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GUIDE TO THE DESIGN OF HEARING PROTECTORS FOR GENERAL INDUSTRIAL USE

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BRITISH OCCUPATIONAL HYGIENE SOCIETY TECHNICAL GUIDELINE

GUIDE FOR THE DESIGN OF HEARING PROTECTORS FOR GENERAL INDUSTRIAL USE

BOHS Technology Committee

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Abstract—Guidance is given on some of the physical requirements for comfortable, durable and generally acceptable personal hearing protectors. These aspects are not covered by British Standard 5108 (1974) 'Method of measurement of attenuation of hearing protectors at threshold'.

INTRODUCTION

A British Standard (British Standard 5108, 1974) 'Method of measurement of attenuation of hearing protectors at threshold' was published in July 1974. However, there are many factors, other than attenuation, relevant to the design and specification of hearing protectors which will be comfortable, durable and generally acceptable to the user, and which are not covered by the British Standard.

The working party considered information available in the scientific literature and in other national standards, codes of practice and similar documents. This was supplemented by user experience of the hearing protectors currently available in Great Britain and a trial of various types of ear muffs using industrial subjects.

This Guideline is intended to cover the design of all hearing protectors, including those incorporating mechanical moving parts, for general industrial use. Headsets intended specifically for communications purposes and certain special purpose hearing protectors are excluded.

A minimum attenuation requirement has been deliberately omitted, although the method of presenting attenuation data has been specified in accordance with the relevant British Standard (BS 5108, 1974). It was felt that the selection of hearing protection suitable for a particular situation was beyond the scope of the present

Guideline and is best left to the user, who may seek further guidance from a publication such as 'Code of Practice for reducing the exposure of employed persons to noise' (Health and Safety Executive, 1972).

The attention of readers is drawn to the significance of this Guideline in relation to Section 6 of the Health and Safety at Work, etc. Act 1974 regarding the general duties of designers, manufacturers, importers or suppliers of articles for use at work.

TERMINOLOGY

For the purposes of this Guideline, the following definitions apply. These are generally in line with the definitions given in national standards, codes of practice and other documents.

Hearing protector

A device worn to reduce the level of noise heard by the wearer.

Ear plug

A hearing protector which is inserted into or otherwise closes the ear canal (external auditory meatus).

Semi-insert protector

A hearing protector which closes the entrance to the ear canal without being inserted deeply into it.

Ear muff

A hearing protector either fitted over and enclosing the pinna and sealing against the side of the head, or sealing against the pinna. Ear muffs intended for general industrial use are usually of the former type, and this type is referred to as circumaural ear muffs.

Spring band

A band of springy material applying force to semi-insert protectors or ear muffs in order to hold them in the entrance to the ear canal or against the side of the head respectively. The band may pass over the top of the head (head-band), behind the head (neck-band) or under the chin (chin-band).

Helmet

A device covering a substantial part of the head and generally having functions other than, or in addition to, hearing protection.

CONFORMITY WITH GUIDELINE

Hearing protectors should be tested in the condition in which they are offered for sale. The minimum number of samples required for each set of tests is as follows:

durability and spring-band force tests: three samples;

all other tests: one sample.

This requirement should not be confused with, and should not replace, normal quality control techniques applied to the manufacture of hearing protectors. Further guidance on this latter aspect may be obtained from British Standard 6000 (1972) 'Guide to the use of British Standard 6001. Sampling procedures and tables for inspection by attributes' and British Standard 6001 (1972) 'Sampling procedures and tables for inspection by attributes'.

ATTENUATION

All types of hearing protector should be sampled, the attenuation measured and the results expressed according to the provisions of British Standard 5108 (1974) 'Method of measurement of attenuation of hearing protectors at threshold' or any subsequent British or International Standard. The results should also specify the test method, test laboratory and date of test.

Present objective test methods using dummy heads, artificial ears, etc. give varying results and should not be used until a suitable method has been found and accepted by national or international standardizing authorities (see Note 1 in Appendix II).

