ASSESSMENT OF COMFORT OF VARIOUS HEARING PROTECTION DEVICES (HPD)

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To evaluate the comfort of hearing protection devices, two models of ear plugs and five models of ear muffs were tested. The psychophysical method of 'single stimuli' was applied on a group of 30 subjects with or without wearing the devices for a short duration of 15 min under noise condition of 100 dBA in the acoustic chamber as also on a group of 10 weavers with the protection devices worn for longer durations of 1h, 4h and 8h under noise exposure of 102-104 dBA in the weaving shed. Each subject performed 8 trials with each type of device on different days. Application force and tightness of spring were also evaluated. The results yielded a comfort grading for hearing protection devices. The comfort grading, however, depended on several factors in addition to application force and tightness of spring, which has been discussed.

Some workers are exposed to a high level of noise in their work places in industries for a prolonged period of time without ear protection, resulting in gradual hearing loss and finally deafening of the ear. Such hearing loss at high frequencies is known as noise induced hearing loss which is irreversible in nature (NIOSH, 1973). Thus, noise control is of paramount importance either to reduce the risk of hearing loss or to provide better working conditions. The control measures can be affected at least in two ways: (a) control of noise at source and transmission path, (b) control at the individual level with hearing protection devices. While the former is expensive and requires a long time to achieve, the latter can provide an instant solution. However, the workers in general express displeasure with wearing the protection devices because of the discomfort they experience in wearing them, some of which include: irritation on the outer ear and the ear duct, tightness of the ear muff spring, pressure on the skin surface, improper fitting, etc. All such considerations have laid the basis of the present investigation to evaluate the comfort of wearing hearing protection devices and also to examine some of the principal physical characteristics of these devices regarding the overall

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comfort sensation.

MATERIALS AND METHODS

Subjects. A group of 30 male college student volunteers, 20–27 years of age, with sound physical health and normal hearing participated in the experiment for a short-duration wear of the hearing protection devices. They did not have either previous exposure to noise and had not worn devices routinely.

A total of 10 male weavers, aged 20–27 years, occupationally exposed to noise but whose other characteristics were similar to those of the college students, volunteered for a long-duration wear of the devices in their real work situations.

Equipment. Hearing protection devices: Two models of ear plugs (models 'A' and 'B') and five models of ear muffs (models 'A', 'B', 'C', 'D', and 'E') which were tested are depicted in Fig. 1. These were purchased from various manufacturers in India without disclosing their intended use. The physical characteristics of the devices are given in Table 1.

Ear plugs: Both models, made of soft vulcanised rubber, are conical in shape and can fit in the adult ear. Each pair of ear plugs is separated by a long thread to prevent loss. To wear the plugs, the subject pulls up the pinna with the contralateral arm and inserts them with the other arm into the external auditory meatus until they close the opening of the ear.

Ear muffs: Each model of ear muff consists of two cups which are joined together with an adjustable headband. The cups are made of hard plastic. To wear them, the subject positions the headband over his head and rests the cups over the pinna and adjusts them in such a way that a good, leak-free contact is made with the surface of the head. The structures of the ear muffs are as follows:

Model 'A': The cups are rectangular in shape. A thin layer of foam is spread at the base inside the cup. The headband is made of hard plastic.

Model 'B': The cups are oval shaped. The layer of foam is a little thicker than that of model 'A' and is spread inside the cup. The headband is also made of hard plastic.

Model 'C': The cups are rectangular in shape. Two layers of foam, one on top of the other, are placed inside the cup. The headband is made of metal wires (steel), which are covered with a thin layer of foam seal.

Model 'D': The cups are also rectangular in shape, which are joined with a rigid rubber headband. A thick layer of foam is stuck at the centre of the cup, leaving much of the interior unsealed. The volume available inside the cup for accommodating the pinna is considerably less.

Model 'E': Its cups are oval-shaped, more akin to the structure of the pinna. The interior of its cups contain a thick layer of foam spread over at the base followed by another foam seal with a 1-mm thick nylon wire mesh on top of it. The latter foam seal is separated from the former by 37 mm of air. The volume available
Fig. 1. Various models of Hearing Protection Devices.
Table 1. Physical characteristics of hearing protection devices.

<table>
<thead>
<tr>
<th>Model of ear protectors</th>
<th>Length (cm)</th>
<th>Weight (g)</th>
<th>Weight (g)</th>
<th>Thickness of foam in cup (cm)</th>
<th>Area of cushion seat (cm²)</th>
<th>Volume of cup with foam inside (cm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Ear plug</td>
<td>Ear muff</td>
<td>Cup Foam cushion Foam in cup</td>
<td>Headband Total weight</td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>2.0</td>
<td>156</td>
<td>60 10 3 54</td>
<td>200 0.7</td>
<td>52 73</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>1.0</td>
<td>148</td>
<td>41 10 4 50</td>
<td>160 1.2</td>
<td>51 69</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td></td>
<td></td>
<td>41 9 4 57</td>
<td>165 1.5</td>
<td>46 42</td>
<td></td>
</tr>
<tr>
<td>D</td>
<td></td>
<td></td>
<td>26 15 4 80</td>
<td>170 2.5</td>
<td>58 18</td>
<td></td>
</tr>
<tr>
<td>E</td>
<td></td>
<td></td>
<td>40 10 5 70</td>
<td>180 1.0</td>
<td>44 29</td>
<td></td>
</tr>
</tbody>
</table>

inside the cup is just enough for the pinna to be accommodated. The headband made of plastic is sealed with a thick layer of circumaural foam cushion.

