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THE ASSESSMENT OF NOISE EXPOSURE FROM HEADPHONES

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1. THE NEED

Earphones are used by many people at work: for example, disk jockeys, airline pilots and telephonists. Studies[1 2 3] have shown that people listening to earphones may choose to set the volume so high that by normal industrial noise standards there is a long-term risk of hearing damage. (This may be partly because for the same sound pressure in the ear, sound from earphones is less loud than other sound.[4 5]) If ambient noise levels are high (for example, for pilots) the need to make speech on earphones intelligible may cause the wearer to set an excessively high sound level.

The UK Noise at Work regulations[6] (NAWR), and similar laws in other countries, require that people exposed to loud noise at work should have their exposure assessed, so that any necessary remedial action may be taken. Noise exposure from speech or music heard on earphones at work, therefore, may well need to be assessed. However this is more difficult than assessing normal industrial noise.

2. THE PROBLEM - "NOTIONAL UNDISTURBED FIELD"

The NAWR recognise that a simple sound pressure level measurement is not appropriate for earphones. The definition of daily personal exposure ($L_{EP,d}$) specifies that the A-weighted sound pressure should be measured in the undisturbed field, or in the disturbed field adjacent to the person's head adjusted to provide a "notional equivalent undisturbed field pressure".

The current guidance issued by the Health and safety Executive (HSE) for assessing noise exposure does not explain how this is to be done for earphones, but says that expert advice should be sought[7]. The problem has two aspects:

2.1. THE EAR - TRANSFER FUNCTION

If the level of a steady sound field (for example, of pink noise) is measured with an isolated small microphone, and a person's head and ear is then brought next to the microphone, the level will change. The size of the change will depend on the direction of incidence and the frequency of the sound, and on the exact position of the microphone in relation to the ear[8 9]. For pink noise, it can easily be as great as 6dB.

A measurement of noise exposure made next to the ear should, therefore, be converted to an equivalent undisturbed field level. (The type of field is not specified, but either a diffuse field or a field frontally incident on the head is convenient. The assessed exposure will vary slightly with the type of undisturbed field chosen for the conversion.) Sound from an earphone must be measured using a real or simulated ear, and the measured level should therefore be converted. This requires a knowledge of the transfer function from measured sound level to equivalent unobstructed field sound level, for the particular microphone position in the ear. With an artificial ear, the function for the equivalent microphone position in a real ear should be used. Such functions are frequency dependent, and so simple A-weighted measurements are inadequate.

2.2. THE EAR - IMPEDANCE VARIATION

An earphone applied to an ear forms a closely coupled system, so the sound level from an earphone depends on the acoustic impedance of both earphone and ear[10 11]. The impedance of an artificial ear, therefore, should replicate that of a real ear. This depends on the earphone type: the impedance presented to an insert earphone which seals half way down the ear canal is very different from that presented to a supra-aural earphone, which is different again from that presented to a circumaural earphone.

3. STANDARD METHODS OF MEASUREMENT

Over the years, a number of methods of measuring sound from earphones, using either artificial ears or human subjects, have been developed.

3.1. ARTIFICIAL EARS (i) for insert earphones

2cm^3 COUPLERS

Simple couplers with a volume approximately equal to the space in the ear canal beneath an insert earphone, have been standardised, for example in ASA Z24 (1949) and IEC R26. However, the impedance of the middle ear, seen via the eardrum, is very significant, and this is not modelled by such couplers. They are therefore used mainly for comparison of earphones, rather than absolute measurements.

COUPLERS TO IEC711 (CCITT REC.P.58 TYPE 2) AND ANSI S3-25

These are also designed for insert earphones, but they model the impedance of the eardrum and middle ear as well as the volume of the relevant part of the ear canal. The microphone is in the position corresponding to the eardrum in a real ear. The best known couplers of this type are those due to Bruel (Bruel and Kjaer type 4157) and to Zwislocki[12] (as sold by Knowles Electronics).

3.2. ARTIFICIAL EARS (ii) for supra-aural earphones

6cm^3 COUPLERS

Similar to the 2cm^3 couplers, such types have been standardised for supra-aural earphones, as in US NBS 9A, ANSI S3-6 and IEC 303. They have a similar limitation, in that they do not model the variation of impedance due to the presence of the resonant ear canal.

IEC318 TYPES

For example, Bruel and Kjaer type 4153. These were originally designed for the calibration of audiometric earphones, and they attempt to model accurately the impedance presented to a supra-aural earphone by a typical ear[13]. Unfortunately, with this type, it is not certain what position in a real ear corresponds to the microphone position, and therefore a proper transfer function to notional undisturbed field cannot be found.

