 and TDH49) rest on the ear and have traditionally been used for a-c audiometry. Circum-aural earphones (Sennheiser HDA200) surround and cover the entire ear. However, both supra- and circum-aural earphones can be cumbersome, particularly when used for masking bone-conduction thresholds, and may cause the ear canal to collapse. Insert earphones (e.g. Etymotic Research ER3 and ER5) use a disposable foam tip for directing the sound straight into the ear canal and therefore prevent the ear canal from collapsing. Insert earphones are also associated with less transcranial transmission of sound than supra-aural earphones so reduce the need for masking (see Section 8.1). However, insert earphones may not be appropriate in ears with infections, obstructions or abnormalities. In cases of excessive wax, insert earphones could also push the wax further into the canal and therefore must be avoided.

The tester shall 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 shall be aligned with the ear canal entrance. If insert earphones are used, 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. In all cases, incorrect placement may invalidate calibration and provide less protection from ambient noise.

With a-c, vibrotactile perception can occur at frequencies of 500 Hz and below, and at high hearing levels. The tester should be aware of the possibility that thresholds at these frequencies and levels may be vibrotactile.

6.4 Test order

Start with the better-hearing ear (according to the subject's account) and at 1000 Hz. Next, test 2000 Hz, 4000 Hz, 8000 Hz, 500 Hz and 250 Hz in that order. Then, for the first ear only, retest at 1000 Hz. If the retest value is no more than 5 dB different from the original value take the more sensitive threshold as the final value, but if the retest value differs from the original value by more than 5 dB then the reason for the variation shall be investigated. The subject may need to be re-instructed and the full test repeated for that ear (but see also Sections 5.2 and 6.8 regarding the effects of a test taking too long). Unusually variable results shall be noted on the audiogram. Where needed and practicable, test also at intermediate frequencies 750 Hz, 1500 Hz, 3000 Hz and 6000 Hz (3000 Hz and 6000 Hz may be required in cases of high-frequency hearing loss). Test the opposite ear in the same order. The retest at 1000 Hz is normally not required in the second ear unless tests in the first ear revealed significant variation.

6.5 Timing of the test stimuli

The duration of the presented tone shall be varied between 1 and 3 seconds. The interval between the tones shall be varied between 1 second and at least 3 seconds. The tester must ensure that the timing of each tone is not predictable; random variations in durations are intended as a check against false positive responses. It is important that the tester does not stop the signal as soon as the subject responds, signals must be of the full duration and the subject must respond throughout each one.

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, increase the level of the tone in 10-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 the 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 first response using an ascending approach, 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 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.
5. Proceed to the next frequency, starting at a clearly audible level (e.g. 30 dB above the adjacent threshold, but see notes on familiarisation in Section 6.6) and use the 10-dB-down, 5-dB-up sequence described in Step 4 until the threshold criterion is satisfied.

6.8 Variations in method

There will be situations where the test frequencies will vary from those in Section 6.4. For example, industrial audiometry (Health & Safety Executive, 2005, Appendix 5) requires testing at 500 Hz, 1000 Hz, 2000 Hz, 3000 Hz, 4000 Hz, 6000 Hz and 8000 Hz.

Subjects with short attention spans, and some elderly subjects, may find the full test rather tiring. In these cases it may be appropriate to test fewer frequencies, as it is better to test fewer frequencies accurately than to attempt a complete test on an un-cooperative subject where the accuracy will be in doubt. When frequencies are omitted from the test the reason shall be recorded. With such subjects other modifications to technique may be required, such as the use of longer test tones or alternative response methods. Again these variations in technique shall be recorded.

If the subject is unable to perform an accurate test at some frequencies due to an inability to distinguish between their tinnitus and the test tone, then a frequency-modulated or warble tone may be used as a stimulus. Subjects often find a warble tone easier to hear against their tinnitus than a pure tone. However, there are calibration and perception problems with warble tones, and the thresholds measured may be in error as a result. It is essential to record at which frequencies and in which ears warble tones were used. The use of pulsed tones and narrow-band noise is not advised due to calibration and perception problems.