*Testing conditions.* An acoustic chamber (BHATTACHARYA et al., 1985), a sound level meter (B & K, Denmark) and an audiometer with loudspeakers (M/s. Arphi (India) Ltd.) were used in the experiment.

*Vernier sliding caliper.* The caliper was modified to increase its length to 16 cm and its cross-arms were lengthened by the addition of tapered brass extension riveted to the original arms (HUGHES and LOMAEV, 1972).

*Design.* The test was carried out in the acoustic chamber under white noise condition of 100 dBA, generated by the audiometer, then amplified and finally led into a set of speakers.

The subjects were randomly divided into two groups of 15 each. A statistically balanced design was followed (WINER, 1971) whereby one group of subjects experienced the noise with an open ear condition and then with the hearing protection devices in position, while the other group experienced the same first with the hearing protection devices in position followed by an open ear condition. This procedure eliminated bias in comfort responses in that subjects starting with the open ear condition may find later the wearing of the hearing protection devices uncomfortable compared to those starting with the hearing protection devices in position and they may continue to feel the wearing uncomfortable even when wearing the most comfortable one. The hearing protection devices also were worn in a random order. The psychophysical method of “single stimuli” involving absolute impression of comfortable-uncomfortable sensations (WOODWORTH and SCHLOSBERG, 1971) produced by the hearing protection devices was followed. The sensation of the subjects were obtained after they had worn the devices for a short duration of 15 min. Each subject performed a maximum of eight trials with each model, spread over 4 days, thus yielding a total of 1,680 responses.

An equal number of responses were also obtained from a group of 10 weavers who also performed likewise in their workplaces in the weaving shed interposed.
with noise of 102–104 dBA, following wearing of the devices for longer durations of 1 h, 4 h, and 8 h.

Other characteristics such as bizygomatic breadth of subjects (a maximum distance between the bony structures forward of the ears), tightness of headband spring, application force, application pressure, etc. were also taken into consideration.

Procedure. In the acoustic chamber, the subjects were tested individually, once per day, at the same time of day (10:00 h). They were seated on an adjustable stool in front of the speaker in such a way that the horizontal axis of the speaker coincided with the vertical axis of the head. They were then briefed about the nature and purpose of the experiment. Their queries were answered, if any. They were also given the option to discontinue their participation if they so wished. No subjects declined to participate. The principal investigator then left the acoustic chamber.

The subjects experienced the noise condition for 15 min either with open ear or with the hearing protection devices in position. Proper fit of the protection devices was ensured. The subjects were not allowed to know which model of the devices was placed in position into their ear ducts or over their heads. Neither were they allowed to talk or chew during the experiment. They were then required to judge their sensation as ‘comfortable’ or ‘uncomfortable’ including while moving their heads. On the day before the test day, the subjects were familiarised with the tests in try-out sessions.

Similarly, the weavers were tested for comfort in wear while they were doing their normal routine work in the weaving shed.

The bizygomatic breadth was measured with a vernier sliding caliper with its arms pressed lightly against the bone at its most prominent positions following the method of Hughes and Lomaev (1972).

A brief interview was conducted to identify the specific deficiencies of the devices that could produce discomfort.

RESULTS

For each model of the hearing protection devices, the proportion of comfort responses was calculated to be the ratio of the number of ‘comfort’ responses to the total number of responses, obtained separately by the student volunteers as well as the weavers. These proportions were then multiplied by 100 to obtain percent of comfort responses. The standard deviations were also calculated.

For each of the two models of ear plugs, the percentage of comfort responses was very high, 98.5% for model ‘A’ and 97.9% for model ‘B’, indicating that almost all the subjects felt comfort in wear.

For ear muffs, the percent of comfort responses with the standard deviations depicted in Fig. 2 indicate that the comfort responses varied considerably from one
Fig. 2. Comfort ratings for each model of ear muffs.

model to the other. The highest percentage of comfort response was obtained for model ‘E’ followed in order by models ‘A’, ‘B’ and ‘C’. Model ‘D’ was cited as the least comfortable. It may also be seen that the variability in comfort responses for model ‘E’ is small and for model ‘D’ high compared to the other models.

Figure 3 shows that the comfort responses of the weavers were similar to those of the student volunteers, but the percentage of comfort responses decreased with time as the duration of wearing the muffs increased up to 4 h, which further decreased as the wearing continued up to 8 h.

