Design and Standardization of a Portable Audiometric Booth

Many studies have established that the ear suffers a temporary and ultimately a permanent hearing loss when exposed to high intense sound, depending upon its spectral characteristics, duration and years of exposure. The ability of the ear to respond to weak sounds, though very subtle, is vital in industries to avoid many hazardous situations. This can be obtained by assessing the threshold of audibility for pure tones.

In India, attempts have been made to estimate threshold shifts of the workers exposed to a high level of noise recently. One of the reasons may be due to the lack of availability of audiometric booths which are a prerequisite to ensure quiet conditions for pure tone audiometry. While anechoic sound proof rooms and audiometric booths are well developed abroad, technical expertise are yet to take shape in this country (import of audiometric booths would, however, tax the exchequer quite considerably). Hence, an attempt has been made for the first time to design a portable audiometric booth wholly indigenous, so that it may be manufactured and marketed at a comparatively low cost. A portable audiometric booth can be used by several industries for the evaluation by the quantitative and valid means of normal and impaired hearing.
Materials and Methods:

The Booth:

The frame, bodywork and construction of the booth were carried out by a commercial firm. The National Physical Laboratory, New Delhi, and the National Institute of Occupational Health, Ahmedabad, were consulted when required.

The booth is a trapezium shaped box (Fig. 19). Its external dimensions are: 0.90m long X 1.06m wide X 1.51m high with 0.46m wide roof, and internal dimensions are: 0.77m long X 0.95 m wide X 1.37 m high with 0.41m wide ceiling. It is mounted on four anti-vibration caster wheels (14 Cm dia.) for portability. The wheels are wrapped with rubber guards. The total weight of the booth is 700 Kg.

The back wall of the booth is constructed with alternate claddings of 3 mm thick aluminium and lead sheets in six layers, followed by a plaster of 3 Cm thick sponge foam. The sponge foam (3 Cm thick) has been used wherever it was considered necessary from design point of view. The two side walls are made of aluminium sheets (3mm thick) embedded with sponge foam. The floor is structured with 3 mm thick aluminium-lead-aluminium sheets, with sponge foam sandwiched between lead and aluminium sheets. The inner walls, floor, and ceiling are covered with 2 mm thick hardboard (Fig. 20).

The door (1.36 x 0.83 m) inclined at an angle of 45º is constructed of 2 Cm thick lead sheet. In the upper half of
the door $50 \text{ Cm} \times 50 \text{ Cm}$ lead sheet is cut out. It is replaced by sponge foam followed by 1mm thick lead sheet sandwitched between two glass panes (each 3 mm thick). The glass panes are fitted with 2 Cm wide aluminium strips lined with 4 mm thick rubber gasket on the inner and outer surface of the door. The inner portion of the door is covered with sponge foam. The inner and the sandwitched sponge and the lead sheets are cut out so as to form a viewing window (15 Cm dia.). The glass panes of the window are obviously separated by 3 Cm thick air space. The door is further bordered with a double layer of sponge foam followed by 32 Cm wide X 4 mm thick gasket internally. The door is also provided with a handgrip to facilitate opening and two locking devices to ensure adequate sealing.

On the roof is mounted 90 Cm long X 39Cm wide X 27Cm high metal ducting over 4mm thick rubber gasket. While the front and back walls of the ducting are made of 3mm thick aluminium-lead-aluminium sheets, the two side walls and top are made of 3mm thick aluminium sheets. A 52 BTXL centrifugal blower (Air Flow Developments, U.K.) with spigot guard access is fitted on the metal ducting for general ventilation. The fan has a flow setting device. The ducting is lined with lead loaded absorbing material (1.15Cm thick) so as to increase transmission loss through the duct.

Test Room:

The audiometric booth was placed in a front open room
measuring 5.69m long X 3.05m wide X 3.50m high on the ground floor. The background noise level was found to be 50 dBA to 52 dBA.