If there is reason to suspect that the hearing thresholds are exaggerated, published variations in technique may help with this (e.g. Cooper & Lightfoot, 2000). When used, a note citing the method shall be added to the audiogram form (Section 10).

7. Bone-conduction 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 sensation level of masking noise in the non-test ear. When testing without masking, thresholds may appear more acute by about 5 dB due to binaural stimulation.

7.1 Bone vibrator

The bone vibrator is normally initially placed over the mastoid prominence of the worse hearing ear (as defined by the a-c thresholds averaged between 500 Hz and 4000 Hz), with the required area of the vibrator in contact with the skull. It shall be placed as near as possible behind the pinna without touching it and without resting on hair. The vibrator shall be held firmly in place by means of a headband that holds it against the skull with the required static force. The side on which the vibrator was placed shall be noted on the audiogram form. See Section 10.2 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.

7.2 Test frequencies and test order

The preferred test order is similar to that used in a-c audiometry starting at 1000 Hz, however alternatives are acceptable. Bone-conduction should only be performed in the frequency range 500 Hz to 4000 Hz, and it may not be necessary or appropriate to test at all these frequencies in every case. 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 a-c audiometry. See Section 6.5.

7.4 Instructions

Instructions are the same as for a-c audiometry, as described in Section 6.1. However, emphasis should be given that the subject should respond regardless of the side on which the sound (tone) is heard.

7.5 Methods for finding threshold

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

Determine hearing threshold levels 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, there is large inter-subject variation in vibrotactile thresholds. Care must be taken not to misinterpret vibrotactile perceptions as hearing. Any threshold considered to be vibrotactile shall be noted on the audiogram form.

7.7 Limitations of bone vibrators

Bone vibrators tend to emit levels of air-borne sound sufficient to influence b-c results at frequencies above 2000 Hz (Lightfoot, 1979; Bell et al, 1980; Shipton et al, 1980). When testing b-c thresholds at 3000 Hz and 4000 Hz, in order to prevent the subject hearing any air-borne sound, an ear plug should be inserted into the test ear canal (e.g. a foam plug as used for hearing protection purposes) or covering the test ear with a supra-aural or circum-aural earphone. This attenuates the air-borne radiation from the bone vibrator to a satisfactory degree. The tester shall record whether or not the test ear was occluded. It is not necessary to occlude the non-test ear. Failure to occlude the ear canal at high test frequencies is likely to lead to artificially acute b-c thresholds, resulting in a false air-bone gap in the audiometric results. The canal must not be occluded at test frequencies below 3000 Hz, as this may artificially improve b-c thresholds due to the 'occlusion effect'. The problem of air-borne sound might be reduced using forehead placement as described in Section 7.1 above, provided that calibration issues are accounted for (see Fagelson and Martin, 1994; Harkrider and Martin, 1998; BS EN ISO 389-3).

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.

Headband tension has an impact on the sound levels delivered. It is difficult to measure the actual headband tension *in situ*, but testers need to be aware of this source of error (e.g. with a small head) and record any suspected errors from this source.

8. Cross-hearing and masking

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 interaural attenuation, also referred to as transcranial transmission loss, varies considerably from person to person. It is also earphone dependent. It varies between 40-80 dB when using supra-aural or circum-aural earphones. When using insert earphones, the transcranial transmission loss is higher, with a minimum transcranial transmission loss of 55 dB if the earphones are inserted correctly (Munro and Agnew, 1999). The situation with b-c is very much worse, and there can be little or no transcranial transmission loss.

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 at 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 normally 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 different psychophysical phenomena.

