"EVALUATION OF THE ATTENUATION CHARACTERISTICS OF EAR PROTECTIVE DEVICES"

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Reg. No. M 9708

An Independent Project Submitted As Part Fulfilment of First M.Sc. (Speech & Hearing) to the University of Mysore.

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May-1998

DEDICATED TO
MUMMA AND PAPA,
with love.

CERTIFICATE

This is to Certify that Independent Project entitled " Evaluation of the Attenuation Characteristics of Ear Protective Devices " is bonafide work in part fulfilment for the First Year M.Sc. in Speech & Hearing of the student with Reg.No. M9708.

Mysore.

May, 1998.
Diretor

All India Institute of Speech & Hearing
Mysore.

CERTIFICATE

This is to Certify that Independent Project entitled " Evaluation of the Attenuation Characteristics of Ear Protective Devices " has been prepared under my the supervision and guidance.

Mysore.

May, 1998

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DECLARATION

I hereby Declare that this Independent Project entitled " **Evaluation of the Attenuation Characteristics of Ear Protective Devices"** is the result of my own study under the guidance of Mrs. Manjula P., Lecturer in Audiology, All India Institute of Speech & Hearing, Mysore, and it has not been submitted earlier to any University for any other Diploma or Degree.

Mysore.
May, 1998. **Reg. No. M9708**

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CHAPTER- I

INTRODUCTION

World population explosion , urban sprawl,blatant water, air and noise pollution, depletion of mineral resources.... these form just a part of the virtually endless list of results which are the outcome of urbanization and advancements in science and technology. These developments have contributed on the one hand, to a rise in the standard of living, but on the other hand, they have been major sources of environmental contamination. Over the past few decades a definite increase in the extent of exposure to loud levels of noise has been observed. Today we are all exposed to noise of high intensities while travelling, (some of us) at work and often our hobbies include noisy activities.

Noise is a word used to describe sound conditions in certain instances. The most common operational definition of noise that it is an unwanted sound or it is a wrong sound in a wrong place at the wrong time.

Even though the development of noise into a major environmental pollutant has happened recently, the problem of industrial noise seems to be as old as the industry itself. Deafness has been referred to as an occupational "disease", among millers and coppersmiths even in the 18th century.

Further, over the years there have been several reports of deafness among blacksmiths, ship carpenters, shear grinders, boiler makers, engine drivers and people who fire guns. Thus it has been a known fact that chronic exposure to loud levels of noise, as well as a sudden exposure to a very intense impulse noise could result in a hearing loss. However, in recent times various other effects of exposure to loud levels of noise, on man, have been identified. These include:

(1) interference with communication
(2) effect of noise on the efficiency and accuracy of work
(3) annoyance
(4) masking of other significant sounds and signals in the environment eg: masking of an emergency alarm in a factory.
(5) negative physical, physiological and psychological reactions to vibrations caused by noise.
(6) physical reactions like headache, earache, increased heartbeat, and fatigue.

Noise Induced Hearing Loss (NIHL) develops insiduously and is thus often difficult to identify in its early stages.

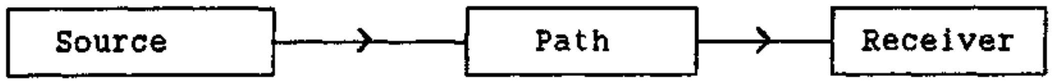
This is because the first frequencies to be affected by NIHL lie around 3KHz and above. As these frequencies do not contribute significantly to speech perception, a mild hearing loss at these frequencies goes unnoticed. Later with continuous noise exposure as the loss at these frequencies increases and the surrounding frequencies also get affected, the individual starts experiencng a difficulty in speech perception.

Fortunately NIHL can be prevented if a comprehensive hearing conservation program is framed and followed consistently. This requires the co-operation of the industry's management, engineers, workforce, and medical staff, working for that industry.

Countries all over the world have developed their own norms regarding the maximum permissible duration of exposure to high levels of noise of different types. The different types of noise include steady state noise, impulse noise, a combination of the two, etc. These norms must be followed in the industries in order to prevent NIHL. In factories where the employees' duration of exposure to hazardous noise levels exceeds the permissible limits, the management must undertake appropriate measures for hearing conservation.

Hearing protection by means of noise control is a complex system. The components of this system can be manipulated to achieve the desired result. This system consists of 3 parts

(1) The Source (2) The Path (3) The Receiver.



The SOURCE is that part at which the noise energy originates, eg: a moving part of a machine, gear, fan,press, pump compressor, etc.

The PATH is the direction taken by the sound pressure wave. Different paths have different properties of attenuation, radiation frequency's and absorption. Further the paths maybe direct, indirect, airborne, structure borne, or a combination of any of these.

The RECEIVER is the complainant or the person affected by noise - he may be a factory worker, a soldier or a student who gets disturbed by the noise while attending a lecture.

Hearing protection by means of noise control can be carried out at these three levels.

I. Control at the level of the source - This can be done in several ways, such as :
   a. Eliminating the noise completely by stopping it.
   b. Removing the noise source to a distance.
   c. Reducing the noise at source, by

1. turning down the volume
2. reducing the amplification of loudspeaker systems
3. maintaining machinery and replacing the wornparts.
4. reducing the impact noise
5. reducing turbulence
6. increasing damping.

d. Modifying the noise by altering its parameters.

II. Control of noise in the path - This too can be done in several ways such as ;

a. Changing the site of the noise source, i.e., from an outdoor site to an indoor site.

b. moving machinery from a more open room where radiation is high to an inner room where radiation is low.

c. Providing baffles and noise barriers in the path of sound transmission.

d. Constructing special sound insulated chambers for the machinery.

e. Improving the acoustic characteristics of the workplace.

f. Masking one noise by another.

g. Isolating machinery which create a lot of vibration,

h. Cancellation of the sound waves of noise by another wave which is 180° out of phase from the noise, is another method of noise reduction.

III. Control at the level of the receiver : This can be done by :

a. Providing personal Ear Protective Devices <EPDs)

Workers who are exposed chronically to intense noise levels must be protected as they are at a risk for developing a hearing loss especially in the higher audible frequencies. There are various factors which are involved in NIHL and one among these is the noise spectrum to which the subject is exposed.

It has been found that noise of narrow band concentration is more likely to endanger the hearing than noise of a wider frequency range.

In general, there appears to be a resistance among employees to wear ear protective devices even when they operate machines that emit extremely high levels of noise. This is either because they are not aware of the effects of noise exposure or due to the discomfort associated with some ear protective devices or because the management is unable to adequately motivate its employees and insist that they use the EPDs.

There are several types of EPDs available in the market today. These can be broadly classified into four major subtypes.

i) Earmuffs/ defenders : These consist of ear cups that are held together by a headband. The headband tension varies in different muffs and the cushions of the ear-cups in different muffs is made up of different materials like sponge, fluid and other sound attenuating materials, In general, ear muffs help to attenuate noise levels upto 35-45 db depending on the frequency of the sound.

ii) Ear-plugs : These come as a pair and there are various and types available. Some look like simple eartips while others are flanged and a few are of a soft,moldable foam-like material. In general, they provide an attenuation, of upto 15-35 db depending on the frequency of the sound, whether they are inserted correctly and whether they are of the right size for the user.

iii) Semi-inserts : These are devices that close the entrance to the ear canal without actually being inserted into it. They are held in place usually by a slender headband or a cord. They do not provide very effective attenuation by themselves, i.e., only about 10-25dB, depending upon the frequency. They can however be used along with the disposable moldable ear plugs,

iv) Helmets with earmuffs : These are devices that cover -the entire skull like a cap, attached to a pair of earmuffs.

They provide good attenuation if they fit well and if they earmuffs fit snugly. Further the attenuation they provide is not only by occlusion of the external auditory canal but also by covering a part of the mastoid/ skullbone. They provide an attenuation of 30-45dB depending upon the frequency. The disadvantages of this EPD is that it is bulky and heavy.

v) Removing the complainant : This is usually adopted as a last resort when no other means of hearing conservation/ protection are possible or effective. The employee, who, on testing is found to be very susceptible to developing NIHL, can be shifted to a different department in the industry where the noise levels are lower, i.e., called rescheduling or rehousing the employee. This however, is not always feasible.

Thus at the level of the receiver the more frequently used mode of hearing conservation is by providing ear protective devices. To determine the efficacy of EPD'S we need to study their attenuation characteristics (i.e., their ability to reduce noise levels at the receivers' ears), for loud levels of noise. The efficacy of EPDs is judged on the basis of factors like:

(1) the amount of attenuation they provide for noise

(2) the comfort when worn

(3) their fit

(4) the percentage of time they are worn by the worker

(5) the extent to which speech communication is affected in conditions of noise and quiet when the EPDs are worn.

Methods of measuring attenuation characteristics;

These are many standard methods available for measuring attenuation characteristics of an EPDs which may be subjective or objective in nature.

Among the subjective method is the Real Ear Attenuation at Threshold (READ which can be performed in sound field or under headphones.

It involves obtaining the thresholds of a person with and without EPDs and finding the difference. In the more complex techniques involving the above threshold procedures, we have techniques such as masking,loudness balance, midline lateralization, temporary threshold shift and speech intel1igibi1ity.

Among the objective methods, we have the Acoustical Test Fixture method which involves the use of artifical-head ear and the technique of probe tube microphone in real ear. Both techniques involve probe tube microphone measurements of insertion response of an EPD.

NEED FOB THE STUDY :

A comparative study of the attenuation characteristics of the four types of EPDs namely, Earplugs, .Semi-inserts, earmuffs, helmets with earmuffs using the subjective method of Real Ear Attenuation at Threshold (REAT) in sound field, has not been carried out before in India. Such a study will help us assess which EPD provides maximum attenuation. Based on these findings the appropriate EPD can be recommended for employees working in different setups, where they are exposed to different levels and types of hazardous noise. Further, no study has collected data on the subjects' ratings of the comfort of the different EPDs. This will help gather information on which EPD is most favored by subjects in terms of comfort and its effect on communication.

AIMS OF THE STUDY :

This study aimed at investigating the attenuation characteristics of the various commonly available and frequently used EPDs.

The study also aimed at collecting the subjects' responses and ratings of each EPD in terms of comfort, weight, case of wearing/removing and the effect on communication.

CHAPTER - II

REVIEW OF LITERATURE

Occupational hearing loss is not a new phenomenon . It has generally been accepted until recent times AS a part of the price to be paid for full employment and technological progress. Fortunately a growing awareness of this problem in the industry, changing attitudes to employment and the availablity of noise reduction techniques and hearing protectors, have resulted both in the quantification of the noise hazard and the reduction of the risk of hearing damage in many instances (Martin,1976).

However, Miller (1996) reported that while the prevalence figures of people with sensori-neural (SN) hearing loss in the United States ranged from 28-33 million, approximately 1/3 of this population suffered from a hearing loss whose major cause was exposure to noise at hazardous levels. According to him, noise induced hearing loss accounted for more cases of sensori-neural hearing loss and tinnitus than all other factors combined. The other causes of sensori-neural hearing loss included genetic factors, congenital abnormalities,infections, space occupying lesions, Meniere's Disease, trauma, age, ototoxic drugs, etc. While a lot of these causes may not be easily preventable, noise is by far the most preventable of all the causes.

Sound is a wave motion in which a source sets the nearest particles of medium into motion. Sound is such a common part of everyday life that we rarely appreiciate all of its functions. It permits us the enjoyable experiences like listening to music; it permits spoken communication ; it alerts us or warns us, Eg: with the ringing of a telephone or a knock on the door; and it permits us to make quality evaluations and diagnoses, eg: the clattering, noisy valves of a car, a squeaking door/wheel, etc.

However, many sounds are unwanted, unpleasant and annoy us. Unwanted and unpleasant sound is often called noise. In 1977, the Air Pollution , Noise and Vibration Convention (No.148) defined noise in the working environment as "the term 'noise' covers all sounds which can result in hearing impairment or be harmful to health or otherwise dangerous". Noise is a form of pollution that must be controlled.

TYPES OF NOISE :

Industrial noise may be divided for convenience into two seperate types : steady state noise and impulse / impact noise. However, in practice both types often occur together. In general, industrial noise has a broad band frequency spectrum. However, this spectrum may have discrete puretones superimposed upon it. Berglund, Hassmen and Job (1995) have reported several sources of low frequency noise, eg:emission from artificial sources like the aircrafts, industrial machinery, air-movement machinery including wind turbines, compressors,ventilators, air-conditioning units, etc. Sources of impact noise as reported by Martin (1976) include drop forges, pneumatic hammers and stamping machines. Other sources of impulse noise are mining explosions and artillery noise, eg: gunshots, firecrackers, etc.

The single most destructive sound for the human hearing mechanism is impulse noise. Whenever the ear is subjected to a brief but very intense sound the possibility of accoustic trauma results. This presents a serious hazard to hearing (Martin, 1976; Agnew, 1987). A short duration sound with a fast rise time acts so quickly that the inherent protective mechanisms of the middle ear are unable to react fast enough to dampen the sound. When exposed to continous (steady state) loud sounds, the stapes inside the middle ear changes from its usual mode of efficient sound transmission, to a rocking action that creates an inefficient transfer of energy across the middle ear. This prevents damaging energy levels from being transmitted into the cochlea from the middle ear. Loud sounds also cause the tensor tympani and the stapedius muscles to contract in a protective reflex action called the acoustic reflex. This contraction dampens the movement of the tympanic membrane and stiffens the action of the stapes to prevent it from being driven forcibly into the cochlea. Both these protective mechanisms are too slow to provide effective protection against impulse noises.

The precise relationship between exposure to damaging noise and the resulting degree of hearing loss is not totally clear. Damage due to noise exposure is not a simple product of the intensity of noise and its duration, but is a more complex function involving the duration, the temporal pattern and the frequency spectrum of the sound and also the exposed individual's susceptibility.

In addition to the acoustic characteristics of the impinging sound, hearing loss due to noise exposure also involves other complex physiological factors such as the effects of disease and aging, any pre- existing hearing loss, previous exposure to noise and exposure to drugs or chemicals with ototoxic effects (Agnew, 1987).

OCCUPATIONAL HEARING LOSS

Some of the most important features that are characteristic of an occupational hearing loss are :

i) The hearing loss is of a sensori-neural type causing damage chiefly to the cochlear hair cells.

ii) The degree and pattern of hearing loss evident in the audiological findings reflect a history of long term exposure to intense noise levels.

iii) The hearing loss develops gradually over the first 8 -10 years of exposure to noise.

iv) The hearing loss intially starts in the higher frequencies (3kHz - 6kHz); the speech discrimination scores (even with substantial high - frequency losses) are generally good (over 75 %) .

v) The hearing loss stabilizes once the patient is removed from noise exposure.

ITS AUDITORY EFFECTS

Chronic exposure to occupational noise damages the hair cells in the cochlea causing a sensori-neural loss. No damage to the outer or middle ear (conductive loss) can be caused by daily exposure to loud industrial noise. Over time some of the nerve fibres supplying the damaged hair cells may also become damaged and thus result in a neural hearing loss too (Sataloff and Sataloff, 1987).

It has been known for many years that prolonged exposure to high intensity noise results in senori-neural hearing loss that is greatest between 3kHz - 6kHz. In such cases the classic audiogram shows a 4kHz dip in which hearing is better at 2kHz and 8kHz. While there have been several hypotheses that attempt to explain the 4kHz dip in noise -induced hearing loss, its pathogenesis remains uncertain. This loss intially affects the hearing between 4khz and 6kHz and then spreads to other frequencies. NIHL may be temporary (temporary threshold shift, TTS) or permanent (permanent threshold shift, PTS).