3.3. MANIKINS

Acoustic manikins, or head and torso simulators, have been standardised (as in ANSI S3.36 and IEC 959) for hearing aid measurements and other purposes. Since they have approximately anatomically realistic ears, earphones can be placed on them for measurement. They usually incorporate couplers to IEC711, so the microphone position corresponds to the eardrum in a real ear, and an appropriate transfer function correction must be applied. (Not all manufacturers provide the appropriate function, so it may be necessary to measure it.)

The use of a manikin has obvious advantages, not least that it has been informally recommended by the HSE for measuring noise exposure from earphones. However, manikins were not invented primarily for earphone measurement, and it is necessary to take care that the differences in skin texture and pinna flexibility between humans and manikins, which affect how well circumaural earphones seal to the head, do not give misleading results.

An example is given in figure 1. This shows how a Helmholtz resonance can arise with a high acoustic impedance circumaural earphone on a manikin, due to imperfect sealing and lack of damping by the plastic and rubber surfaces. With A-weighting, this can give a significant error. A corresponding resonance does not arise with typical human subjects. (To be fair, such errors will not arise with more common types of earphone, which have a lower acoustic impedance.)

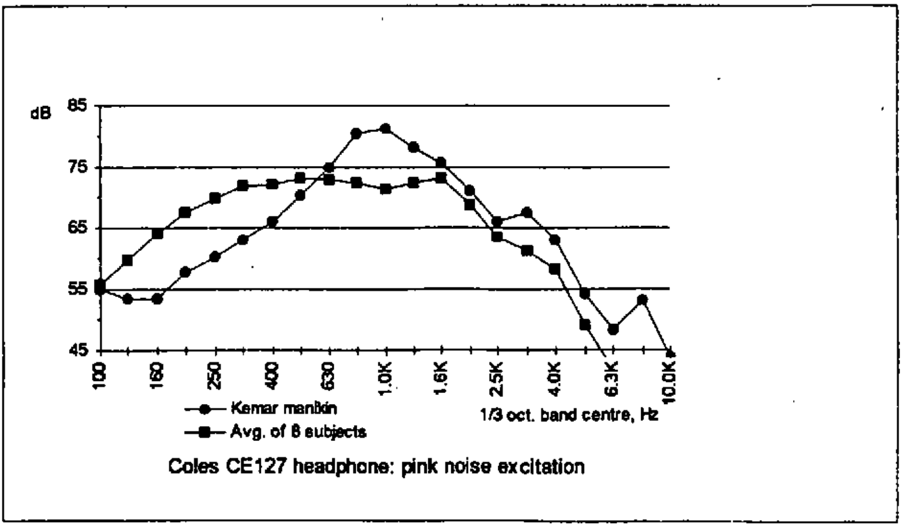

Figure 1: Helmholz resonance on manikin

3.4. HUMAN SUBJECT METHODS

Putting a miniature microphone under an earphone on a human subject seems an obvious way to make a measurement. However it is necessary to make the unobstructed field transfer function correction as outlined above. The correction may be found by measuring the output of the in-ear microphone in, for example, a diffuse field, and then measuring the same field in the same position with the same microphone, in the absence of the person[14]. However, if the microphone is located in the concha, modal behaviour may occur in the presence of the earphone which does not occur in its absence[14]. The relationship between level at the microphone and level at the eardrum may therefore not be the same with the earphone present and absent, which, strictly, makes the transfer correction measurement invalid. Ideally, the microphone should be located at the eardrum position.

In research, probe microphones may be used to measure very close to the eardrum, but this is impractical for noise assessment work. Theile, at the IRT, has used a small electret microphone inserted 4mm inside the entrance of the ear canal, and this method has been adopted as a proposed IEC standard for earphone measurements[4 15]. However even this is not ideal for assessment work, as, while most people are prepared to have a microphone placed in the concha, many are reluctant to have anything inserted into their ear canal, except by a medically qualified person.

3.5. THE "FLAT PLATE"

Manikins are expensive, and both they and human subject methods require some complexity in measurement. At the least a frequency analysis is necessary in order to apply the frequency dependent correction. If a miniature electret microphone is used, it will also be necessary to measure its frequency response and sensitivity. However, an approximate measurement, which may be adequate for assessment, may be made with a simple A-weighted sound level meter. The simplest possible adaptation to a sound level meter, for measuring earphones, is to set the front of the microphone flush in a flat surface, to which a supra-aural or circumaural earphone can be applied[1 14].