8.3 Masking noise

Narrow-band masking noise of the type specified in BS EN 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 (EML) according to BS EN ISO 389-4. In the presence of noise at a particular centre frequency and effective masking level, the pure-tone threshold of hearing (dB HL) at that frequency will be raised to that level. For example, a 1000-Hz noise at 50 dB EML presented to an ear will normally raise its hearing threshold for a 1000-Hz pure tone to 50 dB HL.

When masking noise is calibrated in terms of effective masking level it is not necessary to measure the subject’s hearing threshold for the masking noise prior to testing with masking (see Section 8.8).

8.5 Measuring the threshold for masking noise (M) if required

When the noise is not calibrated in effective masking level, the threshold for masking noise (M) shall be measured. This indicates the lowest level of a masking noise that can be detected, measured in dB (relative to an arbitrary zero). The initial masking level used shall be M+10 (see Section 8.8).

If possible 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. Where it is not possible to determine M using the usual threshold technique, perhaps because of audiometer design, care should be taken to determine M as accurately as possible.

8.6 Indicators of cross-hearing and the rules for masking

The indicators (or 'rules') given below are to be considered independently at each frequency. Note that words such as 'better' and '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 being presented with the pure-tone directly. The non-test ear is the ear which may have to be masked to prevent detection of the pure tone.

It is preferable to mask two or three frequencies properly, rather than incorrectly or hurriedly masking more frequencies. It is not essential to mask in the order that the rules are given below.

8.6.1 Rule 1

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

8.6.2 Rule 2

Masking is needed at any frequency where the not-masked b-c threshold is more acute than the air-conduction threshold of either ear 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.

Notes on Rule 2:

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. For example it may not benefit patient management to mask more than two b-c frequencies on one ear, or to mask small air-bone gaps.

If the b-c threshold with masking remains the same or only increases by 5 or 10 dB, it is possible that the not-masked b-c result was from the ear with the worse a-c threshold, and it may be necessary to test the better ear whilst applying masking to the worse ear.

8.6.3 Rule 3

Masking will be needed additionally where Rule 1 has not been applied, but where the b-c threshold of one 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 a-c threshold attributed to the other ear.

Notes on Rule 3:

Rule 3 is necessary because an a-c frequency that does not require masking under Rule 1, may need to be masked if the b-c 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 b-c 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.

At frequencies where no b-c thresholds have been measured, doubt may exist regarding the possible effect of Rule 3. If there is a possibility that a-c thresholds at these frequencies (including 250 Hz and 8000 Hz) are not the true thresholds, they should be masked or 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.

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 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 b-c because the occluded not-masked hearing threshold level is required.

2. Introduce masking noise to the non-test ear. The initial level of masking noise should be the effective masking level equal to the tonal hearing threshold level of that ear at that frequency. 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 using the normal threshold technique as described in Sections 6.6 and 6.7. Take this tone level as the pure-tone threshold at that level of masking.
4. Increase the level of masking noise by 10 dB. Re-measure the hearing threshold level in the test ear. Take this tone level as the pure-tone threshold at that level of masking.
5. Continue repeating Step 4, using 10-dB increases in masking noise, until you have at least four measurements, and until three successive measurements yield the same tonal threshold or until the level of the audiometer is reached or until the subject finds the masking noise uncomfortable. (See also Sections 8.10 and 8.13.)
6. When three successive levels of masking yield the same tonal threshold, or one threshold no more than 5 dB different from the other two, this is the 'plateau' (see Figures 1 and 2, and Section 8.10). The mode of the three hearing threshold levels at plateau is taken as the correct hearing threshold of the test ear and no further masking is required. Withdraw the masking noise and plot the hearing threshold level on the audiogram.

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 and the aspect ratio is 1:1. See Figure 1 for an example.

Notes on masking method:

It may be appropriate on occasions to use smaller step sizes when increasing the masking noise, particularly where the plateau is not well defined (see also Sections 8.11 and 8.12).