With exposure to intense sound lends the normal processes of the ear break down and acoustic truama results. Permanent loss of hearing can result from even a single brief high intensity exposure , such as a gunshot very close to the ear. The high energy content of such an impact sound drives the stapes suddenly inwards creating a high pressure wave in the fluid of the cochlea. As this wave travels down the cochlea, it can literally sweep away the hair cells, cause collapse or degeneration of segments of the organ of Corti and can tear the reticular lamina and Reissner's membrane. Intense sound pressure caused by explosions can actually rupture the tympanic membrane, dislocate the ossicular chain and tear the organ of Corti (Agnew, 1987).

Apart from the hearing loss the other effect of exposure to hazardous noise levels is tinnitus. It presents a significant problem in industries. Tinnitus is common, but rarely disabling; it may be quite disturbing to some individuals and in severe cases it may interfere with the quality of life on a daily basis. (Sataloff and Sataloff, 1987).

Tinnitus refers to noise in the ear and it usually indicates some damage to the auditory pathway. Exposure to impulse noise like a gunshot without adequate hearing protection results in an immediate hearing threshold shift usually accompained by a type of tinnitus that sounds like a gushing or high-pitched ringing noise. The onset of such a tinnitus following exposure to a gunshot is a warning of acoustic insult and that there is impending hearing damage.

NON AUDITORY EFFECTS

Parbrook (1963) and Mani (1988) have reported the non-auditory effects of NIHL as :

1. Interference with speech communication
2. Disruption of job performance (efficiency and accuracy) and safety
3. Annoyance
4. Increased blood circulation, stress and other psychological effects.
5. Negative reactions to vibrations at the physical,

physiological and psychological level, eg: damage caused by blow of the heart against the lungs due to vibration, motion sickness due to vibrations interference with communication and reduction in work efficiency.

Interference with Communication :

Speech communication is relatively easy in quiet conditions but in the presence of noise, communication can become difficult or impossible. This interference with communication is a special case of masking of one sound by another. Interference increases with the loudness of the intruding sound and the more continous in time it is. Impulse sounds that are widely spaced in time are obviously of little consequence as far as interference in communication is concerned, unless an important signal is lost during the short loud sound. The spectrum of the intruding sound as compared to the wanted sound is also important. The effects of high levels of noise in the speech spectrum 300-300Hz are most significant . The amount of annoyance engendered by the intruding sound is also a relevant factor. Further it has been noted that conversational speech starts to become difficult when the speaker and listener are seperated by about 60cms, in noise levels of about 88dBA.

While it may be possible to overcome this problem of masking of speech by high ambient noise to a certain extent, eg: by the use of visual gestures and exaggerated articulation, such operations are only of value in limited situations such as close face-to-face conversation. Effects of masking are even more serious in purely auditory communication systems , such as the telephone because, not only is the listener unable to make use of any such visual cues but he also has to cope with an additional source of noise from the transmission channel.

The degree of interference of noise with communication depends on the complexity of the transmitted messages.

Effects of Noise on Efficiency **and** Accuracy of Work

Broadbent (1957) summarized the necessary conditions for demonstrating impairment in work efficiency:

1. The task should be continous and of relatively long duration (atleast 30 minutes)
2. Task performance should be presented at a high rate and/or with a high degree of temporal and spatial uncertainity.
3. The details (microstructures) of performance should be examined rather than relying on gross measures of efficiency.
4. The noise levels need to be greater than 90dB.

Recent literature in the area of memory and perceptual selection however has revealed that the efficiency is affected even on quite brief tasks when the SPL may be less than 90 dB. Laboratory tests using sound under controlled conditions do show a slight deterioration of performance in certain circumstances like:

i) When the sound is very loud (sufficiently loud to cause a risk of hearing damage)

ii) Performance in certain work is more affected than than in others due to noise. It is hypothesized that intense noise/ sound causes a momentary and periodic interruption in the worker's ability to take in sensory information which may be due to a brief period of shift in attention. If the pace of the work or action is outside the worker's control, these momentary lapses of attention can lead to failures in reaction or mistakes and thus reduce the efficiency and accuracy.

The spectral content of loud intruding sounds of frequencies greater than 2 kHz has a greater influence than those less than 2 kHz.

Rhythm seems to be important as it has been reported that sound interruption (one second on and one second off) continously cause a less drop in efficiency than an equally loud steady sound. People differ in their reactions to noise. While some people concentrate better in moderate noise than in quiet, others do not. Thus changes in work efficiency are observed to be much less than 5% and these changes occur at levels when the intruding sound is very intense.

Annoyance caused by sound /noise

Annoyance is felt if the intruding sound:

1. Produces a feeling of fear (possibly requiring action) where sound is considered unnecesary
2. Produces an irrational fear
3. Poses a problem requiring a solution
4. Is incongruous to the work in hand
5. Is considered to arise from anti-social behaviour.

Thus the annoyance value of a sound depends on :

1. The loudness of the noise with respect to the ambient noise (thus it depends on the climate, time of the day, our community, etc.)
2. Whether it produces fear (eg: very low or high pitched sounds are more annoying than a sound of a uniform spectrum)
3. If the sound is of unknown type/direction
4. If the sound has very sharp transients
5. If it has unpredictable intensity/ rhythm
6. If it is unclear and is just near threshold of audibility.

Exposure to loud sound can cause stress, fatigue, an increase in blood pressure, palpitations and could also lead to headache, tinnitus, etc.

Reactions to vibration

This occurs at various levels: physical, physiological, and psychological. Vibration can upset the body mechanism, eg: it disturbs the vestibular mechanism. It can interfere with or reflexes and also reduce the efficiency of working in jobs that require precision of placing or movement of hands. It can affect peoples' attitudes and feelings but reactions may be diverse. The more intense the vibrations the less the tolerance. Further, vibrations caused by high frequencies have little effect just as those caused by one cycle per five minutes.

PREVENTION OF HEARING INJURY

Workplace noise regulations typically establish criteria selected to limit the percentage of workers at risk of acqui-ring "beginning" hearing impairment over a working life time. There are different standards for maximum perrois-sible levels of exposure to noise that have been developed.

The Occupational Safety and Health Administration, (OSHA) a branch of the Department of labour, in 1983, gave permissible values for noise levels and duration of exposure.

The 5dBA rule is one standard that is often used; i.e., for every 5dBA increase in noise level, the permissible duration of exposure decreases by half. Eg: a person can be exposed to 85dBA of noise for 8 hours a day without the risk of developing a hearing loss, and to a 90dBA noise for 4 hours a day without the risk of acquiring a hearing loss, and so on, upto 130dBA at which the permissible duration of exposure is less than one minute.

The permissible exposure level and the number of impulses permissible per day is are as follows : when the level of impulse noise increases from say 130 to 140dBSPL, the permissible number of impulses per day decrease from 1000 to 100. No exposure > 140dB SPL (peak SPL energy of impulse) is permissible.

Thus, to ensure that no exposure greater than the permissible level occurs, suitable engineering control or administative measures should be employed.

HEARING CONSERVATION PROGRAMME (HCP)

An effective HCP is one that accomplishes the goals established for it. The goals of an industrial HCP are:

1. The primary goal must be the prevention (or, atleast, limitation) of permanent hearing loss associated with exposure to industrial noise i.e., prevention of noise induced permanent threshold shifts (NIPTS)
2. Compliance with OSHA regulations
3. Reduction of employee stress and absenteeism
4. Reduction of work place accidents due to plant noise level
5. Reduction of the company's liability to worker compensation claims for occupational hearing loss.

Features of a comprehensive HCP (Stewart, 1994) which are necessary for its effective functioning and which have been widely accepted are:

1. Measurement of work area noise levels
2. Identification of over-exposed employees
3. Reduction of hazardous noise exposure to the extent possible through engineering and administrative controls
4. Provision of personal hearing protection if other controls are inadequate
5. Initial and periodic education of workers and management
6. Motivation of workers to comply with HCP policies
7. Initial and periodic evaluation of workers hearing levels

8. Professional audiogram reviews and recommendations
9. Follow up program for audiometric changes
10. Detailed records keeping system for the entire HCP
11. Professional supervision of the HCP

As stated earlier noise is radiated from the source, via the path, to the receiver. Noise control is basically a system problem. In theory, the problem should always be approached in a way so as to reduce the noise at its source. This is the optimum solution. The reduction of the transmission of the sound via the path is the second best method of attenuation. Personal protection of the receiver should ideally be considered as a last resort. Yet, in practice where reduction at source not feasible for technological or economic reasons, some form of acoustic and /or vibrational barrier in the path as well as personal hearing protection must be used.

CONTROL OF NOISE AT SOURCE **AND** IN **TRANSMISSION**

A) Reduction of noise at source

In the industrial situation the main sources of noise include internal combustion engines, moving machinery drills, aerodynamic and hydrodynamic flow and impact between two or more masses, .etc.

Martin (1976), divided procedures for control of noise at source into two main categories:

Alteration of the duty or operating procedures of a machine (in terms of adjusting speed and loading of the machine, compatible with production requiements) and scheduling operating times of noisy equipment when a minimun number of personnel are present.

Alteration of the design of the machine by changing the mass stiffness or by damping of certain parts to avoid friction.

Mani (1988) gave the following methods of noise control at the source:

1) Reduction of the vibration intensity by maintaining a dynamic balance, diminishing the force acting on the vibrating part and reducing the number of revolutions per minute.

2) **Reduction of turbulence and speed** at which fluids contained in pipes /ducts pass through the inlet and outlet openings.

3) **Replacement of Spur gears** with straight teeth, by spur gears with helical teeth; substitution of plastic for steel materials.

4) **Prevention of impact** when objects/bulk material are mechanically conveyed, and prevent them from dropping freely from conveyors.

5) **Appropriate designs** of burners and combustion chambers.

6) **Appropriate designs of** compressed air lines, gas-mains or pipe-work for liquids, to prevent noise propagation.

7) **Installation of damping of elements at** points of contact between machine and plant equipment, etc.

B) Noise control in Transmission

Acoustic energy may be "transmitted through air as noise or through a solid structure as a vibration. The latter may also result in acoustic radiation and thus get transmitted through air as noise too. In practice, noise reaches the receiver via several paths. Thus, control procedures involve the determi-nation of the relative importance of each path of transmission in order to ascertain the predominant path and take appropriate measures to control it.

Several methods to control noise during transmission have been reported by Martin (1976) and these include:

DSiting of the Source and Receiver - This refers to increasing the distance between the source and the receiver. As we know, when distance is doubled in value the intensity of noise reduces by 3-6dB. Thus situating the noisiest parts of the factory as far as possible from the quiet areas can reduce the noise levels.

2) Use **of Radiation Patterns** - Some noise sources radiate sound/noise more effectively in certain directions than in others. Thus, in such situations, careful siting and orientation of the source may result in a reduction of the

noise level at the receiver. This is most effective under free field conditions where reverberation is minimal.

3) Building Designs - Carefully designing the location of rooms where noisy machinery is to be kept with respect to other rooms, can help isolate the noise source. Installation of vibration isolation equipment while designing the building is also useful.

4) Path Deflection by Barriers - This is usually effective only when the barriers are large in relation to the wavelength of the sound being transmitted. Barriers are useful when the source/receivers are close to them. Buildings themselves, under certain circumstances, could be employed as effective screens.

5) Control by Enclosure - Using properly designed acoustic enclosures around either the source or the receiver is an effective means of noise reduction and provides a conside-rable degree of attenuation. The amount of attenuation of the enclosure depends on the surface mass of the material from which it is constructed including the floor and the ceiling. If the worker is located in the near field of noise source, control by treatment of the walls of the room is not practical to reduce noise levels. However when the worker as located in the far field, treatment of the walls is effective in protecting the listner as the effects of reverberation are minimized.

6) Noise Control by Absorption - Application of sound absorbent materials to the surfaces of the room containing a noise source is not very efficient as only the reverberant sound field is affected. Thus a reduction of only about 6dB is provided (Martin ,1976).

7) Vibration Isolation - The transmission of structure borne energy from a source to a receiver via other radiating surfaces can be reduced significantly by mounting the source on resilient pads thus isolating it from the floor. Anti - vibration mounts can be designed to suit the specific machine depending on its mass, operating frequency and resonant frequ -encies. The rigid pipework ducts, etc, connected to the machine also need to be modified with flexible connectors to reduce vibration.

8) Acoustic filters **and Mufflers** - Noise from internal combustion engines , fans and blowers and pneumatically operated machinery may be reduced effectvely by the use of acoustic silencers. These devices provide a relatively economic means of noise reduction in industrial situations.

Mani, (1988) reported the following methods for noise control in path;

i) Installation of machines on vibration damping bases which are isolated from the floor and wall.

ii) Isolation of damping materials between machine bases and foundations and use of anti-vibration mountings,

iii) Separate installation of noisy machines to avoid noise propagation off the premises,

iv) Complete or partial enclosure of noisy equipment, installation of sound barriers, sound-absorbing linings and sound-isolating partitions,

v) Lining of walls, partitions, floors and ceilings with damping and absorbing materials,

vi) Using mufflers, silencers for steam and air jet noises to prevent noise propagation, etc.

C) Noise Control at the Receiver

The application of techniques for reducing the noise at source, by minimizing the existing forces generating the energy, is often not practical; and procedures for reducing the transmission of energy from the source to the receiver may have to be applied. These too, may often not be practical sufficient or economical. Thus, when neither of these remedies are adequate or feasible to limit noise to safe levels one has to resort to personal hearing protection or noise control at the receiver. Thus workers exposed to noise above the permissible levels, must be provided with personal hearing protection. It is the responsibility of the employer to provide ear protectors that attenuate noise sufficiently to remove the hazard.

In the eyes of law, it is not good enough merely to supply hearing protection, but the ear protective devices (EPDs) provided must be capable of removing the hazard to hearing from the noise enviornment in which they are being worn. Further, the employer must also educate the employee about noise and the need to wear ear protectors and persuade him to do so. Thus, knowlede is required not only of the the physical characteristics of noise and the acoustic attenuation characteristics of the hearing protectors, but also of the non-acoustical properties of the EPDs such as comfort, wearer-acceptability, etc. EPDs provide immediate and often effective protection against occupational hearing loss. In general, EPDs must be worn when a worker is exposed to sound pressure levels of 85dB and above in any of the speech interference frequencies for the duration of normal working hours.

The protection afforded by hearing protector depends on its design and on several physiological and physical characteristics of the wearer. Sound energy may reach the inner ear of persons wearing protectors by four different pathways:

a) by passing through the and tissue around the protector
b) by causing vibration of the protector, which in turn generates sound into the external ear canal

c) by passing through leaks in the protector and

d) by passing through leaks around the protector (Sataloff and Sataloff,1987).

The following figure (Fig.l) illustrates the pathways of noise leakage.

