EAR PROTECTIVE DEVICES : A REVIEW

REG. NO: 8706

AN INDEPENDENT PROJECT WORK SUBMITTED IN PART FULFILMENT FOR FIRST YEAR MASTER OF SCIENCE (SPEECH-& HEARING) TO THE UNIVERSITY OF MYSORE

ALL INDIA INSTITUTE OF SPEECH & HEARING

MYSORE-57O0 06

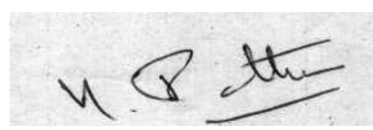
MAY 1988

To,

My Beloved Parents

C E R T I F I C A T E

This is to certify that the Independent Project entitled "Ear protective devices - A Review" is the bonafide work on part fulfillment for the Degree of Master of Science (Speech and Hearing) of the student with Register No. 8706.



(Dr.RATHNA)
Director
A.I.I.S.H.

C E R T I F I C A T E

This is to certify that the independent project entitled "Ear protective devices - A Review" has been prepared under my supervision and guidance.

Dr. M.N. Vyasamurthy

Guide.

D E C L A R A T I O N

I hereby declare that this independent project entitled "Ear protective devices - A Review" is the result of my own study under the guidance of Dr. M.N. Vyasamurthy, Department of Audiology, All India Institute of Speech and Hearing, Mysore and has not been submitted earlier at any university for any other diploma or degree.

Mysore

Dated: May 1986 Reg. No. 8706

A C K N O W L E D G E M E N T

First and Foremost, I wish to thanks Dr. M.N. Vyasamurthy, Lecturer in Audiology, All India Institute of Speech and! Hearing, for his patient reading, invaluable guidance and timely help in my work.

I Extend my thanks to Dr. Rathna.N., Director All India Institute of Speech and Hearing, Mysore.

I would like to express my thanks to all my classmates, especially Miss Revathi and Miss Sheela, for their encouragement, co-operation and understanding.

My special thanks to Mr. Ravi for his concern, help, encouragement and moral support.

Last, but not least, my sincere thanks to Basavaraj Patil.K. for taking such great care and typing out my project.

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Introduction:

There is no more subtle or wily enemy than excessive noise. And few that bring such devastation to ordinary life. Advancing hearing deterioration dooms the victim to life in a silent and lonely world, from which there is no return.

NIHL is the most common occupational injury in industry today. What makes NIHL so dangerous and so widespread is that it starts as a virtual "Symptomless disease". Initially, losses appear as small "holes in the hearing" - deficiencies in picking up sounds of certain pitches. Such losses are difficult to defect, except through professional testing. By the time even the most alert sufferer becomes consciously aware of it, hearing loss has grown quite severe. And it's already too late to do anything about it.

The fact is, hearing, once lost, can never be restored. Hearing losses not only affect our ability to defect sounds but also change our sensation of loudness and impair the clarity with which we listen. Hearing aids can amplify what is heard, but do not clarify it. It can be compared to a dim bulb projecting a 35mm slide onto a dirty screen with many tears and holes. The use of a brighter bulb with the same, damaged screen, produces a stronger image but one still lacking the defail needed for proper viewing.

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Obviously, because losses are permanent. Hearing protection offers the only effective way to fight hearing loss. And the first step to protection is recognizing that modern life pases many threats to hearing. Any loud noise from heavy machinery to music to power lawn mowers and chain can damage hearing. And no one, no matter how acute his or her hearing, is immune.

In any situation where loud noises persistently occur - where one must shout to be heard - effective steps in hearing protection should be taken. And anyone exposed to such conditions should undergo periodic hearing examinations, without exception. Taking proper steps to protect hearing isn't a matter of being overly cautious. It's a matter of arming everyone against a persistent and vicious enemy - an enemy which can, like a thief in the night, steal one of life's most precious gifts. Because that gift, once taken away, can never be regained.

Coming to the steps involved in Hearing protection, there are various steps that could be employed in Hearing protection they are,

1) Stop making the noise
2) Remove the noise source
3) Reduce the noise at source
4) Screen the noise source
5) Modify the noise
6) Employ acoustic consultant
7) Remove the complainant.

Thus preventing the generation of noise itself occupies a first place in the steps derived for reducing the exposure to noise. But there is possibility where. We may not be able to reduce the noise levels to within safe limits by treating the source. In such cases use of quieter machine, and use of noise barrier or acoustic hood to cover the source can be recommended. Still other means could be just offending the machine, change the work place of a person or limiting the total exposure time of a person in noise. But however, there are situations where all these steps may be found to be just impractical, insufficient to apply & economically unfeasible. In such cases the use of Ear protective devices constitutes an important element in any industrial hearing conservation program.