Procedure

The audiometric booth, facing front, was positioned 3.45m off the speaker. The audiometric switch was turned on at 10 dB. Sound pressure level was measured with the sound
Fig.-20 showing audiometric booth with the door open.
level meter and frequency analysis was carried out with the octave band analyser in the booth with its door open and also closed tightly. The sound pressure level was measured at subject's head level while sitting in the booth i.e., 85 Cm off the floor of the booth. The audiometric switch at 10 dB relayed ambient noise of 90 dBA. Similar measurements were taken when the audiometric switch was shifted to 20 dB, 30 dB and 40 dB to generate noise of 98 dBA, 106 dBA and 114 dBA, respectively. The data were recorded for seven days, four times a day, viz., 0600 hrs, 1000 hrs, 1730 hrs and 2200 hrs. The experiment was repeated when the booth was turned sideways and back to the position of the speaker. The centrifugal fan was kept off when the measurements were taken.

Sound pressure level in the test room was recorded each time before the start of the experiment. Noise level was also recorded in the booth with the centrifugal fan 'off' and 'on'.

Results & Discussion

The place (NIOSH) where the experiment was conducted is situated in the northern part of the city and is away from the traffic corners and far off from the textile mills and other noisy industrial establishments. While the extraneous sources of noise and the frequency of movement of vehicular traffic during early hours of day (0600 hrs) and late night
(2200 hrs) are almost negligible, the frequency increases during 1000 hrs to 1100 hrs, and 1700 hrs to 1800 hrs, due to the starting and closing time of a few administrative offices nearby. This has necessitated the measurements to be recorded during those hours so that the effect of ambient noise levels on this experiment might be studied.

As the limitation of the sound measuring devices available at the time of the experiment precluded measurements lower than 44 dB, sound pressure levels in the booth could not be recorded exactly but only as less than 44 dB. The sound pressure level in the booth with its door closed was measured to be less than 44 dB at the ambient sound pressure levels below 90 dBA, and hence the standardization of the booth was carried out at ambient sound pressure levels 90 dBA and above. As the measurements in all the directions (front, side and back) and over different periods of day differed by only 2 dB at the most, the sound pressure levels were averaged over all the measurements at each frequency. The results are shown in Figs. 21a to 21j.

The results show that at 'All Pass' sound pressure levels of 84 dB, 94 dB, 104 dB and 109 dB in the booth with the door open, decreased to 45 dB, 54 dB, 62 dB and 69 dB with the door closed at ambient sound pressure levels of 90 dBA, 98 dBA, 106 dBA and 114 dBA. Sound attenuation (door open against door closed) at ambient noise level of 90 dBA were found to be: 1 dB (56 dB against 55 dB) at 31.5 Hz; 4 dB
FIG. 21:

FIGS. (a-j) SHOWING SOUND PRESSURE LEVELS, \( \gamma = 2 \times 10^{-2} \text{ N/m}^2 \), MEASURED ON DIFFERENT FREQUENCIES IN THE Audiometric Booth WITH ITS DOOR OPEN AND CLOSED, AT DIFFERENT AMBIENT NOISE LEVELS.

- (a) 'A' DOOR OPEN
- (b) DOOR CLOSED
- (c) 63 Hz
- (d) 25 Hz
- (e) 250 Hz
- (f) 300 Hz
- (g) 1000 Hz
- (h) 2000 Hz
- (i) 4000 Hz
- (j) 8000 Hz

AMBIENT SOUND PRESSURE LEVEL (dBA)
(58 dB against 54 dB) at 63 Hz; 13 dB (57 dB against 44 dB) at 125 Hz; 23 dB (67 dB against 44 dB) at 250 Hz; 31 dB (76 dB against 45 dB) at 500 Hz; 33 dB (77 dB against 44 dB) at 1000 Hz; 29 dB (73 dB against 44 dB) at 4000 Hz; and 31 dB (75 dB against 44 dB) at 8000 Hz. Thus it indicates that attenuation increased a little at low frequencies, and considerably high through higher frequencies, i.e., 1000 Hz through 8000 Hz, with maximum attenuation being at 1000 Hz and 2000 Hz. Similar results were obtained at the ambient sound pressure levels of 98 dBA, 106 dBA and 114 dBA.