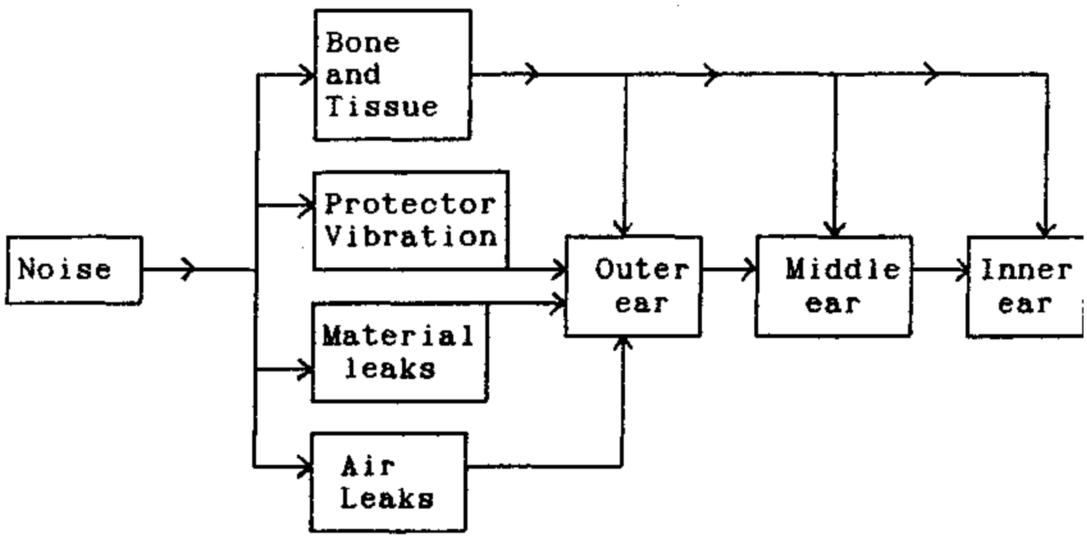


Fig-1 **NOISE PATHWAYS** TO ***TEE*** OCCLUDED EAR

For EPDs to provide optimum noise reduction, acoustical leaks through and around the protectors must be minimized. This can be achieved by:

a) Using EPDs made of imperforate materials

b) Using protectors that are designed to conform readily to the head or ear canal configuration so that an efficient acoustic seal can be achieved and the protector can be worn with comfort.

c) The protector should have a support means or a seal compliance that will minimise its vibration.

d) Muff type protectors should not be worn over long hair, poorly fitted eye-glass temples, or other obstacles.

As vibrations of the skull from impinging sound waves are transmitted to the inner ear by way of the outer and middle ears or directly to the inner ear, the maximum attenuation attainable with any hearing protector is approximately 55dB (Vasallo and Sataloff, 1978).

There are several types and brands of EPDs available while selecting the most appropriate type for a given situation, there are several factors that need to be considered.

The primary factor is that of the amount of hearing protection (attenuation) the EPD provides, in the required frequency range.

The other desirable features include comfort for long duration use, cost, durability, chemical stability, availability, wearer-acceptance acoustic environment in which the EPDs are used, effect on user's skin (i.e., the EPD should be non-allergic and non-toxic), cleanability and hygiene.

Different hearing protectors possess varying amount of these properties, both good and bad, thus the requirements of the wearer and his environment must be taken into account while a particular type of EPD is selected.

EPD ATTENUATION MEASUREMENT

There are two ways to monitor the usefulness of EPDs:

a) **Real world tests** : These are methods to evaluate the real world performance of the EPDs. This method provides a more realistic picture of the attenuation characteristics of an EPD as compared to the Laboratory methods, which often provide an exaggerated picture.

b) **Laboratory** tests : These include the REAT method, auditory threshold shift measures, loudness balance comparisons, acoustical test fixtures, etc., some of which are described below.

1) The standard Real Ear Attenuation at Threshold (REAT) method (ANSI 1974): This method has been modified along with the Japanese Standard Association (1955) and Canadian Standard Associataion (1965)to formulate the Indian Standards in 1979.

The subjective method of REAT in sound field has been described by Berger (1986). The REAT is the most common method of measuring EPD attenuation. ' Virtually all the available manufacturers' reported data are derived via this method. The procedure involves:

i) Determining the subject's thresholds of hearing in sound field without wearing the EPDs (open threshold).

ii) Then the subject's thresholds are determined while wearing the EPDs (occuluded threshold)

iii) The difference between the two thresholds, i.e., the threshold shift, is determined which is a measure of the attenuation or is the Insertion Loss (ID afforded by the EPD.

2) Insertion loss of hearing protectors can also be measured using the Acoustic Test Fixtures (ATF) method.
This method is frequently used for quality control of ear-muffs in hearing protector factories.

3) The measurement of attenuation (insertion loss) using artificial heads with and without a torso is also common, but a great deal of effort needs to be expended to construct artificial heads acoustically similar to the average human head.

All these methods have advantages and disadvantages, and by and large, the REAT method is accepted as one that gives true and reliable results. However, this method too has been criticized for producing minor errors in attenuation at low frequencies, for being time consuming and for measuring attenuation only at low-exposure sound levels (Helstrom, 1990).

4) Insertion Response Measurement (insertion loss). Another method for measuring the attenuation or insertion loss is by placing a soft probe tube microphone in the ear canal. The length of the microphone inserted is kept constant at a length equal to the earplug/semi-insert that enters the ear canal, plus 2-3mm more.

To measure the insertion loss the sound pressure level (SPL) is measured in the unoccluded ear of the subject. The subject is seated at 45° azimuth, 12 inches away from the loudspeaker, with the speaker height adjusted to the height of individual's ear. (Location of the subject varies with different equipment for measuring insertion loss). A sweep frequency warble tone at a constant level (eg: 70dB SPL) is presented.

Then, without disturbing the position of the probe tube microphone, the EPD is anchored in the ear. The occluded measurement is done in the same way as for the unocculuded condition, is done, with the EPD in the ear. The insertion loss for the warble tone is objectively measured from 500Hz to 8KHz in dB. The insertion loss (ID is equal to:

IL (dB) = Occluded SPL -unoccluded SPL.

Thus the insertion loss values can be obtained and compared across frequencies.

The variables involved while measuring the attenuation characteristics of EPDs are :

a) Dependent variables eg: the attenuation sppposed to be provided by the EPD.

b) Independent variables eg: 1) types of EPDs being measured andthe material it is made up of; its retention properties after repeated use and cleaning 2) the combination of EPDs whose attenuation is being measured 3) the instrumen -tation used in measurement 4) the method of measurement that is selected, the test envi>onment and the test stimuli used.

c) Nuisance variables 1) the subject himself is a variable 2) the effect of climatic conditions on the EPD 3) the placement and fit of the EPD in the ear and chances of its dislodgement 4) the amount of vibration in the test envir -onment 5) the order of use of EPDs during attenuation measurement.

TYPES OF EPDs

There are primarily four main types of EPDs namely:

1) Ear plugs
2) Semi-inserts
3) Earmuffs
4) Helmets with earmuffs

In each of these type of EPDs there are several different subtypes and brands that are available. Different types of

EPDs provide different amount of attenuation. Other types of EPDs include amplitude sentitive and frequency selective devices.

1) EAR PLUGS : These are inserts that fit directly into the ear canal. They come in many configurations and are made of rubber,plastic or wax impregnated cotton or other materials. A correct fit depends on a proper seal along the entire circumference of the ear canal walls. These EPDs are fairly cheap, small and easily portable. They usually can be easily cleaned in soap and water.

Ear plugs are, however, not usually tolerated in the ear for more than two hours or so at a time. On an average, they provide an attenuation of between 15-35dB depending on the type of ear plug. Kumar, Venkatesh, Ragini, (1982) reported the attenuation of earplugs using REAT methods with earphones as 27.75dB at 250Hz, and 46dB at 8KHz.

Chandrashekar et.al. (1993) did a study to obtain the NRR (Noise Reduction Rating) values of EPDs available, indigenously. The NRR values were calculated using the method recommended by Berger in 1983. They reported the NRR values of earplugs that were manufactured in India to range between 1.98 and 21.83. Imported earplugs were found to have a NRR value of 22.5-23.

The different types of earplugs available are :

Pre-fabricated/Pre-molded ear plugs

They are manufactured from flexible materials such as vinyls, cured silicones and other elastomeric formulations. One of the most common devices is the V-5IR earplug. It is available in 5 sizes. Premolded plugs are available with varying number of flanges (between 1-5). Generally greater the number of flanges, better is the seal and greater in the attenuation. Values of attenuation for premolded earplugs as reported by Agnew (1987) are between 20-30dB with greater attenuation in the high frequencies than at low frequencies.

Berger (1994) reported values of attenuation for premolded earplugs as around 25dB at 1KHz and approximately 40dB at higher frequencies.

Formable / Moldable earplugs :

They are also known as disposable and malleable earplugs. They may be manufactured from cotton, wax, spun, fiber glass, silicone putty and slow recovery foam. Their life expectan -cies are short and may vary from a single use to use over a few weeks. Their primary advantage is comfort, but the size of the EPD prescribed should be based on a careful examination of the user's ear canal. Moldable earplugs are inserted by kneading the material to form a cone, or a thin cylinder and then pressing it to the entrance of the ear canal. Once inserted it begins to expand to gain full size in about 10 seconds. Slow recovery foam ear plugs were first introduced in early 1970s. The attenuation values for the foam earplugs range from about 30dB at 125Hz to 45dB at 8KHz (Berger,1994). Martin (1976) reported attenuation values of between 8dB and 43dB.

While disposable and moldable earplugs may be more comfortable to wear than prefabricated ones they require greater standards of cleanliness from the wearer. If they are inserted with dirty hands, foreign bodies or dirt may get inserted and may lead to irritation and infection.

Custom - Molded Earplugs :

These are made either from two part curable silicone putties or vinyl. These fill the a portion of the ear canal as well as the concha and pinna. The canal portion provides the acoustic seal while the concha and pinna part provide support. These are easier to wear, usually more comfortable and as they are customized they are useful to motivate subjects to use them.

Berger (1994) reported that the average attenuation provided by these earplugs was between 15 and 35dB.

In general, earplugs need to be handled carefully and cleaned regularly, or else they could lead to infections and irritation to the skin of the ear canal. They require skill to insert and remove them without damaging the plug or hurting the user. They should be prescribed according to the size of the user's ear canal.

While they are easily portable, it is difficult to monitor their use in industries due to lack of visibility. Further, most of them are prone to hardening, cracking, shrinkage, becoming dirty and losing their flexibility and thus need to be replaced frequently.

2) **SEMI INSERTS** : These are also referred to as conca seated hearing protectors or canal caps. They consist of pads or flexible tips or rubber caps attached to a light weight head-band that presses the caps against the entrance to the external ear canal. They are far easier to wear and remove than ear plugs and are also easily portable.

These devices are principally intended for intermittent use conditions, where they roust be removed and replaced repea -tedly. During longer use periods, the force of the caps pressing against the canal entrance may be uncomfortable, but the semi-inserts with good head-band tension can provide fairly adequate attenuation. Berger (1994) reported that these devices may provide between 25dB and 45dB attenuation. These devices, however, tend to create the most noticeable occlusion effect and consequently distort, the wearer's perception of their own speech more than other EPDs do. These devices that partially enter the ear canal, in addition to capping the canal entrance, provide better attenuation than those which just cap the ear canal entrance. Sataloff and Sataloff (1987) have reported that semi-inserts provide only about 15-20dB attenuation below 1KHz.

3) EAB MUFFS :

Most types of ear muffs are of a similar design and are made of rigid cups specially designed to cover the external ear completely. They are held against the sides of the head by a spring loaded adjustable band and sealed to the head with circumaural cushions.

For maximum attenuation of sound, the protector cups should be made from a rigid, dense non-porous material. Each cup is partially filled with an absorbent material to reduce the high frequency resonances that may otherwise occur within the shell.

The earmuffs seal may be liquid-filled or plastic foam-filled. Liquid-filled seals usually provide marginally better protection with only slight headband tension, but they suffer from the additional problem of leakage of fluid if treated roughly. Further, as the liquid gradually gets absorbed, these type of muffs become more stiff. Modern foam -filled seals are almost as good as liquid seals and have the additional advantage of robustness. However, they require slightly higher headband pressure to provide a satisfactory seal. Leakage in seal due to eyeglasses, big earrings, etc., should be ruled out, as the attenuation provided by earmuffs is related to the force of with which they are pressed against the sides of the head. According to Martin, (1976), this could reduce the attenuation by 5 to lOdB. Thus care should also be taken not to bend the head-band severely as it will alter its tension.

some earmuffs are asymmetrica and thus can only be worn one way i.e., only one of the oupe with fit the left ear and the other the right.

Earmuffs in general, are known to provide the greatest protection and attenuation. Further, one size usually fits most people and muffs can be easily removed and replaced in a hygienic fashion. This makes them extremely suitable for dirty and high-level noise areas and also for people who frequently move in and out of noisy environments or for people who may suffer from minor diseases of the external ear canal and thus cannot wear earplugs.

Berger (1983) reported that the average attenuation provided by the earmuffs was between 15dB and 40dB.

Agnew (1987) reported that their attenuation ranged from 25 to 35dB. The disadvantages of earmuffs lie in their bulkiness, initial cost and the fact that they tend to make the ears hot. Further, they are also usually more susceptable to damage than other forms of hearing protection. However, as they are bulky, they are clearly visible and thus their use can be easily monitored even from a distance. Earmuffs also pose a problem then they are not compatible with other safety appliances like goggles, helmets, etc., Further, owing to their weight they may sometimes slip down. Thus a head-band that is worn under the chin is attached to them; this may make them comfortable for long periods of use.

Chandrashekar et.al. (1993) reported the NRR values for earmuffs, that were manufactured in India, to range between 1.51 and 8.87 while the imported earmuffs had a NRR value of 16.

SPECIAL TYPES OF EAR PROTECTORS

There are several earmuffs designed for special purposes such as improved communication and selective attenuation of high level transient noise.

Amptitude Sensitive Devices :

These are nonlinear EPDs that are designed to attenuate loud sounds more than soft ones - they are designed to provide little or no attenuation at low sound levels. Communication is thus unimpaired during quiet periods. These earmuffs incorporate an electronic peak-limiting device or incor-porate mechanical valves which operate when high level gunfire noise is incident upon them. These devices are extemely valuable in industrial military or sporting situa - tions where people are exposed to impulse noise or inter - mittent noise.

At sound levels below 110-120dB, at low frequencies (i.e < 1000 Hz),these devices do not provide any attenuation; the attenuation increases to as much as 30dB at higher frequen - cies (Berger, 1986). At even higher sound levels, the attenuation values increase by ldB for each 2-4dB increase in the sound level.

These devices are however relatively expensive, heavy, require batteries and need to be handled with much greater care than ordinary earmuffs.

<u>Frequency Selective Devices</u> :

All hearing protectors attenuate some frequencies more than others. Some are designed to augment this effect. These devices are usually fitted with an acoustic low-pass filter which ensures that the attenuation below 2KHz is relatively small. This filter enables the lower speech frequencies to be passed and this allows easier speech communication between wearers. However, improved speech communication in noise will only result if all the external noise is at a higher frequency. This is not the case in majority of the industrial situations and consequently noise below 2KHz is insufficiently attenuated and the communication advantages of this device are often not realised. Further, these devices are not suitable for use on the factory floor.

4) HEMLETS WITH EARMUFFS :

This is also called earmuffs attached to a hard hat. When the use of protective headgear is required, hardhats with attached earmuffs provide a convenient alternative to the use of earmuffs attached with a head-band. However, these are more difficult to properly orient and fit since the attachment arms can never provide as adaptable an adjustment as do the head-band-attached muffs; nor can they fit as wide a range of head sizes. For these devices the attachment arms must be properly extended and the helmet's webbing must also be adjusted to properly locate the hat on the head.