So what are Ear protective devices? E P D 's are personal hearing protective devices which when worned appropriately by an individual provide the most effective means of eliminating a potential hazard to hearing. They are capable of reducing the noise level at the ear by 10 to 45 dB and occasionally to 50dB, depending on their make and the sound frequency. These personal ear protectors when used in combination reduces the noise level at the ear to a harmless one if not to a pleasant one.

Bar protector also as an advantage of improving the speech communication. At the same time there is also a wide spead belief that Ear protectors impair hearing acvity, interfere with speech communication and warning signal. But this holds good only in quite environment where there is no necessity of wearing ear protectors. In noisy situation they not only prevent the impairment of hearing acuity but they may even improve it by cutting down the noise interference level, speech becomes easier to understand and communication improves. The exception being an intermittent noise with periods of silence between the burst of noise.

In the market ear protectors are available in many brands and types. Depending on their position relative to the ear they can be divided into four categories hamely - ear plugs. Semi-inserts, Earmuffs and helmets.Ear plugs are devices that are inserted in the ear canal and remain in place without any additional support, semi-inserts are those that closes off the entrance to the ear canal without actually being inserted into the canal and are held in place by a head band. Ear muffs are devices that cover the entire outer ear and are held in place by a spring head band, helmet, or same other type of head covering. Helmets are those which cover most of the head surface and either through a close fit or through integral earmuff or other types of built - in earpieces supply hearing protection against noise. While selecting the most suitable type of ear protector device for any given situation several factors are to be considered in addition to the protection to hearing they provide. Some of them are comfort, cost, durability, chemical stability, availability, wearer acceptance and hygiene.

Finally, It is quite surprising that in spite of the fact that the workers were informed that they work in noise which could affect their hearing. Some report of noise level not being particularly high to wear ear protecting device, some consider that this gives them a feeling of isolation and difficulties in communication. Some report discomfort or side effects as a reasons for not wearing ear protecting device. Hence, despite their undoubted value, it is difficult to conceive of ear protectors as more than a very adequate form of protection, when for whatever reasons, other methods cannot be used. The only way to overcome this problem is by successful hearing conservation program. A review of literature suggests that the pivotal characteristics of a successful hearing conservation program are - support of management, enforcement. Education, Motivation, comfortable and effective EPD's.

Ear Protector Performance:

How they work - and - what goes wrong in the real world

It is important to know how EPD's perform in real world environments. It was found that laboratory attenuation measurements significantly over estimate the real world performance of EPD's due to the unrealistic, optimized manner in which experimental subjects can wear these devices for short duration tests. These concepts can be examined further by analyzing how a correctly worn BPD operates and how its effectiveness is compromised by misuse, misfitting, EPD aging and abuse.

Before going in detail about it, it is better to know how normally sound is transmitted to the unoccluded and occler ear.

Sound Transmission to the unocluded Bar

The hearing mechanism can be divided into three parts as shown in figure I. These are the outlet, middle and inner ear. Sound (airborne vibration) is received by the outer ear. The incident sound propagates along the auditory canal, setting the eardrum (tympanic membrane) into motion. The eardrum motion is transmitted via. the tiny middle ear bones(ossicular chain) to the inner ear, aliquid filled cavity of complex shape tying within the bony structure of the skull. This causes the liquid in a portion of the inner ear, the cochlea, to vibrate. Membranes and hair cells inside the cochlea, which are very sensitive to this vibration, generate electeical impulses when appropriately stimulated. The impulses wre transmitted along the auditory nerve to the brain, where they are " decoded* the result is the sensation, sound.

When the vibration that excites the cochlear hour cells is the result of the chain of events described above, this is called air conduction when sound directly vibrates the skull and/or excites vibration of the ear canal walls, which in term stimulates the cochlea, it is called bone conduction. The final sense organ, the cochlea, is the same in either case, only the path of excitation has changed* Since most sound and/or vibration sources will excite both transmission paths, the ear will usually receive both air conducted and bone conducted signals simultaneously.