Maximum permissible sound pressure levels in the audiometric enclosure for measurement of hearing loss as suggested by Burns (1973) and the American National Standards Institution (ANSI-1960) are given in Table 2. The data recommended by Burns and the ANSI differ because Burns' data are designed to allow hearing levels to be measured to -10 dB re. BS 2497 (DSI 1969), while the ANSI data allow masking of threshold below 0 dB (ANSI 1960). Sound pressure with its door closed level measured in the booth at different ambient noise levels is shown in Table 3. It may be noted that at ambient noise levels of 90 dBA up to 500 Hz the values obtained in the booth appear to be a little above than those recommended by the ANSI; while the values exceed the recommended standards up to 1000 Hz for 98 dBA, and 2000 Hz for 106 dBA and 114 dBA. This suggests that audiometry in this booth may not be advisable in situations prevalent with noise levels greater than 90 dBA.
The noise generated by the centrifugal fan at different speeds was recorded as shown in Table 4. It is seen that the noise level was found to be 64 dB and 63 dB at 125 Hz and 250 Hz, respectively, when the speed of the fan was set at maximum. The sound pressure levels, however, were recorded to be less than 44 dB at higher frequencies from 500 Hz. The values of the fan noise level exceed that of the recommended standard for audiometry. This shows that fan noise would greatly influence the audiometry. While it may not be necessary that noise should be inaudible to the subject undergoing audiometry, it should be below that which masks the test tone at the threshold levels (Burne and Robinson, 1973).

The framework of the booth had to be strong enough so as to be carried for within-industry audiometry. The sound attenuation is mass controlled, indicating higher the mass of the partition greater the sound reduction at low frequencies (Webb, 1976). Hence sound reduction at frequencies upto 500 Hz may be attributable to the heavy weight of the booth (700 Kg), the heaviness being due to the use of lead sheet which possesses high mass and damping characteristics. Further, stiffness of the partition indicates that more the stiffness of the partition the greater the attenuation of sound at low frequency (Webb, 1976). Hence, sound reduction at low frequencies may be due to the construction of the outer skin of the booth with aluminium metals, and the interior of
of hardboard, all of which are relatively stiff. It is known that the porous materials reduce sound at high frequencies (Lipscomb & Taylor, 1978). Sound reduction at frequencies from 1000 Hz through 8000 Hz may be because of the sponge foam (porous) plastered on the interior walls and the door of the booth. The porous layer (sponge foam) being in connection with unporous layers (lead-aluminium sheets, and hardboard) may also have contributed to sound reduction in the booth at frequencies below 500 Hz (Lipscomb & Taylor, 1978). The spacings of the inner and outer glass panes separated by 3mm thick air column might have added to sound reduction. The gasket bordering the interior of the door provided good sealing and thereby reduced flanking noise.

The door of the booth was made inclined so as to accommodate a person to be seated inside. This would minimise the use of metallic sheets, thereby reducing the cost. This booth requires some further modifications which are under consideration.

The study indicates that:

(a) Audiometry can be carried out in this booth, in the winter (without the use of a fan) at ambient levels not exceeding 90 dBA.

(b) The cost of the booth (Rs. 20,000) is well below the cost of that available abroad (Rs. 80,000).

The drawbacks observed during the standardization of the booth are noted and further necessary modifications are
planned for improving the performance:

- Wiring inside the booth with multichore wires would allow a few more necessary connections.

- The centrifugal fan contributed considerably to the background noise level in the booth, due to which audiometry cannot be carried out. The fan noise may be reduced by reducing the voltage of the fan. The fan noise could further be reduced by replacing the existing ducting system with double ducting.

- Air movement in the booth was found to be unidirectional, due to which the subjects sitting inside for audiometry might feel stuffy. To improve freshness, the movement of air need be homogeneous, which can be brought about by installing air diffusers on the side walls of the booth.

- Neither auditory nor good visual communication system is existing between the subject and the experimenter. While the auditory system could be developed by providing microphones in the booth, the visual communication can be improved upon by removing the sponge and the lead sheet from the space where the glass panes are fitted.
on the door, so that the inside of the booth may be visible from outside.

Lighting arrangements inside the booth would further facilitate visibility from outside.

A handle on the back of the booth need be attached to, for easy portability.
at Burns (1973), when TDH 39 telephones fitted with Mx41/AR cushions are used.

<table>
<thead>
<tr>
<th>Octave Band</th>
<th>125</th>
<th>250</th>
<th>500</th>
<th>1000</th>
<th>2000</th>
<th>4000</th>
<th>8000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Center Freq. (Hz)</td>
<td>22</td>
<td>16</td>
<td>19</td>
<td>26</td>
<td>36</td>
<td>38.5</td>
<td>34.5</td>
</tr>
<tr>
<td>Sound Pressure Level, dB</td>
<td>40</td>
<td>40</td>
<td>40</td>
<td>40</td>
<td>47</td>
<td>57</td>
<td>67</td>
</tr>
</tbody>
</table>

a: Burns (1973), when TDH 39 telephones fitted with Mx41/AR cushions are used.