These devices to some extent help reduce the vibrations of the skull due to intense noise levels and thus reduce the noise reaching the inner ear via bone conduction. Depending on the type of earmuff attached to the helmet, they provide different amount of attenuation that ranges from 20dB-40dB.

These devices, however, compromise on comfort as they pay attenuation to safety. Further, they are very bulky and not easy to wear and remove frequently.

One of the principal problems faced by hearing conservationists is overcoming employee resistance to the use of hearing protection devices. The causes for this resistance

include:
The EPD interefore with or distorts the sounds that the user wishes to hear. Speech, for example. sounds muffled and distored.

-> The user experiences an occlusion effect and has diffi - culty in monitoring his own voice.

-> Machine sounds are altered and are thus more difficult to evaluate, in case of a fault in functioning. Alarms, warning bells, signals that convey information regarding change of shifts, end of duty, etc. , are also attenuated and are difficult for the client to hear while the EPDs are worn. However, visual alarms may also be used.

-> Further, a lot of the EPDs are bulky, heavy, uncomfortable and cause irritation to the skin when used over long periods.

-> Workers feel insolatted and have an altered body image when they wear EPDs.

Thus due to all these reasons there is a lot of resistance to the use of EPDs among industry workers. Abuse of EPDs by workers alter the attenuation provided.

Some of these situations or factors can be tackled or overcome by using EPDs which are designed to provide a uniform attenuation (i.e., EPDs that possess a flat frequency response) across frequencies and by using EPDs that provide an 'optimized' rather than a maximized amount of attenuation.

Further, use of EPDs specific to noise conditions in a setup, rather than use of those EPDs which provide maximum protection will also be useful.

An effective EPD is one that is worn and worn correctly. Extensive strategies for training and motivating the workers must be employed to overcome resistance to the use of EPDs.

This can be done using large scale in-field experiments, demonstrating the short and long term effects of noise exposure on exposed individuals wearing EPDs and those not wearing EPDs-thus demonstrating their achieved protection (Berger and Lindgren, 1990). Other methods involve public education about the hazards of noise - its auditory and non auditory adverse effects and further fitting subjects with customized EDPs, like custom-made earplugs, will make the hearing conservation program more personalised and will help motivate workers to use EPDs.

Effects of Ear Protective Devices on :

Communication and warning signals -

Wearing EPDs obviously interferes with speech communication is quiet environments; however, wearing a conventional set of earplugs or muffs in noise levels above 90dB in octave bands (or about 97dBA for flat spectra) should not interfere with, and indeed may improve, speech intelligibility for normal hearing ears. Wearing EPDs High level noise can improve communication for normal ears because, speech-to-noise ratio is kept nearly constant and the protected ear does not distort from over-driving caused by the high speech and noise levels. The efficiency in ears with a hearing loss has not been demonstrated as conclusively, but it seems to be helpful in that situation too.

In general, studies have shown that those with normal hearing who wear EPDs in noise levels greater than 85 dBA demonstrate an ability to hear machinery sounds, warning signals and speech that is either unaffected or slightly improved. These activities may be affected when EPD's are warn in quiet conditions.

Localization and Depth Perception -

Another effect of EPDs is to confuse one's ability to locate the direction of origin of sounds. Studies indicate that a helmet with muffs, or earmuffs alone interfere with locali-zation accuracy to a greater extent than do inserts that leave the outer ear exposed. Furthermore, it is reported that subject are unable to learn to compensate for the adverse effects of earmuffs. Berger (1994) reported that several studies suggest that EPD may alter the depth per - ception ability of the wearer i.e., the ability to judge the distance from a sound source.

Comfort of the various EPDs -

Earplugs and semi insets are in general considered to be comfortable because they are light and are suitable for even hot enviornments.

However, when these devices provide a very good seal, they are reported to be slightly uncomfortable. In hot environments they may lead to irritation of the skin of the external auditory canal.Thus, they are a little uncomfortable to wear for long periods of time. High headband tension of semi inserts also leads to discomfort. Further, they cannot be worn in the presence of ear infections.

Muff type protection and helmets with muffs - These can be worn in the presence of ear infections. They are however, heavy and bulky and are uncomfortable to wear especially in hot enviornments when their use leads to sweating. They are difficult to carry around. High head-band tension (or weight of the helmet or muffs, or both) leads to a lot of discomfort and pain and may even cause a headache. These devices are incompatible with spectacles or sun-glasses. Despite these limitations, the muffs are still the EPDs that provide best attenuation.

Thus the literature available on hearing conservation and noise control suggests, that while noise control at the source or during transmission is more effective, it it often not feasible or ideal to achieve and thus one needs to resort to the use of EPDs. Among the various types of EPDs available earmuffs are currently the devices that provide maximum attenuation.

CHAPTER-III

METHODOLOGY

This study aimed at comparing the attenuation characteristics of six different Ear Protective Devices (EDPs), in the sound field set-up. This study also compared the subjective responses of the subjects for comfort, wearability, weight etc., of the six EPDs used.

According to the classification of EPDs into a) Earplugs b) Semi-inserts c) Earmuffs d) Helmets with earmuffs, at least one, or a maximum of two EPDs were taken from each category of EPDs. The EPDs used were as follows:

1) Ear Ultra-fit (flanged) Earplugs NRR21 :
   This EPD looks like an eartip with three flanges. This EPD weighs 2gms for a pair. . (plate 1)
2) Soft moldable EAR Earplugs:
   This EPD is made up of foam-like moldable material that is light yellow in colour. It weighs 1 gm for a pair. Cplate 1).
3) TASCO Semi-insert T-100 NRR 17 :
   This device just closes the entrance to the ear canal without actually entering into it. The ear pieces of the device are connected with a slender head-band. It weighs 9 gms. . (plate 1)

4) Earmuffs :

This consists of orange coloured ear-cups that are held together by a black head-band. It weighs 151 gms. (plate 2).

5) Peltor Earmuffs (Tactical 7) :

It consists of two foam-padded headphones. The right head-phone has the attenuation control. The Peltor earniuffs have an electronic circuit inside, which allows variable attenuation. At full-on position,it provides amplification of speech and soft environmental noises, but cuts off moderate-to-loud impulse sounds. It is battery operated. It weighs 366 gms. (plate 3)

This EPD was evaluated for its efficacy at three levels by manipulating the attenuator i.e.,

1). Level of complete attenuation (full-off position)

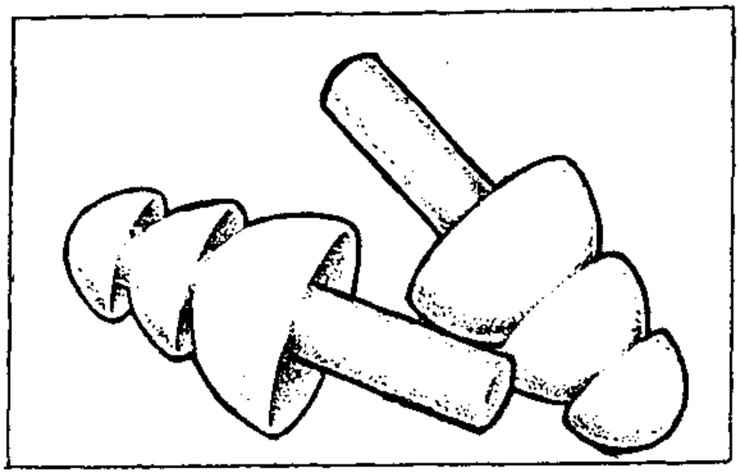
2) Level of 50% attenuation (mid-on position)

3) Level of No attenuation (full-on position).

6) Helmet with muffs:

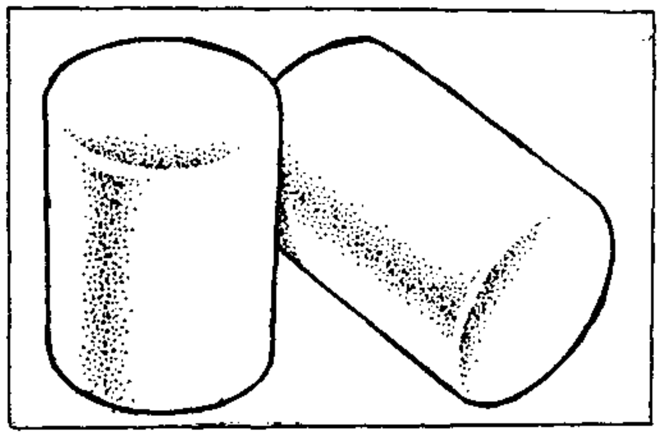
It consists of a plastic helmet which has earmuffs attached to it from inside and it has a neck strap for support. It weighs 452 gms. ("plate 4)

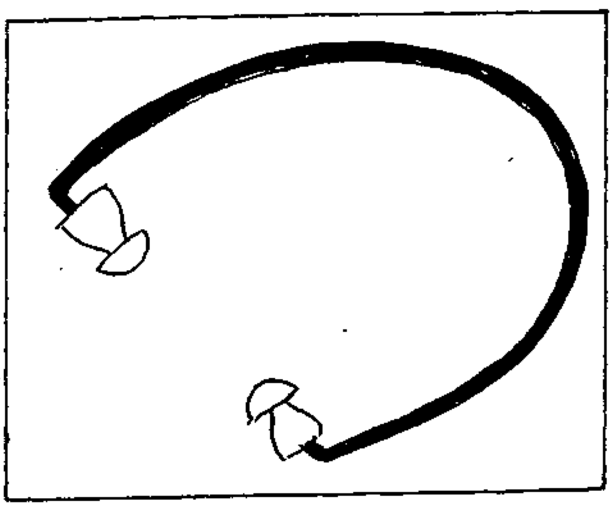
Plate -1



EAR ULTRA FIT [FLANGED]
EARPLUGS NRR 21

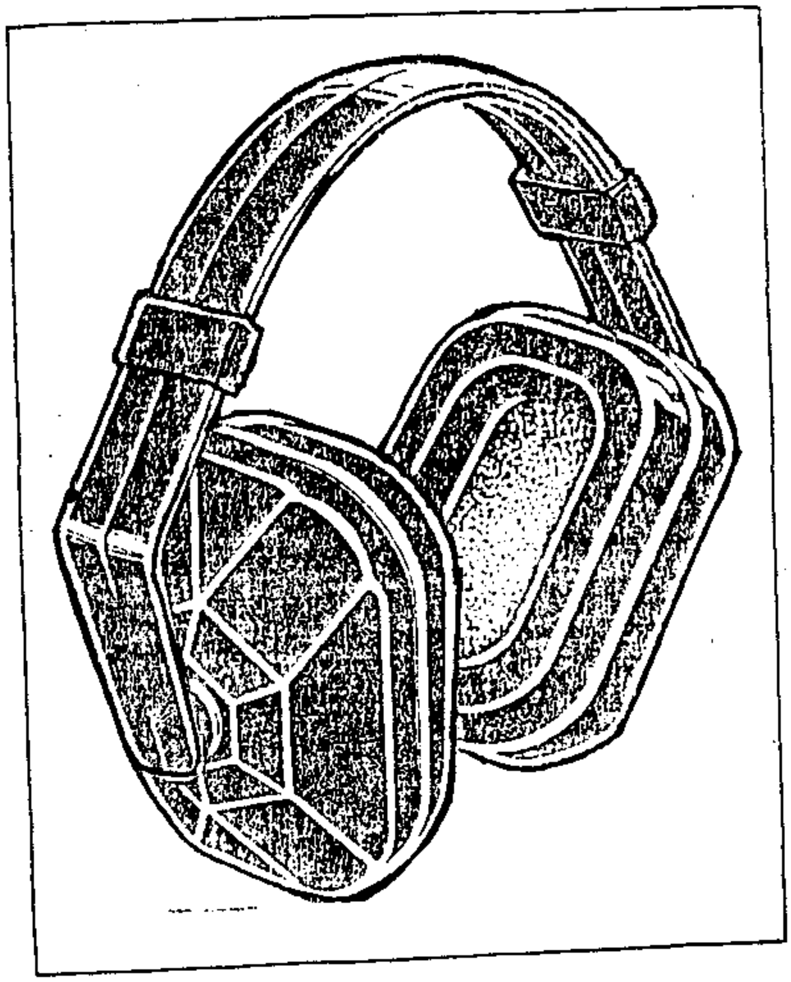
SOFT MOLDABLE E·A·R
EARPLUGS.





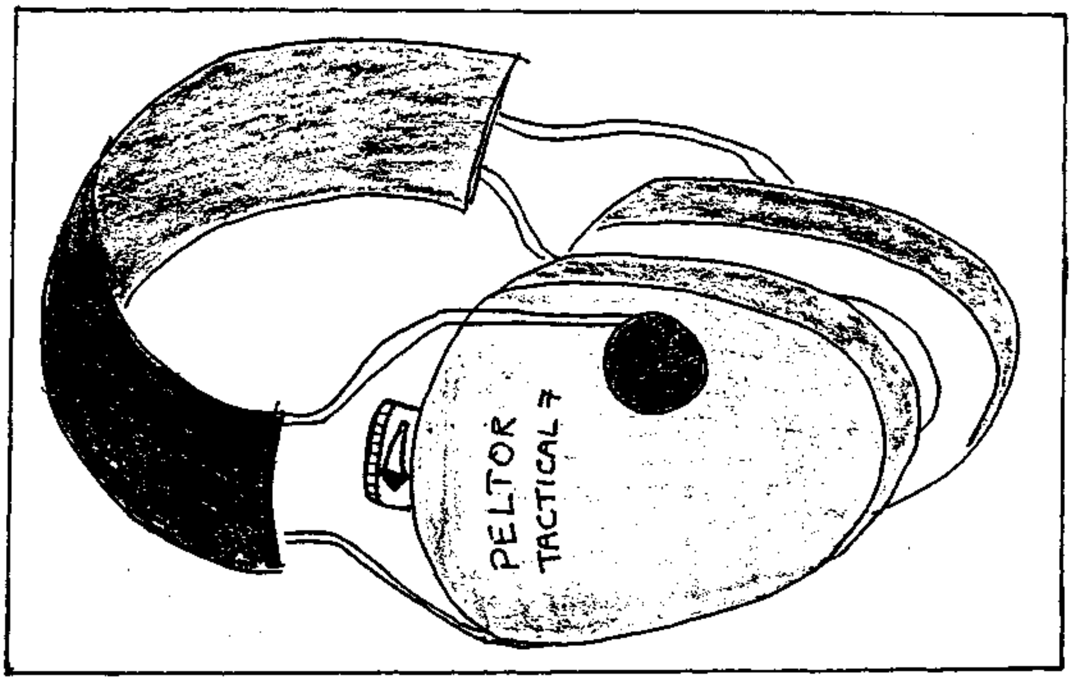
TASCO T-100 SEMI-INSERT
NRR 17.