Some testers use alternative techniques to determine the masked thresholds. Techniques other than those described here are not recommended. Any deviation from the methods described in this document shall be recorded in the subject's records or on the audiogram.

Masking noise above 80 dB EML or tones above 100 dB HL should only be used with caution (see Step 5 above and Section 8.13).

8.9 Masking during bone-conduction testing

An insert earphone should be used to deliver masking noise to the non-test ear for bone conduction testing, for subject comfort and for the advantages of high transcranial transmission loss. If the insert earphone is not of the type Etymotic ER3 or ER5 or has not been calibrated to effective masking level, then it will be necessary to measure the threshold of masking (M; Section 8.5). A supra-aural or circum-aural earphone can be used if there is no alternative.

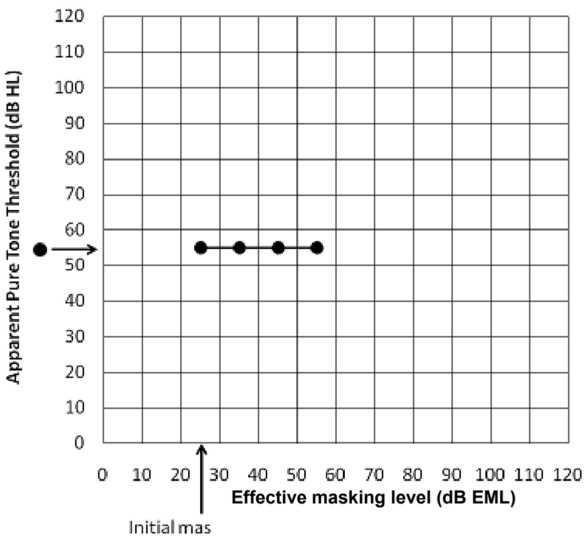
Step1 of the masking function (Section 8.8; which involves the re-determination of the not-masked tonal threshold, but with the non-test ear occluded by an insert earphone) may lead to an improvement of the measured threshold. This is due to the occlusion effect which is more pronounced at the lower 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 important to remember that all threshold measurements are associated with a degree of uncertainty (at least ± 5 dB). Consequently, the measured masking function may not exactly match the idealised pattern and a ‘best fit’ approach should be adopted. The following sections provide guidance on the interpretation of the idealised masking functions.

8.10.1 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.



Test details may be recorded as follows:

Test frequency: 2000 Hz
Test ear: R / ~~L~~
Test mode: a-c / ~~b-c~~

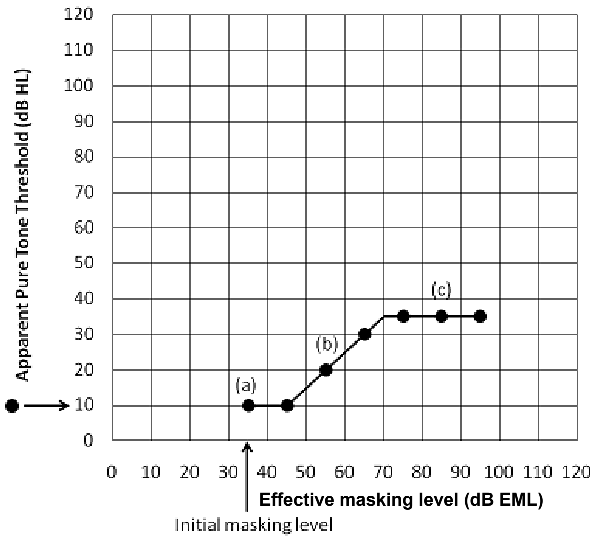
Pure-tone threshold = 55 dB HL

Figure 1

Recommended de and example of masking function derived in a case not present. The horizontal arrow by they axis represer g threshold level.

8.10.2 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, or plateau, (c).