Table 3

Background Noise Level in the Booth at
four different ambient noise levels*

<table>
<thead>
<tr>
<th>Octave Band Center Freq (Hz)</th>
<th>ambient noise level (dBA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SLM. 125</td>
<td>90  44  44  45  44  44  44  44</td>
</tr>
<tr>
<td>250</td>
<td>98  49  53  54  49  44  44  44</td>
</tr>
<tr>
<td>500</td>
<td>106 59  63  66  57  49  44  44</td>
</tr>
<tr>
<td>1000</td>
<td>114 63  69  71  63  55  45  44</td>
</tr>
<tr>
<td>2000</td>
<td></td>
</tr>
<tr>
<td>4000</td>
<td></td>
</tr>
<tr>
<td>8000</td>
<td></td>
</tr>
</tbody>
</table>

* The Octave Band Analyser read the background noise level in the booth as less than 44 dB at ambient noise levels less than 90 dBA. As the audiology is generally carried out from 125 Hz upwards, sound pressure levels below 125 Hz are not compared.
## Table 4.

Noise Level in the Audiometric Booth with the Centrifugal Fan 'off' and 'on' and the ambient Noise Level being 50 dBA to 52 dBA

<table>
<thead>
<tr>
<th>Octave Band Centre Frequency (Hz)</th>
<th>Fan 'Off'</th>
<th>Fan 'On'</th>
<th>Slow dB</th>
<th>Medium dB</th>
<th>Fast dB</th>
</tr>
</thead>
<tbody>
<tr>
<td>125</td>
<td>44</td>
<td>44</td>
<td>54</td>
<td>62</td>
<td>64</td>
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<td>4000</td>
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<td>8000</td>
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<td>44</td>
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</tr>
</tbody>
</table>
Audiometry of the Weavers

It is known that people exposed to a high intense sound suffer hearing loss depending upon the spectral characteristics, duration and years of exposure. Hearing loss is relative to the normal threshold of audibility and may be defined as reduction of hearing sensitivity. For example, if a person has a 40 dB hearing loss at 4000 Hz, it means that for the individual to perceive a tone, the intensity of that tone must be raised to 40 dB above the normal threshold of audibility. Normal threshold of audibility is defined as minimum sound levels at which a person, free from pathological ears due to disease, can just hear the sound 50 percent of the times. Hearing loss may be temporary or permanent in nature. Temporary Threshold Shift (TTS) is ascribed to that partial loss of hearing which is caused by excessive noise for a short duration and is reversible in character, while permanent or noise-induced hearing loss (NIHL) is ascribed that for a long duration and irreversible in character. The full relationship between temporary and noise induced hearing loss is not yet fully understood (Webb, 1976). Since hearing loss varies on different frequencies, the threshold of hearing is determined at each octave frequency.

The weavers of the textile mill were found to have been exposed to high level of noise (104 dBA) for a long
time and hence this part deals with the audiometry to determine the hearing loss that they might have suffered.

Criteria for normal hearing:

The audiograms have been classified in various ways by different researchers abroad for interpreting degree of hearing loss. In India, standards for normal threshold of hearing at each frequency has not yet been developed. Therefore, the average hearing levels of the persons unexposed to occupational noise (control group) has been considered for determining hearing thresholds of the weavers. However, the audiogram developed by the American Standards Association, 1954 (Appendix- 7 ), was also taken into account for comparison of the hearing levels of the control group. This requires that there be no hearing loss greater than 20 dB. If a loss of 25 dB was observed at any frequency higher than 500 Hz, the audiogram was rejected for the normal group except that a single loss of 30 dB was allowed at 250 Hz or 500 Hz.

Procedure:

Following kryter's suggestion (1970) that testing threshold of audibility with speech signals involves problems
that have not as yet been completely solved or identified, pure tone audiometry was carried out for the present investigation.