PLATE-2



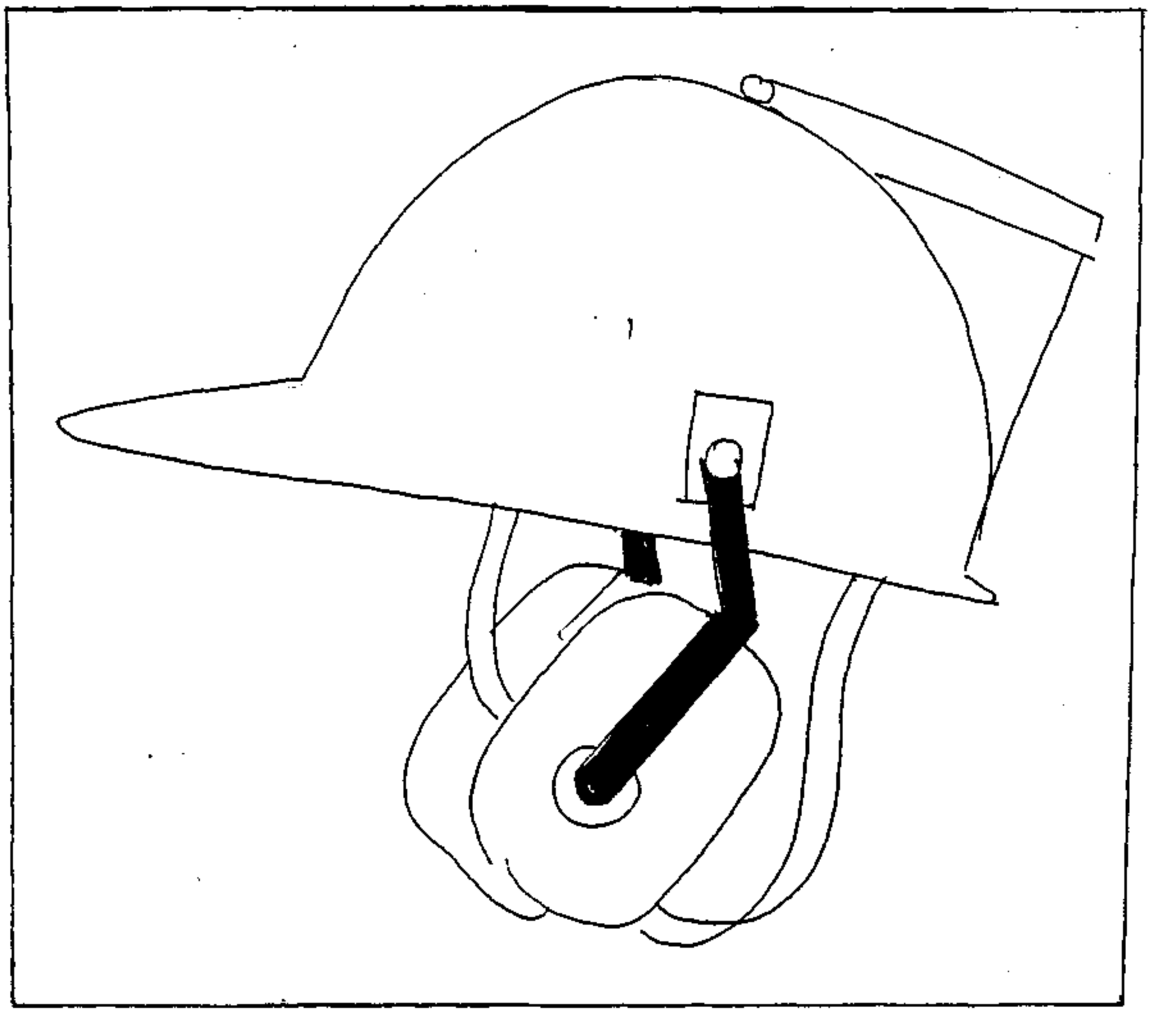
EAR MUFFS.

PLATE - 3



PELTOR EAR MUFFS
TACTICAL 7 .

PLATS - 4



HELMET WITH MUFFS.

SUBJECTS :

Thirty subjects, fifteen males and fifteen females, in the age range 18-35 years were selected for the study.

The subjects were selected on the basis of the following criteria :

1) All subjects had no significant history of any infections of the ears or exposure to loud noise in the past.
2) All subjects underwent an audiometric evaluation and had a Pure Tone Average (PTA) for air conduction no greater than 15dB HL in both ears. In all the other frequencies i.e., 250Hz, 3KHz, 4KHz, 6KHz and 8KHz the thresholds for all subjects were within 20dBHL.
3) All subjects had Speech Reception Thresholds (SRT) that corresponded with their PTA.
4) Immittance audiometry using (Version 2 of GSI 33 Middle Ear analyzer) was done on each subject and only subjects with *"A'* type tympanograms with ipsilateral and contralateral reflexes present in both ears were selected for the study.

EQUIPMENT USED :

A calibrated diagnostic audiometer (Madsen OB822) was used which had the facility to do speech audiometry and present narrow band and white noise in sound field. The audiometer was calibrated according to the ANSI S 3.6-1971

Rev/ ISO-389. 1975/B.S.2497 standards. Calibration data was stored in the audiometer's programmable memory.

The earphones used for the preselection testing were TDH-39P. The loudspeakers used for sound field testing were Madsen Electronics loudspeakers which were placed at a 45° azimuth, at a distance of one meter from the subject .

A two-room sound treated suite was used for the study The ambient noise level in the testee's room was within premissible limits.

Octave Frequency	**Ambient Noise level (dBSPL**
250 Hz	22
500 Hz	16
1 KHz	10
2 KHz	8
4 KHz	9
8 KHz	10
C Scale	35dB
linear scale	48dBSPL.

The material used for speech audiometry, (Speech Reception Threshold - SRT) was the CID W-l and W-2 spondee lists, (see Annexure 1- Spondaic words of auditory tests W-l and W-2 CID).

PROCEDURE :

First, thresholds for narrow-band noise centered at 250HZ, 500Hz,lKHz, 2KHZ, 3KHZ, 4KHz, 6KHz,8KHz, white noise and the SRT were established for each subject in the sound field set-up without any EPDs fitted. These were the "open thre-sholds".

Then each subject's new thresholds were established in the sound field again, for the same narrow band frequencies, white noise and SRT, with the subject fitted with each of six EPDs used in this study. For the test, the tester fitted the subjects with each EPD. These were called the " occluded thresholds" for each type of EPD.

The instructions given to the subjects when determining the thresholds for narrowband noise and white noise (open and occluded) were :

" I will be presenting brief periods of noise. Each time you hear the noise, please indicate by raising your index finger immediately. If you do not hear anything please put your hand down. You should respond for the softest sound that you hear."

The instructions given for SRT were :

"I will say a few words through the microphone. Each time you hear me you should repeat the word that you heard me say. If you are not sure of what you heard, you may try to guess the word ".

PROCEDURE USED FOR ESTABLISHING THRESHOLDS

The modified Hughson - Westlake method of threshold estimation was used.

The procedure used to establish SRT was : The speech (spondee words) were initially presented at 20 dB above the PTA for narrow band noise. The SRT was then tracked using the modified Hughson - Westlake method.

Each subject was tested for all the EPDs in one sitting with a rest period of five minutes between each EPD test.

The difference between the 'occluded' and 'open' thresholds, for each EPD, for the different stimuli, i.e., narrow band noise, white noise and speech reception, were calculated. The value thus obtained gave the amount of attenuation, also referred to as the "Insertion loss", provided by each EPD.

The results thus obtained were subjected to statistical analysis to obtain the mean, range and standard deviation.

The results of these tests are explained in the chapter on Results and Discussion.

Subjective evaluation of EPD :

After testing each subject they were asked to wear and remove each EPD to see if they could do so on their own. The subjects were then administered a questionnaire, (Appendix 2A - Questionnaire for short-term use of EPDs), to collect data on their opinion about the comfort of each EPD in terms of wearability, ease of wearing and removal, weight and size of the EPD.

Later six subjects (three males and three females) were chosen at random from the thirty subjects and were each fitted with one of the six EPDs. These subjects were made to wear the EPD for eight hours with a half hour break after four hours of use. At the end of the day (i.e., after eight hours) a questionnaire, (Appendix 2B - Questionnaire for long -term use of EPDs), was administered to the six subjects regarding the comfort of that particular EPD which they had worn. Questions on how much the EPD affected speech perception and the communication process were also included. The results of the subjects to the questionnaire are discussed under the Result and Discussions.

CHAPTER -IV

RESULTS AND DISCUSSION

This study aimed at comparing the attenuation provided by the six different EPDs across different narrowband frequences, i.e, 250Hz, 500Hz, 1KHz, 2KHz, 3KHz, 4KHz, 6KHz, and 8KHz, white noise and for speech stimuli for thirty subjects.

The review of literature suggests that among the various types of EPDs currently available, the earmuffs provide the maximum, attenuation. However, in terms of comfort, earplugs and some semi-inserts are reported to be most comfortable. As earmuffs are heavier and have a high headband tension they may cause discomfort and pain to the user.

The values of attenuation obtained across frequencies for different EPDs were then subjected to statistical analysis. The mean standard deviation and range were computed.

The mean attenuation represents protection that approximately fifty percent of the test subjects meet or exceed.

The standard deviation provides an indication of the variability in attenuation across subjects and replication. To estimate the protection that a greater percent of the subjects attain, adjustments to the mean may be computed by subtracting one or more standard deviation.

The range represents the minimum and maximum attenuati provided by a particular EPD at a specified frequency aero subjects.

The results obtained for each of the EPDs are. given below.

TABLE - 4.1

Attenuation provided by Ear Ultra-fit (flanged) Earplugs NRR21

Frequency N=30 TEST		250HZ	500Hz	1kHz	2KHz	3KHz	4KHz	6KHz	8KHz	WBN	SET
MEAN		14.833	14.333	17.333	19	21	21.05	21.05	24.33	26.5	25
S.D		3.592	4.097	3.41	3.81	3.32	3.75	3.75	4.49	2.98	3.71
RANGE	MIN	10	10	10	10	15	15	15	15	20	20
	MAX	20	20	25	25	25	25	25	30	30	30

TABLE 4-2

Attenuation provided by Soft Moldable EAR Earplugs.

Frequency N=30 TEST		250HZ	500H2	1kHz	2KH2	3KHz	4KHz	6KHZ	8KHz	WBN	SRT
MEAN		22.833	20.67	25.17	24.83	27	30.67	32.67	33.17	33.8	33.3
S.D		4.49	3.88	3.08	4.04	3.62	4.87	4.30	4.45	3.87	3.56
RANGE	MIN	15	10	20	20	20	20	25	25	30	30
	MAX	30	25	30	30	30	35	40	40	40	40

TABLE 4.3
Attenuat ion provided by TASCO Semi-inset T-100 NRH 17

Frequency N=30 TEST	250H2	500HZ	1kHz	2KHz	3KHz	4KHz	6KHz	8KHz	WBN	SET
MEAN	9.5	11.333	12.833	15 :	6.51	22.33	21.83	21.67	22.3:	i 22.17
S.D	4.02	2.25	2.84	3.47	5.93	2.86	2.45	2.39	2.86	2.52
RANGE MIN	5	10	10	10	10	20	20	20	28	20
MAX	15	15	20	20	25	30	25	25	30	25

TABLE 4.4
Attenuation provided by Earmuffs.

Frequency N=30 TEST	250H2	500Hz	1KHz	2KHz	3KHz	4KHz	6KHz	8KHz	WBN	SRT
MEAN	13.833	17.17	22.33	22.67	26.83	28.83	34	34.61	31.33	35 -17
S.D	3.87	3.95	3.65	3.41	3.07	2.52	3.32	3.42	2.60	3.08
RANGE MIN	10	10	15	15	20	25	30	30	25	30
MAX	20	20	25	25	30	35	40	40	35	40

TABLE 4.5
Attenuation provided by Peltor Earmuffs (Tactical 7) off-Position

Frequency N=30 TEST	250HZ	500Hz	1kHz	2 KHz	3KHz	4KHZ	6KHz	8KHz	WBN	SRT
MEAN	16.67	27	34	38.83	36.66	42	44.16	43	32.83	38.83
S.D	2.73	3.73	3.32	4.29	4.22	2.81	3.49	3.61	3.64	3.13
RANGE MIN	10,	20	30	30	30	35	40	40	30	35
MAX	20	35	40	45	45	45	50	50	40	45

TABLE 4.6
Attenuation provided by Peltor EarMuffs (Tactical 7)
Mid-on Position

Frequency N=30 TEST	250Hz	500Hz	1kHz	2KHz	3KHz	4KHz	6KHz	8KHz	WBN	SRT
MEAN	11.33	11.40	12.33	13.55	16.67	18.33	27.17	24.5;	! 15	13.44
S.D	3.25	2.86	2.54	3.91	2.39	3.62	3.13	4.47	4.15	4.83
RANGE MIN	5	10	10	10	15	15	25	20	10	10
RANGE MAX	15	15	15	20	20	25	35	30	25	20

TABLE 4.7
Attenuation provided by Peltor Eanauffs (Tactical 7)
Full-on Position

Frequency N=30 TEST	250HZ	500Hz	1KHz	2KHz	3KHz	4KHz	6KHz	8KHz	WBN	SRT
MEAN	-6.5	-8.07	-5.33	-1	1.67	6.33	15.67	16.1'	' 1.12	0.833
S.D	3.51	3.33	3.45	3.57	3.30	2.60	3.80	3.13	3.58	3.97
RANGE MIN	-10	-15	-10	- 5	- 5	0	10	10	-5	-5
RANGE MAX	0	-5	0	5	5	10	20	20	5	5

TABLE 4.8
Attenuation provided by Helmet with Muffs

Frequency N=30 TEST	250Hz	500Hz	1kHz	2KHz	3KHz	4KHz	6KHz	8KHz	WBN	SRT
MEAN	16.33	19.5	19.68	21.67	22.81	22.09	22.83	23.23	3 22.1	7 24
S.D	2.92	4.31	4.64	6.89	6.81	5.29	2.84	3.71	3.13	3.57
MIN	10	10	10	15	15	15	20	20	20	20
MAX	20	25	25	20	30	30	30	30	30	30

The attenuation provided by the different EPDs was compared for low frequencies (i.e., mean of means of attenuation at 250Hz and 500Hz) mid-frequencies (i.e.mean of means of attenuation at 1KHz, 2Khz, 3KHz), high frequencies (i.e. means of attenuation at 4KHz, 6Khz, 8KHz), white noise and SRT as shown in the Fig. 1 to 5 respectively.