Test frequency: 500 Hz
Test ear: R / ~~L~~
Test mode: ~~a-c~~ /-b-c

Pure-tone threshold =35 dB HL

Figure 2

Recommended design of masking chart and example of masking function illustrating cross-hearing

In Figure 2:

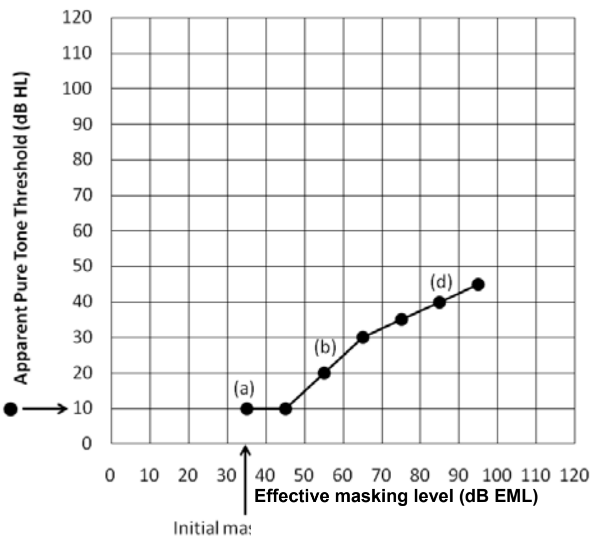
(a) represents an initial condition where the masking noise though audible does not have a masking effect. Low masking levels (up to 10 dB above the initial masking level) are typical for this condition. Both tone and masking noise are heard in the non-test ear.

(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 approximately 1 dB per dB (i.e. approximately 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 (see Figure 6 below).

(c) represents the true threshold of the test ear (35 dB HL in this example). 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. The maximum level of masking required to define the plateau could be recorded for training or audit purposes (e.g. in Figure 2 this is 95 dB EML).

8.10.3 Central masking

This refers to the inability of the brain to identify a tone in the presence of masking, even when they are heard in opposite ears, hence masking is occurring centrally rather than peripherally (in the cochlea). This effect is most commonly apparent at the higher masking levels and may be evident as an upward slope of the masking function of consistently less than 1 dB per dB (i.e. between 5 and 35 degrees) which may lead to an inability to determine the plateau. See Figure 3.



Test frequency: 500 Hz
Test ear: R / ~~L~~
Test mode: ~~a-c~~ /-b-c

Pure-tone threshold =35 dB HL (approx.)

Figure 3

Illustration of central

Line (d) in Figure 3 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. In these cases a reasonable estimate of the true threshold can be made from the masking chart because cross-hearing has been ruled out. In figure 3 the true threshold of 35 db HL is approximated, and this should be clearly indicated on the audiogram.

8.10.4 Cross-masking

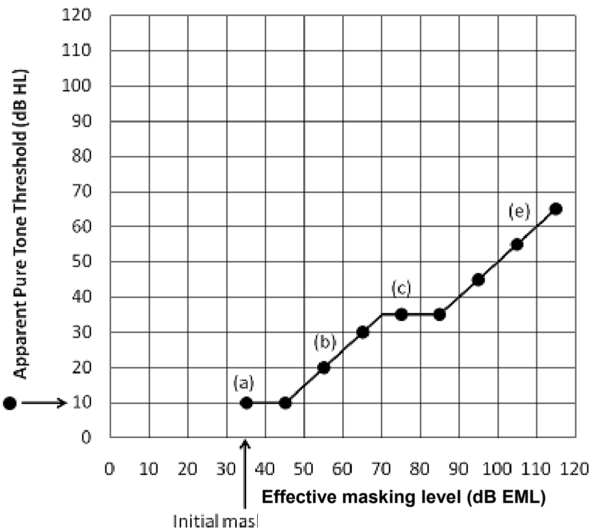
Once masking levels corresponding to the beginning of the plateau of a particular masking function have been reached, additional increases in masking level further raise the threshold of the non-test ear. This may not be apparent initially, since the test ear pure-tone threshold has been reached and 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 ear* through transcranial transmission. This is known as cross-masking.