MATERIALS

All hearing protectors should be constructed of materials suited to withstand normal usage, exposure to sunlight and extremes of environmental temperature and humidity. The materials used should be such that every component has a probable effective shelf life of at least 5 yr, if properly stored and maintained, without corrosion or deterioration which would significantly impair the performance of the protector.

Materials of a highly flammable nature of the same order as cellulose nitrate should not be used.

Materials should not be used which are likely to provoke adverse skin or other reactions. Materials that may come into contact with the skin should be non-staining, soft and pliable. Materials should not absorb atmospheric moisture, or physically absorb or adsorb common chemicals, solvents or oils.

Materials should be resistant to sweat, hair oil, ear wax, barrier creams, cosmetics, etc. and also common industrial liquids such as solvents and oils. Materials should not support the growth of moulds or yeasts. Parts (e.g. ear muff cushions) which are of necessity made from materials which are likely to deteriorate should be readily replaceable unless the cost of the whole hearing protector is such that it may be treated as disposable. Guidance should be given to the user on the substances which are likely to affect these parts of the hearing protector (see Note 2 in Appendix II).

CLEANING

Hearing protectors of the non-disposable type should be capable of withstanding repeated cleaning and disinfecting by recognized everyday procedures. Materials should not deteriorate as a result of washing with soap or a mild non-irritant detergent and water, or, where appropriate, immersion in a weak aqueous disinfectant solution (see Note 3 in Appendix II).

DURABILITY

Hearing protectors should not sustain permanent damage as a result of being dropped three times in quick succession from mutually perpendicular orientations at a

height of 2 m on to a smooth horizontal concrete surface immediately after being maintained at a temperature of $-10°C$ for 3 h (see Note 4 in Appendix II).

PHYSICAL REQUIREMENTS

Ear plugs

Permanent ear plugs should be either custom-made, available in sufficient standard sizes, or adaptable to fit ear canals in the range 7–11 mm mean diameter (see Note 5 in Appendix II).

There should be a projection or other facility to prevent ear plugs being inserted too far into the ear canal and an adequate and permanent means of gripping the plugs to facilitate easy insertion and removal.

Semi-insert protectors

Semi-insert protectors should be made to fit auditory canals in the range 7–11 mm mean diameter. The weight should not exceed 250 g (see Note 6 in Appendix II).

A spring band may be provided to render semi-insert protectors captive, but the force to hold the protectors in place should not exceed 1 N (approximately 102 g).

Ear muffs

The opening in the cups of ear muffs, including the seal or cushion, should not be less than 50 mm by 35 mm, and the cavity should be capable of enclosing an ear measuring 78 mm by 43 mm with a 26 mm protrusion of the ear (measured from the face of the seal).

The spring-band should be adjustable to accommodate a minimum range of head sizes from 320 mm to 385 mm measured in an arc between the upper edges of the ear canals in over-head types, and from 250 mm to 300 mm measured in an arc from between the forward edges of the ear canals in behind-head types.

The weight should not exceed 500 g, except for those ear muffs designed for special purpose applications. The weight should be positively supported on the crown of the head.

The total force applied by the spring-band should be measured after conditioning by forcing the ear cups apart to a distance of 200 mm between the faces of the seals 25 times with the spring-band at half extension. The force should not exceed 20 N (approximately 2040 g) at a separation of 150 mm between the faces of the ear cups at any spring-band extension. One type of apparatus suitable for determining the force applied across the cups is shown in the Fig. 1 of Appendix I. Where the spring-band consists of two separate wires, the differences in forces should not exceed 5%.

The pressure applied by the faces of the ear cups should not exceed 10^4 Pa (approximately 1.02 g mm^{-2}) when the faces are at a separation of 150 mm. The pressure should be more or less evenly distributed around the circumference of the seals. (One suitable method of determining the pressure and its distribution is given in Appendix I.)