As close fit of the ear muff and its ability to attenuate sound depends on the application force, the application force was estimated (in Newtons) for each model of ear muff with respect to the bizygomatic breadth (138–146 mm) of subjects following the guidelines of ANSI (1974) and standard deviations were calculated, as shown in Fig. 4a. Further, ‘tightness of the spring’ of the ear muff was calculated as the ratio of the application force of each ear muff to the width between its cups, as shown in Fig. 4b. It may be seen from these figures that the application force of model ‘E’ was low and the tightness of the spring was also less compared to the other models. The application force of models ‘A’ and ‘B’ were comparatively high.
as also were the tightness of the springs of its headbands. However, the application force and the tightness of the springs for models ‘C’ and ‘D’ were low compared to models ‘A’ and ‘B’.

DISCUSSION

The comfort sensation of hearing protection devices are governed by several physical factors such as its mass, attenuation characteristics, structural features, application force, application pressure, tightness of the spring of the headband, etc.

The sound attenuation characteristics of the two models of ear plugs (‘A’ and ‘B’) and five models of ear muffs (‘A’, ‘B’, ‘C’, ‘D’ and ‘E’) have been reported earlier (Bhattacharya et al., 1993).

The mass of the hearing protection devices are well below the recommended value of 200g (Zwislocki, 1955) and hence its influence on comfort sensation would be insignificant.

The high percentage of comfort sensation for each model of the ear plugs are
Fig. 4. Showing (a) application force and (b) tightness of the spring for each model of ear muffs. Figures in parentheses indicate standard deviations (\(\pm\)).

Attributable to the facts that the plugs are less in weight, the material used for their manufacture are supple enough to be easily compressed and the structural characteristics are similar to those of the ear duct contour, thus providing a good fit into the ear duct. Also, the fact that the ear plugs regained their original shapes on removal from the ear canal and thus would ensure their re-use with comfort. However, the interview session revealed that the ear plugs are not able to provide sufficient attenuation in a high sound field; these findings are in agreement with those reported by BHATTACHARYA et al. (1993). The weavers also gave similar responses when they wore the plugs in their work places with the noise level reaching as high as 104 dBA. However, they revealed that the ear plugs could be worn for a short duration in work situation where sound levels are either at or slightly higher than the safe exposure limit of 90 dBA.

For the ear muffs, the relatively high percentage of comfort responses for model 'E' is due to its low application force and smaller application force of its spring compared to those of the other ear muffs, as the comfort in wear appreciably increases with decreasing values in the former two variables (LUPKE, 1964). The structural features of ear muff 'E' also contributed to its comfort value; firstly, its
oval-shaped cups conform better with the outer structure of the pinna; secondly, the foam in two layers separated by an air column (37 mm) inside the cups facilitated high sound attenuation, and the wire mesh spread on top of the foam layer further enhanced sound dissipation (Bhattacharya et al., 1993), thereby favouring comfort sensations; thirdly, the volume available inside the cup is enough to accommodate the external ear with ease and comfort; fourthly, the cups with plastic foam-filled seal holds the sides of the head without causing any pain on the surface of the skin; and finally, the soft circumaural cushion sealed to the headband further helps reduction of headband tension (Acton et al., 1976).

Models 'A' and 'B' were graded as less comfortable compared to model 'E' because the application force of the former two models are comparatively high, as are the tightness of the headbands. The headband thus holds the sides of the head tightly as the tightness increases with the increase in application force (Lupke, 1964). However, the design considerations of the muffs are also responsible for the diminished comfort: the headsets of both models are made of hard plastic without any foam cushion seal on it, thereby producing high headband tension. Moreover, a single thin layer of foam spread inside its cups caused a lowering of acoustic efficiency.

Model 'C' is rated as less comfortable and model 'D' as least comfortable compared to the other models, despite its low application force and less tightness of the headband (spring) relative to those of models 'A' and 'B'. This is the result of the design characteristics of these two ear muffs. The headband of model 'C' is made of metal wires (steel) with a very thin foam cushion on it, resulting in improper fit on the outer ear. In model 'D', the outer ear is compressed against the foam seal placed inside the cup. The attenuation characteristics of the muff is also considerably less than the other models. The headband is made of hard rubber. The design of its cups is incompatible to the structure of the ear; thus, it fails to provide adequate seal on the outer ear and consequently decreases comfort in wear. This suggests that for comfort in wear application force and tightness of spring (headband) are not the only determining factors, but the complete design features of the hearing protection devices that contribute to the overall comfort sensation.

Although the application pressure of hearing protection devices is another determinate for comfort in addition to application force, its influence in this experiment has appeared to be marginal as the application force of the various models of ear muffs are below the recommended value of 12 N (Brinkmann and Brocksch, 1977). The standard deviations also do not exceed the stipulated range of ±1 N. The standard maintains that application force could produce tangible application pressure should the former be higher than the standard value. Thus, the application pressure did not merit measurement in this experiment.

However, it should be borne in mind that the feeling of comfort is a psychological sensation and any small variation of width between the cups can produce appreciable variation in application force and consequently in the tightness of the
spring, which may result in alterations in comfort responses.

REFERENCES