The portable audiometric booth was placed in the dispensary of the mill (50 dBA) 20 meters opposite the weaving shed. In the individual experiment the weaver was briefed about the nature and purpose of the study. He was then seated on the stool inside the audiometric booth, the earphones were fitted on his ears and the door of the booth was closed, with an instruction (Appendix 6) to report when he could just hear the pure tone, lasting for 1 to 2 seconds (Newby, 1972), by pressing the buzzer switch in hand. The pulsing of the tone was set at 0.50/second. Following the suggestion of Carhard and Jerger (1959) that ascending is better than the descending technique, or both ascending and descending techniques combined, ascending procedure was adopted. The intensity of the pure tone was raised by 5 dB until the threshold of audibility was determined at each test frequency. The actual experiment was started following brief practice session. Right ear, followed by the left ear, was tested. Testing time for each weaver lasted for about 20 minutes including 5 minutes for instruction. It was ensured that the subject would fully cooperate.

Likewise, the experiment was conducted by withdrawing the weavers from the loom shed to the booth soon after 4 hours and 8 hours of exposures, with cotton plugs inserted
into their ears on the 3rd and 5th day, respectively. While one half of the subjects were tested before exposure followed by 4 hours and 8 hours of exposures, the other half were tested in the reversed order.

Audiometry of a control group of sedentary workers (N=60) of the same age range as that of the weavers' group, but unexposed to occupational noise, was also carried out. Care was taken to ensure reliability of the reportings of the subjects' just audible sound, and to avoid 'misses' (error of omission) and 'false alarms' (error of commission), following Bunch's procedure (1943).

Result and Discussion

It may be noted that audiometry is necessary to evaluate base level hearing sensitivity. In India, since it is not customary for the industries to do audiometry at the pre-employment stage, it was decided to compare the threshold of audibility of the weavers against that of the persons unexposed to occupational noise (control group), and to evaluate the threshold shift at various stages of exposures.

Further, the subjects were tested at the pre-exposure level, so as to evaluate the hearing loss recovered from exposure to noise for 8 hours followed by a rest period of 16 hours.

Median thresholds of audibility of all the weavers and the control group by age and years of exposures are given in
figures-22 & 23. Thresholds of audibility had discrete scaling and therefore median, instead of mean, was thought to be a better index. It may be seen that the median thresholds of audibility of the right and left ear of the control group by age ranged from 10dB to 20 dB (Fig.-22a) and 5 dB to 20 dB (Fig.-22b) respectively on frequencies 250 Hz through 8000 Hz. This finding closely follows to that of ANSI (1954). The figures also indicate that the left ear of the control group had comparatively low threshold of audibility at 250 Hz than the right ear. Figures-22c and 22d show that the median threshold of audibility for both the ears of the weavers of all age groups fluctuated a little at low frequencies, with a marked 'dip' at 4000 Hz, as against that of the control group. This finding is also in agreement with that of Burns and Robinson (1973). The hearing thresholds of the test tone of the weavers in the right ear and in the left ear tended to be: 40 dB and 45 dB in the age range 25 years to 29 years against 10dB and 15 dB, respectively for the control group; 55 dB in the age range 30 years to 34 years against 15 dB of the control group for both ears; 60 dB and 55 dB in the age range 35 years to 39 years against 15 dB (both ears) of the control group. Median threshold of audibility for years of exposure to noise reflects similar results (Figs.-23a to 23d). This is quite likely as age generally counts with experience.

In a bid to find out the threshold shift during various periods of exposure to noise, forty of the total weavers had undergone audiometry after 4 hrs and 8 hrs of exposure, as
shown in Figure-24. It may be seen from the figure that
the median threshold shift is only little for both ears
of the weavers of all age groups and almost at all the
frequencies. Analysis of the data reflects similar
results in relation to years of exposures (Fig.-25).

Quartile deviations (Tables-5 & 6) show that the
threshold of audibility for both ears of the weavers of
all age groups range from 2.50 dB to 7.50 dB, against
2.50 dB to 5.50 dB of the control group upto 2000 Hz,
above which the deviations of the weavers were found to
be 7.50 dB to 15.50 dB against 2.50 dB to 10.00 dB of the
control group. This indicates that the threshold of audi­
bility of the weavers were slightly more variable than
that of the control group. Variability in relation to
years of exposure shows similar results (Tables-7 & 8).