The ear cups should be pivoted or otherwise attached to the spring-band to allow swivelling through a conical angle of $\pm 15°$ about the plane where the faces of cups are parallel to each other and at a separation of 150 mm (see Note 7 in Appendix II).

COLOUR

A high visibility colour is preferred (see Note 8 in Appendix II).

COMFORT

All hearing protectors should be comfortable to wear for long periods (see Note 9 in Appendix II).

INHERENT SAFETY

All hearing protectors should be inherently safe and designed to minimize the extent of further injury in the event of an accident (see Note 10 in Appendix II).

INFORMATION, INSTRUCTIONS AND MARKING

Three distinct categories of information should be available from the manufacturers of hearing protectors, namely user instructions, customer or advertising matter, and test reports.

User instructions should be provided with each protector or packet of disposable material, giving the method of fitting, cleaning or disinfecting and routine maintenance if necessary. Consideration should be given to providing instruction in alternative languages for the benefit of users who may not speak English as their native language.

Customer or advertising material should contain information on the correct selection and fitting of the hearing protectors, results of attenuation and other tests, and the information given with the user's instructions.

Manufacturers or suppliers should be prepared to make copies of test reports on their products available to responsible persons on application.

Where ear muffs are asymmetrical front to rear, the correct mode of wearing should be clearly and indelibly marked on the ear muff shells. An arrow towards the front, with the word 'front' is the preferred method of designation (see Note 11 in Appendix II).

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APPENDIX I

A SUITABLE APPARATUS FOR TESTING SPRING-BAND FORCES AND PRESSURE OF EAR MUFFS

A suitable apparatus for testing the spring-band force and pressure on the seals of ear muffs is described below and illustrated in Fig. 1. It should be pointed out that this is only one possible method of test and that variations on this, or even completely different methods of test, may be feasible and equally suitable. However, the pressure on the ear muff seals must be measured under the influence of the spring-band, as the force exerted by the spring band may not be evenly distributed around the circumference of the seal and the area of actual contact will almost certainly be less than the superficial area of the seal. This requirement precludes the use of special rigs of mountings for the cups in isolation or merely pressing them on to a plane surface by hand.

The shape of the wooden block was found to be suitable for all the ear muffs tested by ACTON *et al.* (1976). A semicircular block was not suitable for certain semi-elliptical spring bands which rested on the block at the 10 or 11 o'clock position when the force was applied to the right-hand cup. Similar difficulties were experienced with a simple triangular block when spring bands which were angled at the apex were tested.

Spring band force

A force opposing that of the head-band is applied to one ear cup by means of a spring balance or weight and pulley system; it is increased until the face of the cup is no longer in contact with the test apparatus. This may be determined as the point when a light-weight drop plate is no longer supported between the face of the cup and the apparatus, or a sheet of thin card can be passed freely between. The drop plate should be drilled or punched with holes free of burrs at centres not exceeding 5 mm in order to avoid any suction effects, and should be heavy enough to overcome attraction by electrostatic forces. A sheet of the perforated bakelite material measuring 120 mm × 120 mm × 1.5 mm sold for building electronic circuits makes a suitable drop plate, but care should be taken to ensure that the piece used is flat.

Alternatively, the apparatus may be mounted vertically and the force applied directly by weights. In this case, the free passage of the thin card between the face of the ear cup and the apparatus is an indication that the applied force equals the spring band force and contact with the block has been broken.

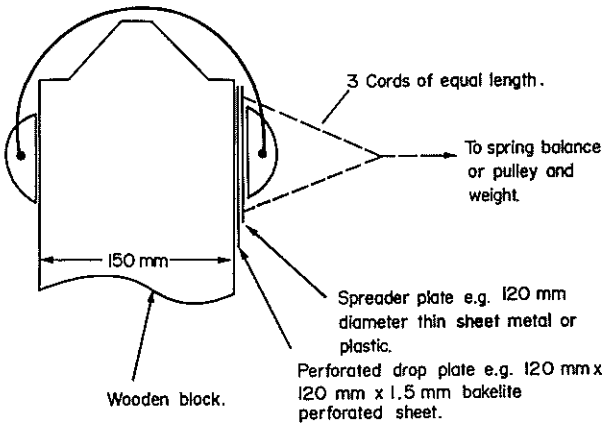

FIG. 1. Apparatus for measuring head band forces and pressure of ear muffs.