This does not present the correct impedance to the earphone; nor can a transfer function to equivalent unobstructed field be established because the system is too different from a real ear. Nevertheless the requirements of measuring A-weighted noise exposure on typical speech and music, are much less stringent than those for finding the frequency response of an earphone's sensitivity. Mathers and Lansdowne found that for two types of circumaural headphone, with pop music, there was excellent agreement between the A-weighted exposure measured with a simple flat plate system, and the exposure measured on human subjects with an in-ear microphone, corrected to equivalent unobstructed field. The author has found that for a range of types of circumaural and supra-aural earphones, the flat plate gave results within -1.0dB to +3.0dB of those found with a Knowles Electronics (KEMAR) manikin (apart from the Helmholz resonance case noted above, where the flat plate gave a level 4.0dB lower than that on the manikin, but only 0.5dB lower than the average of eight human subject measurements).

The result where the flat plate appeared to give the largest negative error (1.0dB) was found with a circumaural earphone having a large, approximately rectangular muff. A sideways mode in the muff, in the region of 2.5kHz where the A-weighted meter has maximum sensitivity, had a pressure minimum at the microphone, causing the low reading. Using pink noise excitation, this effect could be diagnosed by moving the earphone sideways so that it was not centred on the microphone, which gave a rise in level. Apart from such modal effects (which are not wideband so unlikely to give large errors with speech and music), it is difficult to envisage a situation in which the flat plate would give a significantly low result.

However with supra-aural earphones, the volume enclosed on the flat plate may be much less than that with a real ear, and this will give a high result. Most modern earphones have a low acoustic impedance, so the effect on the A-weighted level of this volume difference is fairly small (typically up to 3dB). However some telecommunication types of earphone, such as rocking armature designs, have a high acoustic impedance. Using one such type (Coles CE128), the flat plate gave a positive error of about 6dB, when compared with levels found with a manikin and human subjects.

It therefore seems justifiable to use a simple flat plate for screening assessments of noise exposure from many types of circumaural and supra-aural earphone, where the results will either be approximately correct, or will have a small error on the side of safety. However it cannot be used for insert or intra-concha types, and is not well suited to supra-concha types. The limitations of the system should be borne in mind, particularly with earphones that have a high acoustic impedance.

PRACTICAL DETAILS

Figure 2 shows a practical implementation of a "flat plate" measuring device with a jig for mounting a headphone. With a circumaural earphone with a soft muff, the force applied to press the earphone on the plate, and hence the compression of the muff, can affect the sound level appreciably. It is therefore desirable to standardise the force to that which would be applied by the headband, on a real person. This may be done by using a jig such as that shown. With such a jig, it is necessary to use a meter capable of accepting a microphone extension lead, to allow the microphone to be at right angles to the meter body.

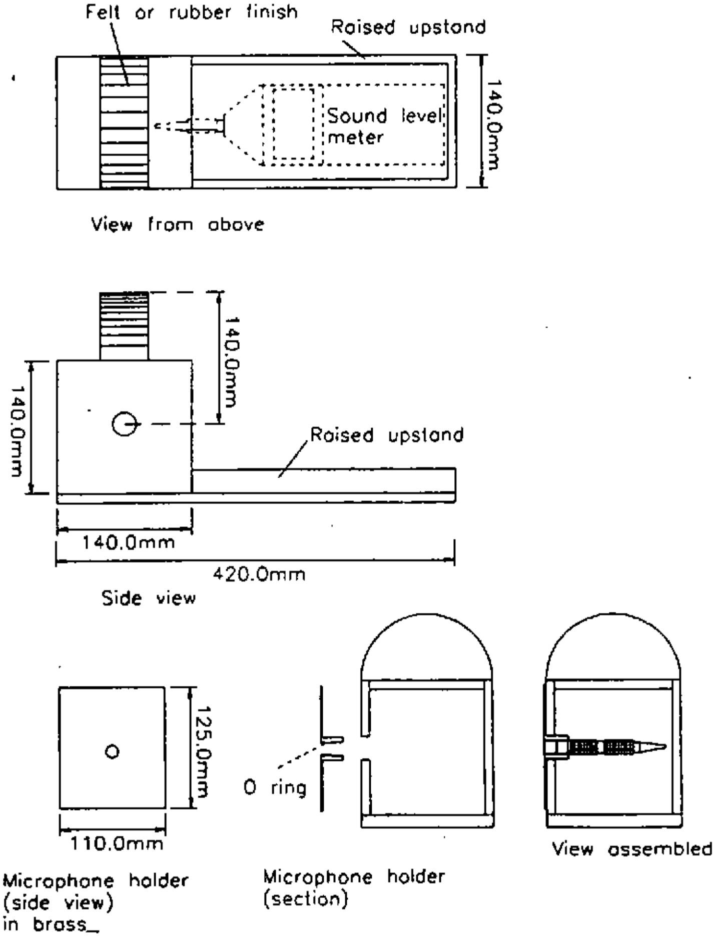

Figure 2: Practical version of flat plate and test jig.

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