Figure 1

LOW FREQUENCY ATTENUATION

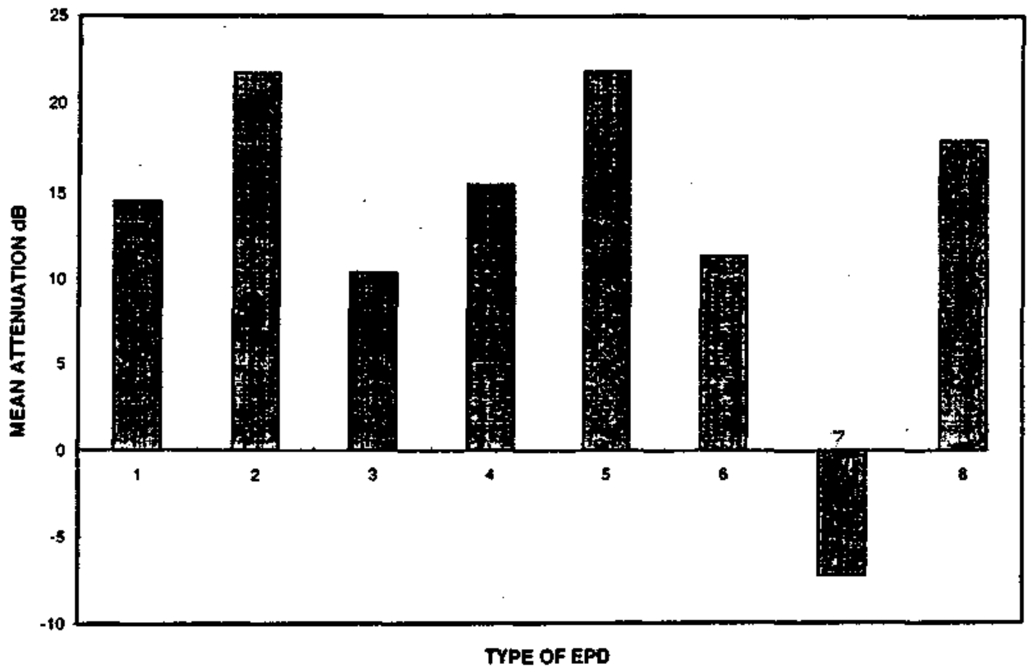


Figure 2

MID FREQUENCY ATTENUATION

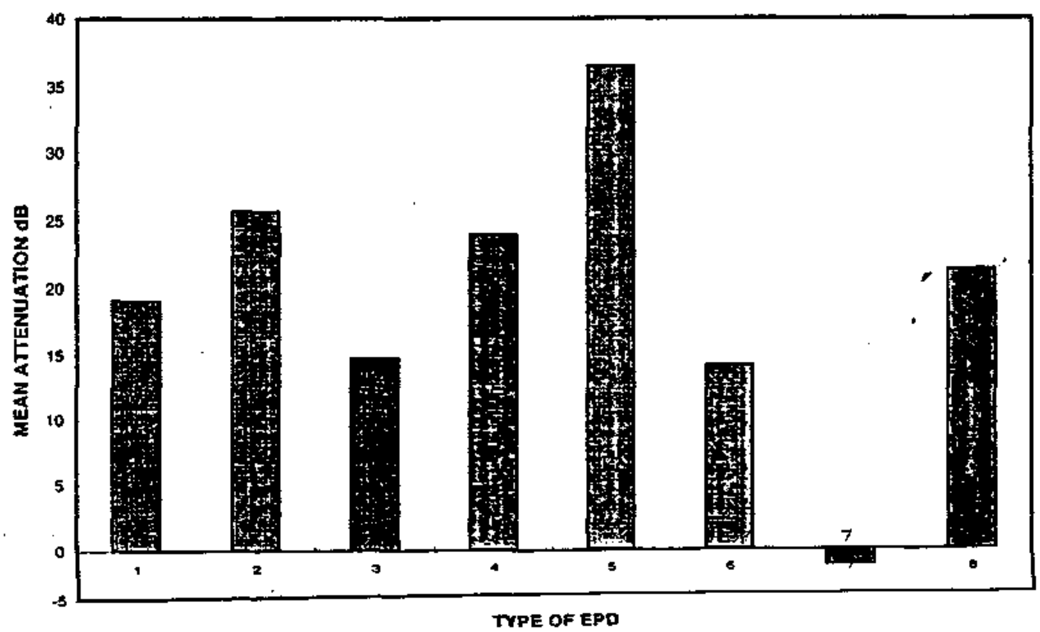


Figure 3

HIGH FREQUENCY ATTENUATION

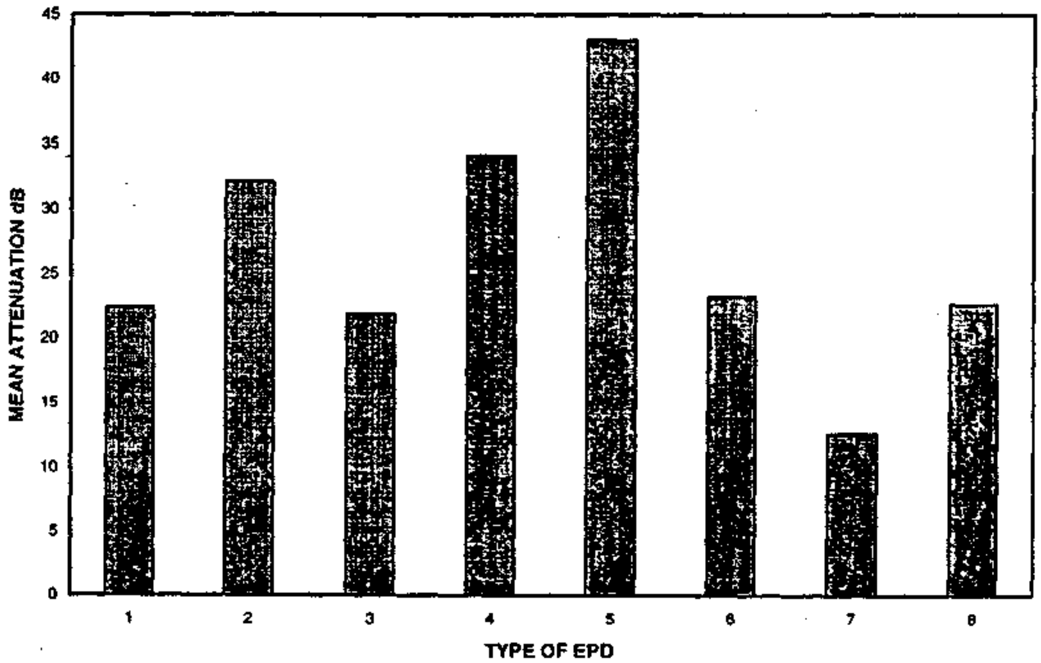


Figure 4

ATTENUATION FOR WHITE NOISE

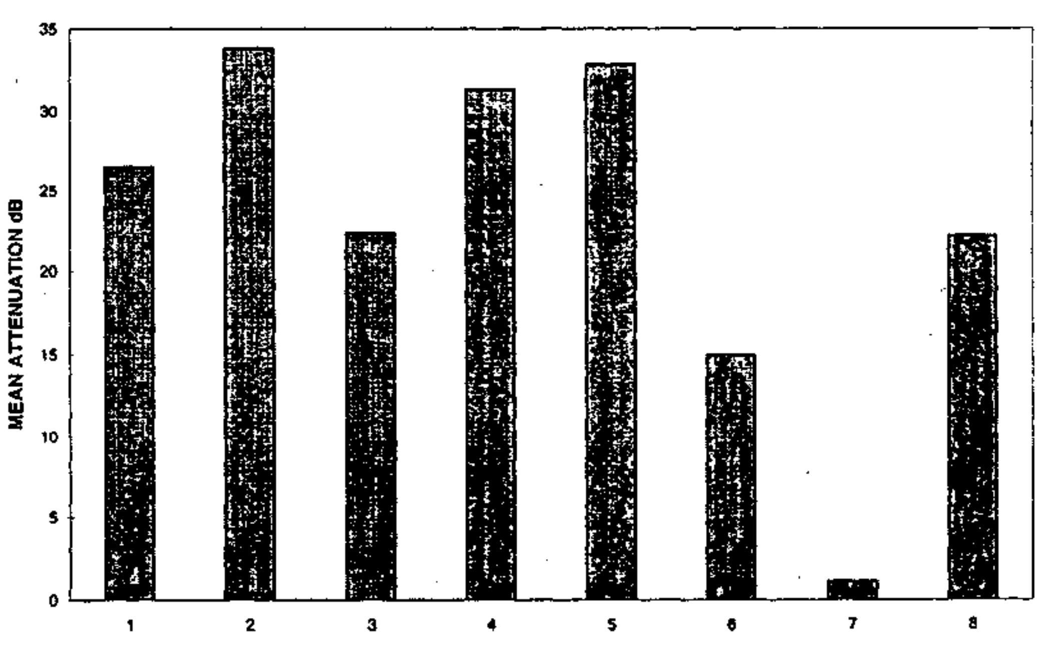
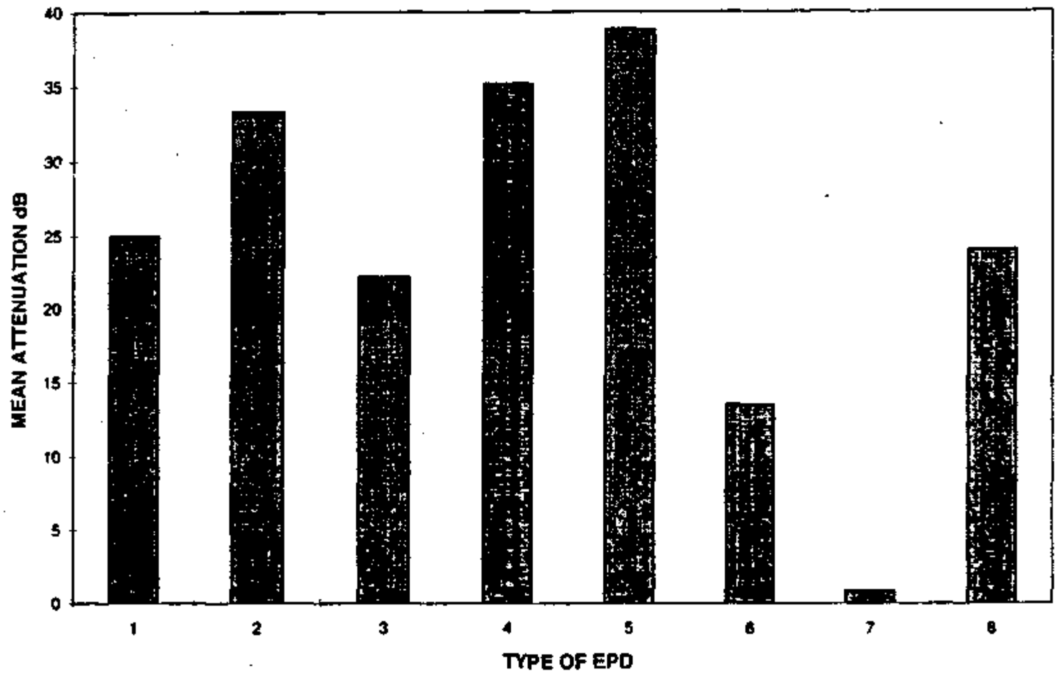


Figure 5

ATTENUATION FOR SRT



Key for Figures 1 to 5

On X-axis : 1 : Ear Ultra fit (flanged) Earplugs NRR 21
2 : Soft Moldable EAR Earplugs
3 :TASCO T -100 Semi-insert NRR 17
4 : Earmuffs
5 : Peltor Earmuffs (off position)
6 : Peltor Earmuffs (mid-on position)
7 : Peltor Earmuffs (on position)
8 : Helmet with muffs

The results obtained in this study are in general, consistent with the finding of earlier studies on attenuation attenuation characteristics of different EPDs.

The Peltor earmuffs (TACTICAL 7) were found to provide maximum attenuation in the full-off position for low, mid and high frequencies as well as SRT. The Soft Moldable EAR earplugs provided maximum attenuation for white noise at low frequencies and for SRT the Soft Moldable EAR earplugs provided, the second best attenuation and the helmet with muffs the third best, for high frequencies however the earmuffs provided the second best attenuation and the soft moldable earplugs the third best. The mean attenuation values across all frequencies for the Soft Moldable EAR earplugs i.e. 22.83 at 250Hz and 33.17 at 8KHz were slightly less than the values obtained by Berger (1974), i.e., 30dB at 125Hz and 45dB at 8KHz but corresponded with the values represented by Martin (1976), i.e., mean attenuation lies between 8 and 43dB for Soft Moldable EPDs across frequencies.

The Ear Ultra fit (flanged) earplugs provided attenuation ranging from 10 to 30dB across frequencies.

The TASCO T-100 Semi-insert provided attenuation ranging from 5 to 20dB at frequencies below 1KHz which correlated with the report by Sataloff and Sataloff (1987) and in general an attenuation of between 5dB and 30dB across all frequencies which is consistent with the findings of Berger (1994) who reported that the attenuation values the between 25dB and 40dB.

The Peltor earmuffs (TACTICAL 7) at mid-on position provided least attenuation for SRT i.e., around 12dB, little attenuation at low and mid frequencies and white noise i.e., around 15dB and most attenuation at high frequencies i.e., around 22dB.

Af full-on position the Peltor earmuffs (TACTICAL 7) provided amplification rather than attenuation at low and mid-frequencies. It provided almost no attenuation only about l-2dB for white noise and SRT. At high frequencies the EPD provided around 14dB of attenuation.

The attenuation provided by the helmet with muffs was better than that of the flanged earplugs and the TASCO T-100 Semi-insert at low-, mid-, and high-frequencies but was poorer for white noise than both the flanged earplugs and the semi-inserts and also for speech than the flanged earplugs.

Further the attenuation of the flanged earplugs may have been a little lesser than that quoted by in the review due to variables like the subject himself i.e., the size of the subject ear canal and effect of the climate on the earplugs.

Thus this study is general indicated that the Peltor ear muffs (at off-position) provided the maximum attenuation followed by the Soft Moldable EAR earplugs and the earmuffs across the narrowband frequencies 250Hz, 500Hz,lKHz, 2KHz, 3KHz,4KHz, 6KHz, 8KHz and for white noise and speech. These devices may thus be used in environments in which the noise levels are moderately loud to loud.

The helmets with muffs,the flanged earplugs, the Peltor earmuffs in mid-on position and the semi-inserts provided only mild to moderate attenuation and could be use only in environments of moderately-loud levels of noise. The Peltor earmuffs (in the mid-on position) could be used in an enviornment which has impulse noise.

In the full-on position the Peltor provided amplification instead of attenuation for low-and mid-frequencies and almost negligient i.e. 0-2dB attenuation for white noise and speech. At high frequencies it provided some attenuation of around 13-15dB. However at the full-on setting the EPD cut off impulse noise (like a clap) and other loud noises but amplified soft environmental noises.

This device at the full-on position is thus useful in environments where the noise levels are only moderately loud and have a high energy concentration or in an environment in which high frequency noise and speech occur together and where comprehending verbal communication is of importance to the employee.

Further it may be useful in the presence of impulse noise as it helps to cut off impulse noise even in the full-on position.

RESPONSES TO THE QUESTIONNAIRE FOR SHORT-TERM USE OF EPDs

The responses of the thirty subjects to the Questionnaire for the short term use of EPDs (Appendix-2A) are given below:

1. Twenty-two of the thirty subjects, were unable to wear and remove the Soft Moldable EAR earplugs, but could wear/ remove the other EPDs on their own. Five of the thirty were unable to wear and remove the Ear Ultra fit (flanged) earplugs and the Soft Moldable EAR earplugs. Three of thirty subjects, could use all the EPDs on their own.

2. All the subjects reported that they found it difficult to wear and remove the flanged and the Soft Moldable earplugs. Twelve of these subjects also found it difficult to wear and remove the helmet with muffs on their own.

3. Twenty-four of the thirty subjects, judged the Peltor muffs to be the heaviest when actually, the helmet with muffs was the heaviest EPD; only six judged the helmet with muffs to be the heaviest. This may have been due to the fact that as the weight of the helmet was distributed over the head, it was perceived as lighter than the Peltor earmuffs by most of the subjects. All the subjects graded the earmuffs as the,third heaviest and the semi-insert as

the fourth heaviest EPDs. Of the thirty subjects, twelve judged the flanged earplugs to be heavier than the moldable ones, sixteen judged the two to be equally heavy and two judged the Soft Moldable earplugs as heavier than the flanged one.