Care should be exercised that the three cords attached to the spreader plate are of equal length, and that the force is applied perpendicularly to the apparatus. The dimensions of the spreader plate are not critical.

Pressure on seals

The procedure devised for determining the pressure on the seals relies on measuring the area of contact and the total force as above. Two methods have been devised of transferring an impression of the seal on to a sheet of paper. The impression must be obtained when the seal is under the influence of the spring band only, as the force may not be perpendicular to the faces of the seals, resulting in an uneven distribution of pressure around the seals.

The first method involves coating the seal with lithographic ink diluted with white spirit or a similar petroleum solvent (e.g. 100/120 petroleum spirit) to a brushing consistency. The ear muffs are then carefully placed over the 150 mm wooden block so that an impression is made on a piece of paper pinned to one surface.

In the second method, the 'toner' powder used in xerographic machines is brushed on to the surface of the ear muff seal, and an impression made on a piece of paper which had been freshly passed through a xerographic machine. It is advisable to take an immediate photocopy of the impression in order to obtain a permanent record. The quality of the impression is not as good as in the first method, but the outlines are usually clearly traceable.

The surface area of the impression is ideally measured using a planimeter. However, if the impression is taken directly onto graph paper, the 'counting squares' method can be used to obtain an approximate measure of the contact area.

Head band extension

Marks made on the side faces of the wooden block may also be used to check compliance of the ear muffs with the requirements for head band extension.

APPENDIX II
NOTES

Note 1

The British Standard method requires a diffuse sound field instead of the frontally incident sound field specified in the American Standard method or its derivatives previously used by most manufacturers for testing their products. The British Standard method involves testing hearing protectors in conditions more akin to realistic industrial conditions, and also seeks to reduce some of the sources of variability inherent in the American Standard test method. Present work towards preparing an International Standard retains the real ear threshold shift method of measurement and a random-incidence sound field.

Although present objective test methods are not considered suitable for specifying the attenuation of hearing protectors, there is nothing to preclude the use of such methods for research, development, quality control or similar purposes. The use of cadaver tests is acceptable, as the major problem with objective tests is reproducing the leakage paths past or around the hearing protector. In practice, cadaver tests remove the sources of variance due to subjective assessment of hearing thresholds from the test results.

Note 2

Although the use of materials which absorb or adsorb common chemicals, solvents or oils is precluded, materials which absorb liquids by purely mechanical means, e.g. glass-fibre or plastic foam, and may be readily cleaned, are admissible. Difficulties may also be experienced by common oils and solvents leaching the plasticizer out of the materials used for ear muff seals.

Hearing protectors for use in areas of potentially explosive or inflammable atmospheres such as may occur in coal mines or oil refineries may need to be made from spark-free and antistatic materials.

Note 3

Hearing protectors which are intended for disposal at the end of each period of use need not conform to the requirements for cleaning.

Protectors should be designed so that they may be partially or wholly dismantled where appropriate for cleaning. Electronic or mechanical components which cannot be removed may require special care for effective cleaning.

Note 4

The requirement for a drop test was taken from the Canadian Standard Z94.2 (1965 with revisions dated 1967) 'Hearing Protectors', except that the temperature requirement has been amended in view of the less severe British climate, and it is in line with the low temperature requirements of British Standards for other protective equipment.

The Guideline refers to permanent damage, such as fracture of components or bursting of seals. Easily rectifiable failures, such as spring-loaded components becoming detached, are acceptable.