For the normal hearing individual, the unoccluded ear's bone conduction(BC) semitivity is much poorer than its corresponding air conduction(AC) semitivity as shown in Figured 2 curve A. For example at l000Hz the sensitivity of the ear is 60dB poorer for the BC path than for the AC path. This means that even if the AC path were totally eliminated by a EPD , that the Ear's sensitivity would only be approximately 6odB worse, i,e,a" perfect EPD could only offer 60DB of attenuation at 1KHz. Even if the satire head was acoustically shielded, the founness level of the sound could only be educed by an additional 10dB to 70BB below tha unocluded AC theshold. In this latter case, the conduction path would be from the chest cavity through the neck to the head.

SOUND TRANSMISSION TO THE OCCLUDED EAR

The utilization of EPD modifies the AC and BC paths- -As discussed above as shown in figure 3. There are:

1. Air Leaks: for maximum pratection the device must make a virtual air tight seal with the canal or the side of the head. Inserts must accurately fit She contours of the Ear, canal and Earmuff cushions must accurately fit the areas surrounding the externalEar(Pinna). Air leaks can typically reduce attenuation by 5-l5dB over a broad frequency range.

2. Vibration of the EPD: Due to the flexibility of the Ear canal flesh, earplugs can vibrate in a piston, like manner within the ear canal. This limits their low frequency attenuation. Likewise an earmuff cannot be attached to the head in a totally rigid manner. Its cup will vibrate against the head as a mass/spring system, with an effective stiffndss governed by the flexibility of the muff cushion and the flesh surrounding the Ear, as well as the air volume entrapped under the Cup. For Earmuffs, premolded inserts and foam insetts these limits of attenuation at 125 Hz are approximately 25dB 30dB and 40dB, respectively.

3. TRANSMISSION THROUGH THE MATERIAL OF THE EPD:- For most inserts this is generally not significant, although with lower attenuation devices such as cotton or glassdown, this path is a factor to be considered. Because of the much larger surface areas involved with earmuffs, sound transmission through the cup material and through the earmuff cushion is significant, and can limit the achievable attenuation at certain frequencies.

4. SONS CONDUCTION: Since a EPD is designed to effectively

reduce the AC path and not the BC path, BC may become a significant factor for the protected Ear.

When the Ear is ocluded with an insert or a muff the B.C path is enheanced relative to the unoccluded Ear for frequencies below 2KHZ. This is called the earplug effect or move generally the occlusion effect this can be easily demonstrated by plugging one's Ear canals while speaking aloud When the canals are properly sealed or covered, one's own voice lakes on a bassy, reaanant quality due to the application of the BC path by which a talker partially hears his own speech. This amplification of BC vibrations results in the differences between curves A and B in figure 2. Curve A represents the threshold of hearing for BC vibrations with open ear canals, whereas curve B is the threshold of hearing for BC vibrations with the Bar canals tightly covered or plugged.

Thus, curve B gives the estimated maximum protection achievable by covering and/or plugging the ears.

A common myth concerning EPDs , is that as the sound level -increases, BC saind becomes more important, and therefore an Earmuff will provide better projection than an Earplug at higher sound levels,. The inaccuracy of this statement is demonstrated by the act that the relationship between the AC and BC theresholds as shown in Figure 2, is not dependent on sound level. Any BC advantage that muffs may have over inserts will be independent of sound level, and will be appovent in a standard threshold level attenuation test such as ANSI 53, 19-1974.

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Due to the occlusion Effects and BC limitations described above, as well as other physical considerations, using muffs and inserts in combination does not yield attenuation values that are merely the arithmetic sum of their individual values. In some cases, at some frequencies, almost no improvement will be noted when inserting a pre-moded insert under a muff. Alternatively for other combinations, not fully defined at this time, better results may be achieved. Curve C in Figure 2 demonstrates performance for a deeply inserted E-A-R plug used in conjuction with a David Clark 19A. Sarmuff. This combination probably represents the highest practical attenuation achievable with currently available EPDS.

WHY EPDs FAIL IN THE REAL WORLD:

When a EPD is properly sized and carefully fitted and adjusted for optimum performance on a laboratory subject, airleak: will be minimized and paths 2,3 and 4 will be the primary sound transmission paths* In the Real world work environment, this is usually not be case, and path I, sound transmission through air leaks, often dominates. Air leaks arise w en plugs do not seal properly in the Ear canal or muffs do not seal uniformly against the head around the pinna. The causes of poor EPD sealing are.

I. Comfort: In most situations the better the fit of a EPD the poorer the comfort. Inserts must be snugly fitted into the canal and Earmuff cups must be tightly pressed against the head. This is not conducive to comfort and although some employees may adopt, many will not. This is why it is important to select several Ear protectors (generally 1 muff and 2 earplugs) from the more comfortable available SPDs and to encourage the Employee to make the final decision as to which he will use.