Since cross-masking is of peripheral origin, this will be evident as a second approximately 1 dB per dB slope (approximately 45 degrees) on the masking function, as illustrated by line (e) in Figure 4. Even though the masking noise is reaching the test ear, the subject will hear only the tone in that ear since the noise will be much louder in the non-test ear.

Here the plateau (c) is shorter than usual, only being defined by two points, but is still sufficient to define the true threshold in this instance; this is not always the case, see notes below on shortened plateau. The highest level of masking noise used to define the plateau was 85 dB HL.

Cross-masking is primarily through bone-conduction (as with cross-hearing; see notes on Rule 3 in Section 8.6.3) and the point at which the masking signal is detected by the test ear will depend on the bone-conduction hearing of that side.

Cross-masking will be a particular problem when the test ear has a conductive loss (with good bone-conduction) and the non-test ear has at least a moderate loss. In this situation high effective masking levels will be required in the non-test ear, which may readily stimulate the cochlea in the test ear leading to cross-masking.



Test frequency: 4000 Hz
Test ear: R / ~~L~~
Test mode: ~~a-c~~ /-b-c

Pure-tone threshold =35 dB HL

Figure 4

Illustration of cross-m

In cases when the po   is apparent, increase the masking level in 5-dB steps, rather than 10-dB steps, as this might help to identify a shortened plateau.

It may be impossible to accurately mask a conductive hearing loss if the plateau is not well defined. Where the masking test could not be performed accurately, or the results are results are in doubt, this should be clearly indicated on the audiogram.

There is less risk of cross-masking with insert earphones.

8.11 Caution

Care needs to be taken when using high levels of masking, particularly when testing at several frequencies, as it can present a risk to the subject (see The Control of Noise at Work Regulations, Health & Safety Executive, 2005).

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. 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.

Descriptor	Average hearing threshold levels (dB HL)
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 HL 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.

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 threshold level lower (better) than 0 dB HL shall be given the value 0 dB HL.

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. Recommended format for audiogram forms

10.1 Audiogram form

Hearing threshold level can be plotted graphically on an audiogram form. The aspect ratio should be fixed at 20 dB:1 octave in all cases to ease interpretation. The recommended format is shown in Figure 5. Other audiogram forms are acceptable, as long as the information shown in Figure 5 is recorded.

10.2 Symbols

Symbols are shown in Figure 5. Air-conduction symbols should be connected with continuous straight lines; bone-conduction symbols should 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 shall be noted.

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 6. These symbols should not be connected with the line to symbols representing measured thresholds.