4. All subjects found the helmet with muffs and the Peltor earmuffs to be heavy. Twenty-three of these subjects, also judged the earmuffs to be heavy. None of the subjects judged the flanged or moldable earplugs or the semi-inserts as heavy.

5. Twenty-three of the thirty subjects, did not report any pain, or irritation of skin while wearing or removing the EPDs. Seven subjects reported pain and irritation of skin, while the soft moldable earplugs were being removed. Three of these seven subjects, also reported irritation of the skin while wearing /removing flanged earplugs.

6. Of the thirty subjects, twenty-eight reported discomfort while wearing the moldable earplugs, the Peltor earmuffs and the helmet with muffs, three of whom reported discomfort, for the flanged earplugs as well. Only two subjects reported no discomfort for all the EPDs.

7. All the subjects reported an inadequate seal for the semi inserts and the helmet with muffs. Five subjects reported the seal of the earmuffs to be inadequate while speaking. These subjective reports correlated well with the objective attenuation measurements.

8. Twenty-three of the thirty subjects, found the Peltor ear -muffs to be too bulky to carry around everyday, if only intermittent use was required. All the subjects found the helmet with muffs to be too bulky to carry around. None of the other EPDs were perceived to be bulky.

9. All the subjects reported that they be would willing to persevere through the initial break-in period and bear the discomfort for the two earplugs, the semi-insert and the earmuffs. Seven of the thirty subjects, said they would be unwilling to persevere during the break-in period for Peltor and ninteen said the same for the helmet with muffs. They said they would opt for a different EPD.

10. All the subjects found the head-band of the semi-insert to be insecure. The five subjects who had reported an inadequate seal for the earmuffs also found its head-band to be insecure. Thirteen subjects found the helmet with earmuffs to be insecure in its fit.

All the subjects reported excellent seal and a secure fit for Peltor earmuffs (Tactical 7).

11. The subjects all reported that the pinna fit comfortably into the Peltor earmuffs but most of them found it to be tight; and they reported that the pinna did fit well into the earmuffs, without bring too tight. Ten subjects reported that the pinna did not fit comfortably into the helmet with muffs.

12. The results of the ratings, on a scale of six, for each the EPDs, with 1 as 'most comfortable' and 6 'least comfortable', are given below.

Majority of the subjects reported the following order of EPDs from most to least comfortable.

1) Ear Ultra fit flanged earplug NRR 21
2) Soft Moldable EAR earplugs
3) Earmuffs
4) TASCO Semi-insert T-100 NRR-17
5) Peltor earmuffs (Tactical 7)
6) Helmets with muffs.

A few subjects showed variations from this pattern and reported the soft moldable EAR earplugs as the most comfor-table EPD and few reported Peltor earmuffs to be more comfortable than the earmuffs, but the majority of the subjects gave the responses as listed above.

13. All the subjects reported the attenuation provided for speech stimuli by Peltor earmuffs in 'off' position as very good, and majority of the subjects i.e. , twenty-one of the thirty, reported the attenuation at the mid-on position as fair while nine reported it to be poor. All the subjects reported that there was no attenuation in the full-on position (amplification was reported instead).

14. All the subjects reported that the Peltor earmuffs (in all the three settings i.e., off, mid and on position) was able to effectively cut off an impulse sound, like a clap.

RESPONSES TO THE QUESTIONNAIRE FOR LONG-TERM USE OF EPDs

The responses of the six subjects to the Questionnaire for the long-term use of the EPDs (Appendix 2B) are given below, and are summarized in the Table 4.10.

Subject: 1 Age/sex : 23y/M EPD used : Ear Ultra fit (flanged) earplugs.

1. The subject reported that the EPD was very light and its fit was just appropriately tight and secure.
2. He said that the EPD did irritate the skin towards to end, after about five hours of use.
3. The subject experienced an occlusion effect which interfered with his communication with others.
4. The subject said that prolonged use of EPD did make him sweat inside the ear canal, especially towards the end of the day.
5. The subject reported that the communication process was affected both as a speaker and as a listener.

   As a listener, the subject needed to frequently ask people to repeat themselves. He had difficulty in hearing, when communicating with a group. He also found it difficult to comptehend the entire message of a conversation.

   As a speaker, he felt that he was always speaking at a louder level than normal, but his rate of speech remained normal. Further, he found communication effortful and tiring, especially as the day progressed.

6. The subject reported that he was relying on both lip reading and contextual cues.
7. Inspite of the discomfort associated with the long-term usage of the EPD the subject said that he would be willing to wear it everyday and persevere during the break-in period in order to protect his hearing.
8. When fitted with the EPD the subject could not hear a telephone ring . He could however, hear a moderate-level door-knock, 3/6 times, and someone calling him from about 12 feet occasionally, when he was not deeply engrossed in any other activity.

<u>Subject</u>: 2 <u>Age/sex</u> : 19y/M <u>EPD used</u> : Soft Moldable EAR earplugs.

1. The subject reported the EPD to be very light, and its fit to be very tight, but not painful.
2. THe subject reported that the ear canal was itching and felt slightly sore by the end of the day, as the EPD kept rubbing against the same place in the ear canal .
3. The subject did experience an occlusion effect which interfered with his communication with others.
4. Prolonged usage of the EPD made the subject feel sweaty and also made him feel as though the ear canal was impacted.
5. The subject reported that communication was affected as a listener as well as a speaker. As a listener he needed to ask for frequent repetitions. Communication with a group

was affected, and he found it difficult to get the entire message. As a speaker, he was speaking louder than normal, but at a normal rate. The subject needed to pay close attention to the speaker which became taxing by the end of eight hours.

6. The subject that he ruled both on lip reading and contextual cues.
7. The subject said that he would be willing to wear this EPD everyday even during the break-in period in order to protect his hearing.
8. When fitted with the EPD the subject could not hear the telephone bell. He could hear a moderate-level door-knock 2/6 times and his name being called, only occasionally.

<u>Subject</u> : 3 <u>Age/sex</u> : 19y/M <u>EPD used:</u> TASCO T-100 Semi - insert NRR -17

1. The subject reported the EPD to be light and slightly loose/lax.
2. The EPD did not irritate the skin.
3. No occlusion effect was experienced and thus the communication process was not completely affected. The subject reported that the seal was inadequate and was affected by movements of the jaw.
4. Prolonged usage of the EPD did not make the subject sweat, but the pressure of the semi-insert at the entrance of the ear canal, but it was slightly uncomfortable.

5. The subject reported that communication process, with him as a speaker, was not affected but with him as a listener, was partially affected. As a listener, he occasionally needed to ask people to repeat themselves when they spoke. Further, communicating to a group was sometimes difficult especially if someone was speaking with his back towards him. Sometimes, a part of the message was missed, which made comprehension difficult. As a speaker, the subject was speaking at a normal rate and loudness and he did not find communication to be effortful or tiring.

6. However, the subject did rely on lip reading and contextual cues to some extent.
7. If exposed to hazardous noise levels, he said he would be willing to persevere through the break-in period and use this EPD.
8. When fitted with the EPD, the subject could hear the telephone ring, if his room door was open. He could hear a moderate-level door-knock, and could also hear somebody calling out from a room next door (at 12 feet) at a moderately-loud level.

SUBJECT : 4 Age/sex : 21y/F EPD used : Earmuffs

1. The subject reported this EPD to be moderately heavy and just appropriately tight and secure in its fit.

2. Prolonged usage of the earmuffs did not irritate the skin.

3. The subject experienced a slight occlusion effect and this did interfere in her communication with others.
4. Prolonged usage made the subject's ears feel sweaty.
5. The prolonged usage also affected the communication process for the subject as a speaker, and as a listener, especially when she was more than 8-10 feet from the person who was speaking to her. As a listener, she needed repetitions occasionally. She could not hear well when communicating to a group of people and often she reported, that she could not catch the entire message. This affected the communication process. As a speaker, she was always speaking louder than normal when the EPDs were worn, but the rate of speaking remained normal. Further the subject reported that as the day progressed she found the communication process to be effortful and tiring.
6. She also reported that she relied on lip reading and contexual cues.
7. The subject said she would be willing to persevere through the break-in period and wear this EPD if she were exposed to hazardous levels of noise.
8. She could not hear the telephone ring, unless the room door was open. She occasionally (3/6 times) could hear a moderate-level door-knock and she could hear her name being called from the room next door (12 feet) if she was not engrossed in some activity.

SUBJECT : 5 Age/sex : 23y/F EPD used : Peltor earmuffs (Tactical 7)tested in off position.

1. The subject reported that initially the EPD was heavy but tolerable, but as the day progressed she found it almost intolerable to wear. Further, she said that the EPD was very tight, but not painful. However, both the weight and the tight fit caused a headache for the subject after three to four hours of use.
2. The EPD did not irritate the skin.
3. The subject did experience a marked occlusion effect, which affected her communication with others.
4. Wearing the EPD made her feel sweaty and uncomfortable.
5. The communication process was impaired for the subject as a speaker, and as a listener. As a listener, she needed to frequently ask people to repeat themselves when they spoke. She had difficulty speaking to a group of people especially when they spoke from behind her or from a distance greater than six to eight feet. She also reported that she kept missing out on part of the spoken message and often only tried to get only the gist of the entire conversation. As a speaker, she always spoke much louder than normal, but at a normal rate. Towards the second half of the test, i.e., last four hours, the subject found speaking very tiring and effortful.
6. The subject relied on lip reading and contextual cues.

7. This subject reported that though she would be willing to persevere through the break-in period and use the EPD if she were to be exposed to hazardous noise levels but she would prefer a lighter one.
8. The subject could not hear the telephone ring even with the room door open, nor could she hear the moderate-level door-knock or her name being called.

SUBJECT : 6 Age/Sex : 22y/.F EPD used : Helmet with muffs

1. The subject reported that the EPD was tolerably heavy but it did get to be cumbersome towards the end of the day and the fit of the EPD was slightly loose/lax.
2. Prolonged usage did not irritate the skin.
3. The subject did not experience an occlusion effect, may be because the seal of the muffs was not adequate. Thus, it did not interfere very drastically in her communication with others.
4. Wearing the EPD made the subject feel sweaty in her ears and also in her hair. Further prolonged usage caused discomfort to the subject.
5. The communication process was not affected for the subject as a speaker but it was affected for her as a listner as she occasionally needed to ask people to repeat themselves. Further, she could not communicate effectively with a group of people and sometimes it was difficult to catch the entire message when the speaker spoke from behind the subject. The subject spoke at a normal

loudness and rate. However, she reported that she found it tiring and effortful to speak as the day progressed.

6. She reported that she did rely on lip reading and contextual cues as aids in communication.

7. The subject reported that though she would try to persevere through the break-in period and use the EPD if exposed to hazardous noise levels, she was not sure if she would be able to do so successfully, and would thus prefer to be give a different EPD.

8. She could hear a telephone bell when the room door was open, she could hear a door-knock at a moderate-level 4/6 times, and could hear her name being called at moderately loud levels.

Thus the results of the subjective evaluation of EPDs indicate that in general, the flanged Ultra fit earplugs were judged as the most comfortable EPDs followed by the Soft Moldable EAR earplugs.

During the short term usage of the EPDs a majority of the thirty subjects judged the helmet with muffs to be most uncomfortable and bulky EPD. Further, they perceived the Peltor earmuffs to be the heaviest EPDs when actually the helmet with muffs was the heaviest. This may have been due to the fact that the weight of the helmet with muffs was evenly distributed over the entire surface of the head, making it seem lighter than the Peltor earmuffs whose weight was concentrated on the head-band and around the ear.

All the subjects in the long-term use of EPDs study reported fatigue, discomfort and the need to use an extra effort for communication for all the EPDs towards the end of the day. Yet, all the subjects said that they would be willing to persevere through the break-in period and use the EPDs if they were exposed to hazardous levels of noise. However, the subjects 5 and 6 who were fitted with Peltor earmuffs and the helmet with muffs respectively said that they would prefer to be fitted with a different, lighter EPD.

The subjective evaluation of EPDs corresponded with the objective results of the attenuation characteristics of the EPDs. Majority of the subjects reported that the Peltor earmuffs (in off position) and the Soft Moldable EAR earplugs were the most effective EPDs and that the Peltor earmuffs in full-on position was the least effective.

During the long-term use of EPDs communication for all the six subjects was more affected for them as listeners, than as speakers. All the six subjects relied on lip reading and contextual cues as aids for communication. Here too, communication for subject fitted with Peltor earmuffs (off position) was maximally affected, followed by the subject fitted with the Soft Moldable EAR earplugs. Thus, both the objective as well as the subjective test results of this study, corresponded well with each other.

It can thus be concluded that depending on the type of environment and duration of use required the following EPDs may be recomended.

TABLE -4.9

EPDs RECOMMENDED FOR USE IN DIFFERENT SITUATIONS BASED ON THEIR ATTENUATION AND COMFORT

ENVIRONMENT	DURATION OF USE REQUIRED	TYPE/TYPES OF RECOMMENDED
Very loud steady-state noise with impulse noise superimposed on the continuous noise	1. Full day use	No alternative but to use Peltor ear-muffs in off position
	2. Use only in presence of im-pulse noise. (2 hours a day)	Soft Moldable EAR ear plugs & use of Peltor earmuffs only in the presence of impulse noise.
Loud continuous noise	1. Full day use	Soft Moldable EAR ear plugs.
	2. Intermittent or short-term use	Helmet with muffs or Peltor earmuffs.
Moderately loud noise	1. Full day use	Soft Moldable EAR ear plugs or earmuffs.
	2. Intermittent or short duration use.	Helmet with muffs or Peltor ear muffs,
Moderately loud noise with inter-mittent impulse noise.	1. Full day use	Soft Moldable EARs ear plugs or earmuffs
	2. Intermittent or short duration use.	Peltor earmuffs (off position)

ENVIRONMENT	DURATION OF USE REQUIRED	TYPE/TYPES OF RECOMMENDED
Moderately loud raid- or high- frequency noise.	1. Full day use	Earmuffs, Soft Moldable EAR plugs,
	2. Intermittent or short duration use.	Peltor earmuffs (off position) Helmet with earmuffs.
Moderate noise in presence of speech at normal intensity	1. Full day use	Ear Ultra fit flanged ear plugs NRR 21, TASCO Semi-insert NRR -17.
	2. Intermittent or short duration use.	Peltor mid-on position Helmet with muffs,
Moderate noise in presence of faint speech.	1. Full day use	TASCO T-100 Semi-insert NRR-17, Ear Ultra fit (flanged) earplugs
	2. Intermittent or short duration use.	Peltor earmuffs (full-on position),

The main strength of this study was that it was conducted on a large population of thirty subjects. This made the results fairly reliable and valid in order to generalize to a larger population.

Further, this study was the first of its kind in which data on the subjective responses regarding the performance, comfort and wearability of the EPDs was collected.

LIMITATIONS OF THE STUDY :

The experiment, to investigate the subjective report on EPDs, where in subjects were fitted with EPDs, for an eight hour period, was carried out on only one subjects for each type of EPD included in the study. In order to generalize these subjective responses, the experiment should have been carried out on a larger number of subjects for each type of EPD.