Thus, the study shows that all the weavers, irre­
spective of age and years of exposures, have suffered
permanent hearing damage at 4000 Hz. In 1966, Bell puts
out (Table-9) that any damage at 4000 Hz indicates 'noise-
induced hearing loss' (NIHL). He further points out that
the workers are likely to be incurring a greater loss if
they continue in the same job without hearing protection
(Table-9). It is, therefore, imperative for the weavers to
protect their ears with some kind of ear protections, so as
to prevent the hearing mechanism from further damage.
Recommendations:

1. Audiogram should be obtained at the pre-employment stage, so as to ascertain the basal level of hearing.

2. An audiogram programme should be done to determine hearing loss of the weavers.

The weavers should be examined at least once a year.

The programme should be continued by a person who had training in operating audiometers.
Fig. 22  MEDIAN THRESHOLD OF AUDIBILITY OF THE
CONTROL GROUP (A & B) AND THE WEavers
(C & D) BY AGE

(a)  

(b)  

(c)  

(d)  

250 500 1K 1.5K 2K 3K 4K 6K 8K

250 500 1K 1.5K 2K 3K 4K 6K 8K

H₂
Fig. No. 23: Median threshold of audibility of the control group (A & B) and the weavers (C & D) by years of exposure to noise.

(a) 1-5 years
(b) 6-10 years
(c) 11-15 years
Fig No. 24 THRESHOLD SHIFTS OF THE WEAVERS BEFORE AND AFTER
FOUR HOURS & EIGHT HOURS OF EXPOSURE TO NOISE FOR THE
RIGHT EAR (a), (b) & (c) AND THE LEFT EAR (d), (e) & (f) BY AGE
(a)  (b)  (c)

(d)  (e)  (f)

250 500 1K 15K 2K 3K 4K 6K 8K
250 500 1K 15K 2K 3K 4K 6K 8K
250 660 1K 15K 2K 3K 4K 6K 8K

H2

x---x 25-29 YEARS
0---0 30-34 YEARS
x---x 35-39 YEARS
Fig. No. 25  THRESHOLD SHIFTS OF THE WEAVERS BEFORE AND AFTER FOUR HOURS & EIGHTEEN HOURS OF EXPOSURE TO NOISE FOR THE RIGHT EAR (a), (b) & (c) AND THE LEFT EAR (d), (e) & (f) BY EXPERIENCE

-© 6-10 YEARS

-© 1-5 YEARS

-© 11-15 YEARS

(a)  (b)  (c)  (d)  (e)  (f)
Table 5.

Quartile Deviation of Thresholds of Hearing in dB of the Weavers of: (a) Right Ear; (b) Left Ear, by Age

(a)

<table>
<thead>
<tr>
<th>Age</th>
<th>250</th>
<th>500</th>
<th>1K</th>
<th>1.5K</th>
<th>2K</th>
<th>3K</th>
<th>4K</th>
<th>6K</th>
<th>8K</th>
</tr>
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<tr>
<td>25-29</td>
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<td>5.00</td>
<td>5.00</td>
<td>5.00</td>
<td>10.00</td>
<td>15.00</td>
<td>10.00</td>
<td>7.50</td>
<td></td>
</tr>
<tr>
<td>30-34</td>
<td>5.00</td>
<td>5.00</td>
<td>2.50</td>
<td>7.50</td>
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<td>15.00</td>
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<td>7.50</td>
<td>10.00</td>
<td>7.50</td>
<td>7.50</td>
<td>12.50</td>
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(b)

<table>
<thead>
<tr>
<th>Age</th>
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<th>500</th>
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<th>1.5K</th>
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<td>5.00</td>
<td>5.00</td>
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<td>7.50</td>
<td>5.00</td>
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</table>
Table 6. Quartile Deviation of Thresholds of Hearing in dB of the Control Group for (a) Right Ear (b) Left Ear.