Note 5

In spite of an exhaustive literature search, no anthropometric data seemed to be available for ear canal and ear hole sizes. The size requirement for ear plugs was taken from dimensions given in the original report describing the development of the V51-R ear plugs by the U.S. Office of Scientific Research and Development (1945) and from measurements of proprietary ear plugs for which records of issue by a large industrial user were also available.

The middle three sizes of V-51R type ear plugs generally available commercially will only provide an effective fit for approximately 75–80% of a typical mixed industrial population. It is necessary for compliance with this Guideline that the full five conventional sizes should be provided.

Note 6

See note 5 above regarding sizes.

Note 7

In spite of an exhaustive literature search, only very limited British anthropometric data seemed to be available for ear and head sizes. The measurements quoted were American data taken from 'Anthropometry of Flying Personnel 1950', WADC TR 52–321, Wright Air Development Centre, U.S.A. and 'Anthropometry of the Human Ear', AMRL TR 67–203, Aerospace Medical Research Laboratories, U.S.A. Head breadth and overhead distances measured between the ear-holes were also given by BOLTON *et al.* (1973) in a Royal Aircraft Establishment Technical Report. The cup sizes quoted will accommodate 90% of male ears freely, and over 99% of male ears with only a slight (less than 6 mm) flattening of the outer part of the ear. The head band sizes will fit 99% of male heads.

The weight, spring band force, pressure applied by the forces of the ear cups and the degree of pivoting between the cups and head band were derived from a survey of ear muffs which were apparently acceptable to industrial personnel in these respects (ACTON *et al.*, 1976).

Muffs with the head band behind the head should have the weight positively supported on the crown of the head, for example by a thin strap, so that they can be worn with safety helmets. Without such support for the weight, the seal between the cups and the wearer's head is likely to be seriously affected during physical work, apart from the discomfort caused by the weight of the muffs resting on the top of the pinna.

Although a provision is made that the forces applied by the wires in spring bands which consist of two separate wires should not differ by more than 5%, this is rarely attained in practical use as the wires are readily strained or deliberately abused. This type of head band is usually not satisfactory for general industrial use.

In determining pressure, the area of contact must be measured with the force applied by the spring band. This will probably be less than the superficial area of the seal, and direct measurements are not acceptable.

Note 8

A high visibility colour is preferred as it enables other persons to see the protector more easily and to appreciate the limitations of hearing or movement which the user may have. It also enables supervisory staff to check more readily that hearing protection is being worn.

Note 9

It is desirable to test the wearability of sample hearing protectors by controlled subjective trials in the users' environment.

Note 10

Safety requirements preclude rigid ear plugs or those with rigid parts; ear plugs which can be inserted the wrong way round and ear plugs without means of preventing too deep insertion.

Head bands should not have sharp edges or protruding ends. Ear muffs should not be made of brittle material which may break into sharp edged or pointed pieces on impact.

Ear muffs which are worn in conjunction with safety helmets should not invalidate the requirements of the relative British Standards for safety helmets. In this context, the prime requirement is free movement of the outer rigid shell of the helmet in relation to the head in the event of an impact. In British Standard 5240 (1975) 'Specification for general purpose industrial safety helmets' and also in International Standard 3873 'Industrial safety helmets' the vertical clearance between the top of the headform or cradle which fits on the head, and the inside profile of the hard shell, should not be less than 25 mm. This requirement seemingly precludes the use of ear muffs attached to the outer rigid shell of the helmet, i.e. the part which is designed to move with respect to the head. This movement would then be transferred to a shearing motion over the ears. Hinges, springs or sliding joints between the ear cups and the helmet may not be satisfactory, as, even when in good order, they are likely to transmit some part of an impact type force. Both the British and International Standards draw 'the attention of users . . . to the danger of modifying . . . any of the original component parts of the helmet'.

Note 11

General purpose hearing protectors should normally be symmetrical so that they cannot be worn incorrectly. However, certain special purpose hearing protectors, for example, high attenuation ear muffs, must be asymmetrical, and these should be clearly marked as described in the Guide.