TABLE -4.10

SUBJECT RESPONSES

Subjective responses for various attributes of EPDs (of Q. 2B)

E P D ATTRIBUTE	Subject 1	Subject 2	Subject 3	Subject 4	Subject 5	Subject 6
	EPD used:EAR Ultra fit (flanged)Ear -plug NRR 21	EPD used: Soft Mold -able EAR Earplugs	EPD used: TASOO Semi -insert NRR 17	EPD used: Earmuffs	EPD used: Peltor Earmuffs (Tactical7)	EPD used: Helmet with Ear - muffs
1. Weight	Very light	Very light	Light	Modera- tely heavy	Heavy, but tolerable for a short duration 2- 3 hrs	Heavy but tolerable for 4-6 hrs.
2. Fit	Just appro - priately tight	Very tight	Slightly loose/ lax	Just appr -opriately tight	Very tight (caused a headache by the end of 8 hrs	Slightly loose / lax
3.Sweating & discom- fort	Sweating (in the ear canal	Sweating present	No swea- ting, slight dis - comfort present	Sweating present	Sweating & discomfort present	Sweating in the ear and hair and discomfort present.
4. Irrita -tion to the skin	Yes, tow -ards the end of the day	Yes, tow -ards the end of the day	No	No	No	No

EPD ATTRIBUTE	Subject 1	Subject 2	Subject 3	Subject 4	Subject 5	Subject 6
5. Occlusion effect	Marked	Marked	No	Slight	Marked	No
6. Appropriate seal	Yes	Yes	No	Yes	Yes	No
7. When fitted with EPD could you hear						
a) Telephone bell	No	No	Yes, if door was open	Yea, if door was open	No	Yes, if door was open
b) Mod.level door knock	Yes,3/6 times	Yes,2/6 times	Yes	Yes,3/6 times	No	Yes, 4/6 times
c) Name call at mod-loud leve] at 12' ?	Occasio-nally, if not engrossed in some other task	Occasio-nally	Yes	Occasio-nally, if not engrossed in some other task	No	Yes
8. Was contnunic-ation tiringf and effort-full ?	Yes, by the end of the day	Yes	Slightly, by the end of the day	Yes	Yes,very tiring & effortful	Yes,by the end of the day

EPD ATTRIBUTE	Subject 1	Subject 2	Subject 3	Subject 4	Subject 5	Subject 6
9. Was cormmunicat -ion affected as:						
a) a speaker	Yes, he spoke loud -er but at a normal rate	Yes, he spoke loud -er but at a normal rate	No	Yes,she spoke loud -er but at a normal rate	Yes,she spoke loud -er but at a normal rate	No
b) a listner	Yes	Yes	Partially	Yes	Yes	Partially
i) needed repetition	Freque- ently	Frequ -ently	Occasio -nally	Occasio -nally	Frequen -tly	Occasio -nally
ii) Could catch entire message	Difficult	Difficult	Slightly diffi -cult	Difficult	Very difficult	Difficult
iii) Difficulty in commun -icating to a group	Yes	Yes	Some- times	Yes	Yes	Yes
10. Reliance on lip reading & contextual cues.	Yes	Yes,to a great extent	Yes, to some extent	Yes	Yes, to a great extent	Yes
11. Willingness to wear EPD if exposed to hazardous noise levels	Yes	Yes	Yes	Yes	Yes, but would prefer a 1ighter EPD	Yes, but would prefer a lighter EPD

CHAPTER V

SUMMARY & CONCLUSION

SUMMARY :

This study aimed at comparing the attenuation characteristics of six different EPDs for narrow-band noise centered at 250Hz, 500Hz, 1KHz, 2KHz, 3KHz, 4KHz, 6KHz and 8KHz, and for white noise and speech (spondee) stimuli for thirty subjects. The Real Ear Attenuation at Threshold (REAT) method was used to study the attenuation characteristics.

This study also involved a subjective evaluation of the EPDs by the thirty subjects as well as a one day experiment in which six subjects (chosen at random from. the initial thrity subjects) were each fited with one of the EPDs under study for eight hours. After this longterm use of the EPD the subjective evaluation of the EPDs was done.

The test results revealed the following; The attenuation performance of the EPDs from best to poorest was as follows;

1. Peltor earmuffs (in off position) were the most effective EPDs followed by the soft moldable EAR earplugs.
2. The ear Ultra fit flanged earplugs, the Helmet with muffs and the earmuffs provided almost equal attenuation.
3. The Semi-insert and the Peltor in mid-on position provided almost similar amounts of attenuation.
4. The poorest performance was shown by the Peltor earmuffs in full-on position.

5. The Peltor earnmffs provided a cut-off of the intensity of an impulse stimulus such as a clap.

The subjective evalualtion of EPDs revealed that majority of the subjects rated the comfort of the EPDs in the following order of decreasing comfort.

1. Ear Ultra fit (flanged) earplugs NRR 21
2. Soft Moldable EAR earplugs
3. Earmuffs
4. TASCO semi insert T-100 NRR 17
5. Peltor earmuffs (Tactical 7)
6. Helmet with muffs

The results of the objective evaluation of attenuation characteristics of the EPDs correspond with the subjective reports of the subjects regarding the performance and efficiency of the EPDs. All the subjects found the Peltor earmuffs and helmet with muffs to be very heavy and the two subjects who were fitted with these two EPDs in the study on long-term use of EPDs, reported that they would prefer to be fitted with lighter EPDs if they had to use them to protect their ears from hazardous noise levels, as the Peltor earmuffs and the helmet with muffs were very heavy and almost intolerable for long-term usage.

CONCLUSION :

The results of the study do correlate with the findings of earlier studies on the attenuation characterstics of different EPDs. Further, this study subjectively evaluated the six EPDs in terms of their performance/efficacy in providing attenuation and also in terms of comfort, wearability, and effect on communication. This study also was one of the first study that required the subjects to evaluate the EPDs a period of prolonged usage (i.e. eight hours) in terms of the comfort, wearabilty and effects on communication as a listener and as speaker.

Thus, in conclusion, this study indicated that the Peltor earmuffs (in off position) was the most effective EPD in terms of the amount of attenuation provided and the ear Ultrafit (flanged) earplugs were reported, by a majority of the subjects, to be the most comfortable EPD.

Thus in conditions of loud noise the Peltor earmuffs could be ideal in providing hearing protection especially in conditions of loud impulse noise were only intermittent use of EPD is required, while in conditions of moderate noise the Ear Ultrafit (falnged) earplug would be a better option especially where prolonged usage is required and the users comfort becomes an important aspect. Peltor earmuffs, and the Helmet with muffs options when the duration of use of these EPDs was short, as they were too heavy and bulky for long term usage.

The other EPDs i.e the soft moldable EAR earplugs, the TASCO semi insert T-100 NRR-17 and the earmuffs were all judged as fairly comfortable and could be recommended in condition which required moderately long hours of use. (4-8 hours).

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APPENDIX I

SPONDAIC WORDS OF AUDITORY TESTS W-l AND W-2 (CID)

1. Aeroplane
2. arm chair
3. baseball
4. birthday
5. cowboy
6. daybreak
7. doormat
8. draw bridge
9. duckpond
10. eardrum
11. farewell
12. grandson
13. grey
14. hardware
15. headlight
16. horseshoe
17. hotdog
18. hothouse
19. iceberg
20. inkwell
21. mousetrap
22. mushroom
23. northwest
24. oatmeal
25. padlock
26. pancake
27. playground
28. railroad
29. schoolboy
30. sidewalk
31. stairway
32. sunset
33. toothbrush
34. whitewash
35. wood work
36. workshop

APPENDIX - 2-A

Questionnaire for Short-term use of EPDs

1. Where you able to wear and remove the following EPDs on your own

    i) Ear Ultra fit (flanged) Earplugs NRR 21 Yes/No,

    ii) Soft Moldable E.A.R. Earplugs Yes/No,

    iii) TASCO T-100 Semi-insert NRR 17 Yes/No,

    iv) Earmuffs Yes/No,

    v) Peltor earmuffs (TACTICAL 7) Yes/No,

    vi) Helmet with muffs Yes/No.

2) If yes, could you do so with ease for :

    i) Ear Ultra fit (flanged) Earplugs NRR 21 Yes/No.

    ii) Soft Moldable Earplugs Yes/No.

    iii) TASCO T-100 Semi-insert NRR-17 Yes/No.

    iv) Earmuffs Yes/No.

    v) Peltor Earmuffs (TACTICAL 7) Yes/No.

    vi) Helmet with muffs Yes/No.

3. Grade the weight of the EPDs with 1= heaviest, 6=lightest mark.

4. Which of the EPDs did you find heavy ? (mark yes for as many as appropriate)

    i) Ear Ultra fit (flanged) Earplugs NRR 21 Yes/No.

    ii) Soft Moldable E.A.R. Earplugs Yes/No.

    iii) TASCO T-100 Semi-insert NRE 17 Yes/No.

    iv) Earmuffs Yes/No.

    v) Peltor Earmuffs (TACTICAL 7) Yes/No.

    vi) Helmet with muffs Yes/No.

5. Did you experience any pain when you wore :

   i) Ear Ultra fit (flanged) Earplugs NRR 21 Yes/No.

   ii) Soft Moldable E.A.R. Earplugs Yes/No.

   iii) TASCO T-100 Semi-insert NRR 17 Yes/No.

   iv) Earmuffs Yes/No.

   v) Peltor Earmuffs (TACTICAL 7) Yes/No.

   vi) Helmet with muffs Yes/No.

6. Did you experience any irritation of the skin when you wore :

   i) Ear Ultra fit (flanged) Earplugs NRR 21 Yes/No.

   ii) Soft Moldable E.A.R. Earplugs Yes/No.

   iii) TASCO T-100 Semi-insert NRR 17 Yes/No.

   iv) Earmuffs Yes/No.

   v) Peltor Earmuffs (TACTICAL 7) Yes/No.

   vi) Helmet with muffs Yes/No.

7. Did you experience any discomfort when you wore :

   i) Ear Ultra fit (flanged) Earplugs NRR 21 Yes/No.

   ii) Soft Moldable E.A.R. Earplugs Yes/No.

   iii) TASCO T-100 Semi-insert NRR 17 Yes/No.

   iv) Earmuffs Yes/No.

   v) Peltor Earmuffs (TACTICAL 7) Yes/No.

   vi) Helmet with muffs Yes/No.

8. Is the reduction in sound level and the seal provided adequate or did the sound intermittently, especially when speaking or moving the jaws, for :

i) Ear Ultra fit (flanged) Earplugs NRR 21 Yes/No.

ii) Soft Moldable E.A.R. Earplugs Yes/No.

iii) TASCO T-100 Semi-insert NRR 17 Yes/No.

iv) Earmuffs Yes/No.

v) Peltor Earmuffs (TACTICAL 7) Yes/No.

vi) Helmet with muffs Yes/No.

9. Do you find the EPDs too bulky to carry around if only intermittent use is required? If yes, which EPD do you find *bv*

i) Ear Ultra fit (flanged) Earplugs NRR 21 Yes/No.

ii) Soft Moldable E.A.R. Earplugs Yes/No.

iii) TASCO T-100 Semi-insert NRR 17 Yes/No.

iv) Earmuffs Yes/No.

v) Peltor Earmuffs (TACTICAL 7) Yes/No.

vi) Helmet with muffs Yes/No.

10. Like a person, who is newly fitted with eye-glasses, experienc some discomfort in the initial period, would you (if you were explained and prepared about some discomfort) be willing to persevere through this break-in period and continue to wear th following EPDs ?

i) Ear Ultra fit (flanged) Earplugs NRR 21 Yes/No.

ii) Soft Moldable E.A.R. Earplugs Yes/No.

iii) TASCO T-100 Semi-insert NRR 17 Yes/No.

iv) Earmuffs Yes/No.

v) Peltor Earmuffs (TACTICAL 7) Yes/No.

vi) Helmet with muffs Yes/No.

11. Grade the EPDs from 1. to 6 on the basis of their performance with 1 indicating maximum or best attenuation and 6 indicating minimum or poorest attenuation ?

12. Does the head-band of the following EPDs provide a secure fit ?

    i) TASCO T-100 Semi-insert NRR 17 Yes/No.
    ii) Earmuffs Yes/No.
    iii) Peltor Earmuffs (TACTICAL 7) Yes/No.
    iv) Helmet with muffs Yes/No.

13. Does the pinna fit comfortably into the ?

    i) Earmuffs Yes/No.
    ii) Peltor Earmuffs (TACTICAL 7) Yes/No.
    iii) Helmet with muffs Yes/No.

14. Rate each of the EPDs on a scale of 6 (1-most comfortable and 6-least comfortable) ?

    i) Ear Ultra fit (flanged) Earplugs NRR 21 Yes/No.
    ii) Soft Moldable E.A.R. Earplugs Yes/No.
    iii) TASCO T-100 Semi-insert NRR 17 Yes/No.
    iv) Earmuffs Yes/No.
    v) Peltor Earmuffs (TACTICAL 7) Yes/No.
    vi) Helmet with muffs Yes/No.

15. Rate the reduction in loudness of speech sounds for Peltor ear-muffs- At setting 1 : off ; setting 2 : Mid-on position ; setting 3 : full-on position, each as ?

    a) good b) fair c) poor d) no attenuation (amplication instead).

16. Do you feel that the sound of a clap gets cut off for the Peltor earmuffs at ?

1) Setting 1 Yes/No

2) Setting 2 Yes/No

3) Setting 3 Yes/No

APPENDIX - 2 B

QUESTIONNAIRE FOR LONG-TERM USE OF EPDs

I. When you wore the EPD for a prolonged period did you find it

i) a) Unbearably heavy b) heavy but tolerable c) moderately heavy d) light e) very light ?

ii) a) Extremely tight and painful b) very tight, but not painful c) just appropriately tight and secure d) slightly loose/lax e) very loose (kept coming off) ?

II. Did prolonged usage irritate the skin i.e., was it abrasive to the skin ?

III. i) Did you experience a feeling that your own voice was sounding loud and that of others sounded very soft Yes/No. ?

ii) If yes, did it interfere in your communication with others ?

iii) If no, was there a sound leakage and an improper seal ?

IV. Did wearing the EPD make you feel sweaty and uncomfortable ?

V. Was communication affected when you wore the EPD for 8 hours, as

i) a speaker - Yes/No,

ii) a listener - Yes/No.

VI. As a listner, if yes :

i) How often did you need to ask people to repeat themselves :

a) everytime they spoke b) frequently c) occasionally d) never ?

ii) Could you hear effectively when communicating to a group ?

Always / Never / Sometimes.

iii) Did you find it difficult to catch the entire message of a conversation and thus did you find it difficult to comprehend what the speaker said ? Yes/No

VII. As a speaker, if Yes :

i) Were you speaking louder than normal: Always /Never/Sometimes?

ii) Were you speaking at a rate : a) faster than normal b) normal c) slower than normal ?

iii) Did you find communication very effortful and tiring ? Yes/No

iv) Did you find yourself relying on lip reading and / or contextual cues ?

Yes/No : (Please specify which one, or if both, say both)

VIII. If you were exposed to hazardous noise levels, in order to protect your hearing, would you be willing to wear this EPD everyday, inspite of the discomfort associated with it (which will especially be evident in the initial break-in period) ?

IX. When fitted with the EPD for 8 hours could you hear:

a) The telephone ring ? Yes/No

b) A moderate-level door-knock. Yes/No

c) Somebody calling out to you from a room next door (i.e., at 12 feet) at a moderately-loud level ?

Yes/ No / Occasionally.