<table>
<thead>
<tr>
<th>Age</th>
<th>250</th>
<th>500</th>
<th>1K</th>
<th>1.5K</th>
<th>2K</th>
<th>3K</th>
<th>4K</th>
<th>6K</th>
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<tr>
<td>25-29</td>
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<td>5.00</td>
<td>2.50</td>
<td>5.00</td>
<td>2.50</td>
<td>5.00</td>
<td>7.50</td>
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# Table 7

**Quartile Deviations of Thresholds of Hearing in dB of the Weavers**

(a) Right Ear  (b) Left Ear, by Years of Exposures

<table>
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<th>Exposure (years)</th>
<th>250</th>
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<th>2K</th>
<th>3K</th>
<th>4K</th>
<th>6K</th>
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<td>10.00</td>
</tr>
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<tr>
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<tr>
<td>Hearing Loss at 4000 Hz</td>
<td>Conservation Programmes</td>
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<tr>
<td>------------------------</td>
<td>-------------------------</td>
</tr>
<tr>
<td>0-10 dB</td>
<td>Not required</td>
</tr>
<tr>
<td>15-25 dB</td>
<td>Advisable to use protection or to reduce exposure time.</td>
</tr>
<tr>
<td>30-40 dB</td>
<td>Essential to use protection or to reduce exposure time.</td>
</tr>
<tr>
<td>45 dB and above</td>
<td>Full procedure of a hearing conservation programme must be applied.</td>
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Evaluation of Attenuation Characteristics of Ear Protectors

Industrialization has started since long. The machineries designed for industrial produces have already been installed and are running for years. These machineries have been found to generate noise much in excess of the international standard of 90 dBA for 8 hours exposure for hearing damage risk criteria (ISO 1971). While replacement of these machineries by relatively quieter and sophisticated ones is considered practically and economically impossible, the use of personal ear protectors to reduce noise could be the only immediate solution. How much noise could the ear protection attenuate at the ear drum of the human ear has been of immense interest to many. Gasaway (1970) has pointed out that there is a need for a method of applying criteria for noise standard to persons wearing ear protection. Many scientists abroad are on the search for standardising procedures, but, unfortunately, criterion for the method of measuring ear protection attenuation that could ensure wide acceptability have not yet been evolved satisfactorily. Ear protector attenuation may be taken as the hearing loss introduced by the device under test.

In India, the statutory laws, codes, etc., for reducing noise have not yet been formulated. The use of ear protectors at high noisy places is neither mandatory nor
obligatory on the part of the management and workers. The scientists, designers and managerial staff have started paying attention to this problem area only recently. The manufacturers are obviously a few. The present work, therefore, makes an attempt to quantify the attenuation characteristics of the ear protectors designed and manufactured indigenously.

Materials and Methods

Subjects

A total of 50 male graduate volunteers with normal hearing, as diagnosed by the ENT specialists, participated in this experiment. They were in the age range 20-25 years with a mean age 23 years. They did not have any previous experience of exposure to occupational noise.

Ear Protectors

The ear protectors were procured from a company dealing with manufacture of personal protective equipment.

Procedure

In the individual experiment in the winter, as stated earlier, the subject was seated on an adjustable stool facing the loudspeaker, the head being 50 cm off the speaker. The horizontal axis of the speaker was made to coincide with the midpoint of the vertical axis of the head. After a brief practice session, the test was started at an intensity below the minimal and raised by 5 dB until a handswitch, cabled to
the buzzer located outside the booth, allowed the subject to signal the threshold of hearing. The subject traced his threshold for 15 seconds at each test frequency. It was ensured that he understood the instructions and was willing to co-operate.

Each subject was tested on four different days. The subjects were tested on four different occasions for different sets of ear protectors, and the order of the open ear and protected ear tests were reversed for half of the subjects, thus rendering the subjects free from biased responses that would have, otherwise, creep in. Half of the subjects worked in the order open ear tone with ear plugs, ear muffs and ear plugs in combination with ear muffs; the other half worked exactly in the reverse order. Care was taken to place the ear plugs and the muffs properly.

Thresholds of audibility were determined by ascending series method, following the suggestion that this method — proceeding from inaudibility to audibility — is preferable to descending technique, i.e. proceeding from audibility to inaudibility, or a combination of both ascending and descending procedures (Carhard & Jerger, 1959); Bunch's (1943) procedure was followed to avoid 'error of omission' and 'error of commissions'. 
Results and Discussion

The method used in this experiment determined the minimum audible field (MAF). As a common practice, measurement of ear protector attenuation using pure tones of octave band center frequencies (ANSI-1957; ISO-1971) has been followed in the present experiment; although Michael & Bolka (1971) argued that this method provides scope for errors. The subjects sat 50 Cms off the speaker against the prescribed distance 1-2M (Harris, 1957) because the audiometric booth used in this experiment was small enough not to provide the prescribed distance from the loudspeaker. Indian Standards (1971) has been driven with the assistance of ANSI, 1957.