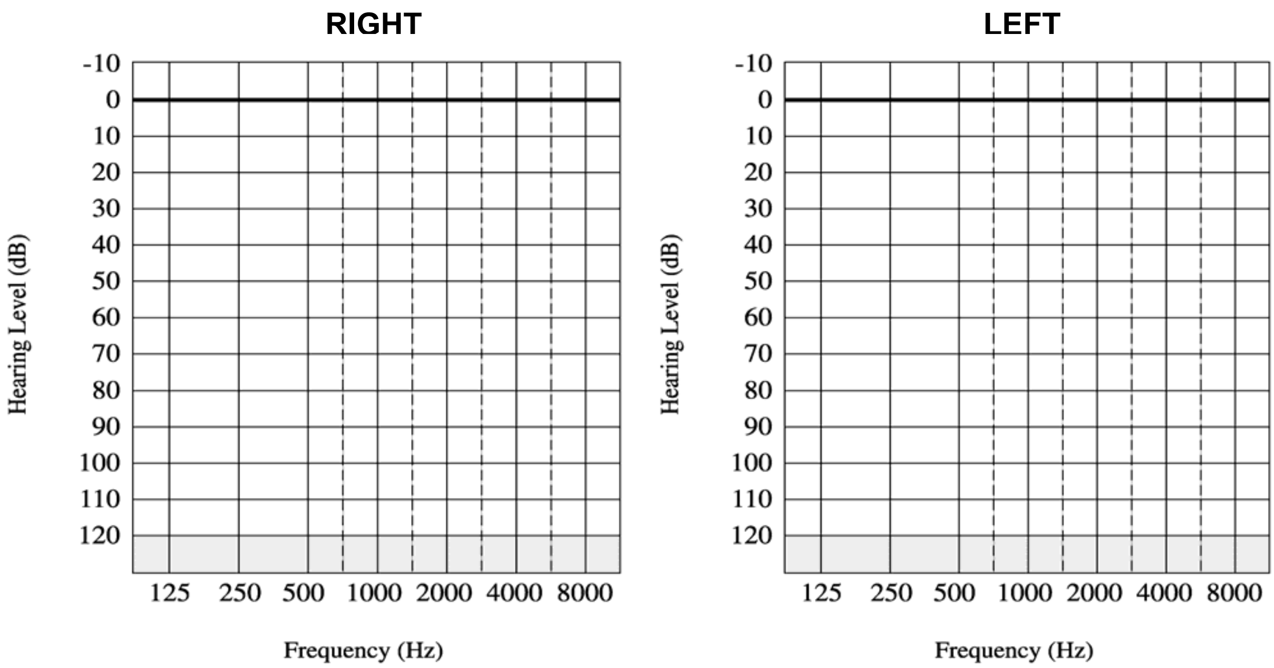
Note:

Some of the symbols used in audiological software packages may differ from those recommended here. This is acceptable as long as the results are clear and unambiguous.

Pure-tone audiogram

Name: **Date:**

Date of birth: **Case No:**



	Right		Left
Air conduction, masked if necessary	O		X
Bone conduction, not masked		Δ	
Bone conduction, masked	[		]
Uncomfortable loudness level	└		┘

Audiometer type & serial number:____

Earphone type:____

Date of last objective calibration:_______________________________________

Tester:________________________________Signature:____________________

Comments:____

Figure 5

Recommended format for audiogram form.

10.3 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 6 is an example of a working audiogram. The application of masking in the testing of the right a-c thresholds revealed shadows at 250 Hz and 500 Hz but not at 1000 Hz and 2000 Hz. (These latter two symbols could have been half-filled in, indicating that masking had been performed, for training or audit purposes.) The right ear threshold at 8000 Hz is greater than 120 dB HL, as indicated by the arrow, and it should not be connected by line to the other results for the right ear.

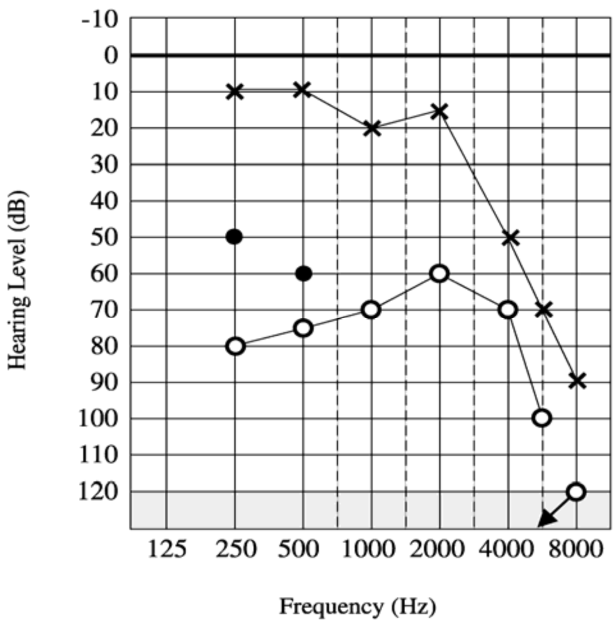


Figure 6

Illustration of a working audiogram.