Mean threshold of audition was computed (May 1978), over the subjects at each test frequency (Fig.26). To obtain attenuation values of the ear protectors, the threshold of hearing with the open ear was subtracted from that with the ear protectors in position. The attenuation values thus obtained were averaged over all the subjects to produce mean attenuation characteristics (Fig.27a). The variability of the attenuation values across the subjects are shown in Fig.27b.

Fig.26 indicates that the threshold of hearing yielded a range of 18 dB to 20 dB for frequencies up to 2000 Hz from 125 Hz. It tended to increase from 3000 Hz through the frequencies to maximum of 28 dB at 6000 Hz. This suggests that the hearing sensitivity of the subjects exceeded the permissible range of audibility (Sivian & White, 1933; Hermann, 1963; Corso, 1963) by 10 dB. The lack of physical
precision (distance maintained less than the recommended standard) and procedural controls as existed in the present study, might have caused the threshold of audition to be higher than that obtained by Sivian et al. Further, as Saunders (See Harris Book) suggests that variability of audition up to 30 dB may depend on the areal ratio (the ratio of the area of the ear drum to that of the oval window), the present findings may be attributable to the probable difference in the areal ratios between the Indians and Sivian's population. The variability across the subjects was slight and consistent at higher frequencies (2000 Hz to 8000 Hz).

Fig. 27a depicts that at higher frequencies the ear protectors showed greater attenuation; ear plugs, up to 14 dB at 8000 Hz; ear muffs, 23 dB to 27 dB at 4000 Hz to 8000 Hz; and ear plugs in combination with ear muff up to 35 dB at 4000 Hz to 8000 Hz. The trend of attenuation obtained in this experiment appears to be in consistence with that of Guild (1958). Fig. 27b shows that the ear plugs produced considerable variability of attenuation ranging from 2.19 dB to 6.06 dB, across the subjects; while the variability of the other two ear protectors was slight and remained fairly constant at higher frequencies which was also observed by Northern et al (1972).

As attenuation decreases with increasing stiffness of acoustic material at higher frequencies (Webb, 1976), the reasons attributable to the performance of the ear
protectors may be: the plug being made of hard rubber appeared to be stiff, thus contributing less attenuation, while the muff being filled with acoustic absorbent foam appeared to be resilient, yielding higher attenuation compared to the plug. Moreover, the surface of the muff is cushioned with foam-filled rexins, the property of which might have added to the attenuation values. The plug in combination with the muff possesses the characteristics of being both stiff and resilient, thereby producing greater attenuation at all the frequencies.

Broadbent (Harris, 1957) observed that a high pitched noise (above 1500 Hz) is more annoying than a low pitched noise of the same loudness and he suggested that the reduction of high frequency components of noise will yield greater benefits than the reduction at low frequencies. The ear protectors under test have been found to have reduced more noise at high frequencies compared to the low frequencies. Hence, these ear plugs and the ear muffs can be used in occupations producing steady state, impulsive and intermittent high frequency noises. The attenuation values of the ear protectors could further be improved upon by modifications as outlined in the recommendations.
Recommendations:

1. Ear plugs should be made of soft material and be air cushioned so that it follows the ear canal contour, thus ensuring better fit and lessening pain in the ear canal.

2. The cups of the muff should be designed symmetrical so that it distributes load more or less uniformly on the outer ear, thereby reducing pain.

3. The cups of the muff should be liquid filled, so as to be ammenable to a wide variability of human outer ear structure.

4. A thin acoustic metallic foil placed between the cup and the foam would further enhance attenuation at lower frequencies.
FIG. 26.
MEAN BINAURAL MINIMUM AUDIBLE FIELD ±1S.D. AT DIFFERENT FREQUENCIES

\[ \text{Hearing level in dB} \]

\[ \text{FREQUENCY IN KHZ} \]
FIG. 27.

SHOWING (a) MEAN ATTENUATION CHARACTERISTICS OF THE EAR PROTECTORS AND (b) STANDARD DEVIATION OF THE EAR PROTECTOR CONDITIONS, AT DIFFERENT FREQUENCIES.

(a)

(b)

MEAN ATTENUATION IN dB

STANDARD DEVIATION IN dB

FREQUENCY IN KHz