10.4 Masking levels

Less experienced testers and students might find it useful to retain any masking charts, or record the masking levels used, for training or audit purposes.

10.5 Notes

If the tester has any doubts about the accuracy of any results, including any thresholds where cross-hearing was indicated but masking not completed, these shall be noted.

The tester's name, signature and date of test should be noted on the audiogram form. 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 the date of the last objective calibration.

When a computerised audiometer is used, care must be taken to ensure all results are recorded and stored correctly. In particular, some systems automatically delete not-masked thresholds when masked thresholds are recorded, even though with bone-conduction tests the initial not-masked result may correctly refer to the contralateral ear. Testers should ensure all potentially useful data are retained.

11. Calibration

11.1 Stage A: routine checking and subjective tests

In order to check the audiometer is functioning across the range, checks shall be carried out by someone with sufficiently good hearing to detect any faults such as described below. They should be carried out in the normal test room, with the equipment set up as installed. These checks should be logged. Where apparent faults are noted, equipment shall not be used until correct performance has been confirmed.

Tests 1 to 8 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. If any transducers are replaced, then the audiometer must 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 those on the instrument's calibration certificate. An instrument's transducers shall not be changed unless a full Stage B calibration is undertaken.

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 dB HL or 15 dB HL). This test should be performed at all appropriate frequencies and for both earphones and the bone vibrator.
4. Check that the masking noise is approximately correct at all frequencies through both earphones, at a level of 60 dB HL.
5. 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 HL for air conduction, 40 dB HL for bone conduction). Listen for proper functioning, absence of distortion, freedom from clicks when presenting the tone etc.
6. Check all earphones and the bone vibrator for absence of distortion and intermittency; check plugs and leads for intermittency.
7. Check that all the switches are secure and that lights and indicators work correctly.
8. Check that the subject response button works correctly.

Tests 9 to 12 should be carried out weekly.

9. 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.
10. Check subject communication speech circuits.
11. 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.
12. Perform an audiogram on a known subject, and check for significant deviation from previous audiograms (e.g. 10 dB or greater).

11.2 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

11.3 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. 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.

12. References

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Appendix A. Authors and acknowledgments

This revision was conducted by the BSA Professional Practice Committee between September 2008 and September 2011 in accordance with BSA (2003). The Committee thanks all involved with previous versions of this document and all who contributed to this review including those who contributed during two consultations (Spring 2009 and 25th October 2010 to 13th December 2010). An electronic copy of the anonymised comments (from 19 individuals) received during the most recent consultation, and the responses to these by the authors, is available from BSA on request.

Appendix B. Standards relevant to audiometry

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 Sound Pressure 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 389-4:2004. Acoustics. Reference Zero for the Calibration of Audiometric Equipment. Part 8: Reference Equivalent Threshold Sound Pressure Levels for Pure Tones and Circumaural Earphones. (Identical to ISO 389-8:2004.)

BS EN ISO 7029:2000. Acoustics. Statistical Distribution of Hearing Thresholds as a Function of Age. (Identical to ISO 7029:2000.)

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 60645-1:2001. Electroacoustics. Audiological Equipment. Part 1: pure-tone audiometers. (Identical to IEC 60645-1:2001.)

Further information relevant to audiometric standards can be found on the National Physical Laboratory website: www.npl.co.uk.

Appendix C. Permitted ambient noise levels for audiometry

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 8253-1:1998). 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.

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 Hz 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		

Notes on ambient noise:

Insert earphones (e.g. Etymotic Research ER3 and ER5) and noise-excluding earphones (e.g. audiocups) will not require such stringent ambient noise levels as they reduce the amount of ambient noise reaching the ears, if they are fitted correctly. However, full details of the frequency-specific attenuation characteristics of these devices needs to be considered, together with full details of the ambient noise, before tests can be carried out in environments that exceed the noise levels listed above.

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 Hz 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		