2. <u>Utilization</u>: Due to poor comfort, poor motivation or poor training, or user problems, earplugs may be improperly inserted and Sarmuffs may be improperly adjusted.

3. <u>Fit</u>: All EPDs must be properly fitted when they are initially dispensed. For multi-sized PVC. molded inserts a suitably sized earplug must also be selected during this fitting procedure. Companies must stock all available sizes of multi-sized Earplugs and must be willing to use different size plugs for an Employee's two Ears, this latter situation occurring in perhaps 2 - 10% of the population. For Example, stocking only 3 of the 5 available sizes of the V 51 -R will reduce the percentage of the population fitable with that device from 95% to 85%. The correct size pre-molded insert will always be a compromise between a device that is too large and therefore uncomfortable, and a device that is too small and therefore provides poor protection. The appropriate compromise can often times be achieved, but only with care and skill.

4. <u>Compatibility:</u> Not all EPDs are equally suited for all ear carnal and head shapes. Certain head contours cannot be fitted by any available muffs and some ear canals have shapes that may only be fitable with certain inserts or canal caps or

sometimes not at all. Earmuffs can only work well when their cushions properly seal on the head. Eyeglasses, sideb or long or bushy hair underneath cushions will prevent this and will reduce attenuation by varying amounts.

5. Readjustment: EPDs can work loose or be jarred out of position during the day. It must be remembered that laboratory tests require the subject to carefully adjust a device prior to testing under typical use. Wearers will Eat, talk, move about and may be bumped or jostled, resulting in jaw motion and possible Perspiration. These activities can cause muff cushions to break their seal with the head and cause certain inserts to work loose. Pre-molded inserts tend to Exhibit this problem, whereas custom molded and Expandable foam plugs tend to move effectively maintain their position in the Ear canal.

6. Deterioration: Even when properly used. Ear protectors wear out. Some pre-molded plug shrink and/or harden when continuously exposed to ear canal wax and perspiration. This may occur in as little as three weeks. Flanges can break off and plugs may crack. Custom Ear-molds may crack, or the Ear canal may gradually change shape with time, so that the molds no longer fit properly. Earmuff cushions also harden and crack or can become permanently deformed and head bands may lose their tension, therefore it is important to inspect or reinue "Permanent" EPDs on a

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regular basis. This may be 2 - 12 times per year or more, depending upon the EPDs that are utilized.

7. Abuse: Employees often modify EPDs to improve comfort at the expense of protection. These techniques include springing earmuff headbands to reduce the tension, cutting flanges off of premolded inserts, drilling holes through plugs or muffs, removing the canal portion of custom ear—molds, or deliberately obtaining undersized EPDs.

Protection Vs Percentage Time Wom:

The EPD Real world utilization problems outlined in the preceding section explain why the Real world attenuation of 5PDs is so much lower than typical manufacturers laboratory data would indicate. In addition to this problem we must contend with the possibility that employees, regardless of how well they wear a EPD, may not wear it during their entire work, shift or period of noise exposure. This will reduce their effective daily protection.

Noise induced hearing loss has been shown to be a function of the cumulative A. Weighted noise exposure incident upon the ears. Adherents of this theory propose that the hearing levels of a noise exposed population can be estimated from a Knowledge of their equivalent continuous noise exposure level (Leq). The Leq is the level of continuous A - weighted noise that would cause the same sound energy to be experienced in an 8 - hour day, as resulted from the actual noise exposure. This leads to the 3 dB trading relationship, that is, if the exposure level is increased by 3 dB, the exposure duration must be reduced by 1/2. A similar approach is embodied in the U.S. occupational safety and Health Act, except that the trading relationship is 5 dB.

The data in Figure 4 can be utilized to determine the Time corrected Noise Reduction Rating (NRR) as a function of the percentage of time that the EPD is worn in the noise. We first assign an NRR value to the EPD in question - either the manufactures labeled NRR or preferably a Real world estimated NRR* If, for example, the EPD has an assigned NRR - 25, then its Time corrected NRR would be only 20 dB if it was not worn for just 15 minutes during each 8 hour noise exposure. This clearly demonstrates that SPDs must be comfortable enough to be worn properly for expended periods. Attenuation and comfort must both be considered when selecting a EPD.

Neither low attenuation nor low comfort devices are acceptable for standard industrial use. Comfortable, user acceptable EPDs, with real world NRRs suitable for the prevailing environmental sound levels will be necessary to protect employee's hearing.

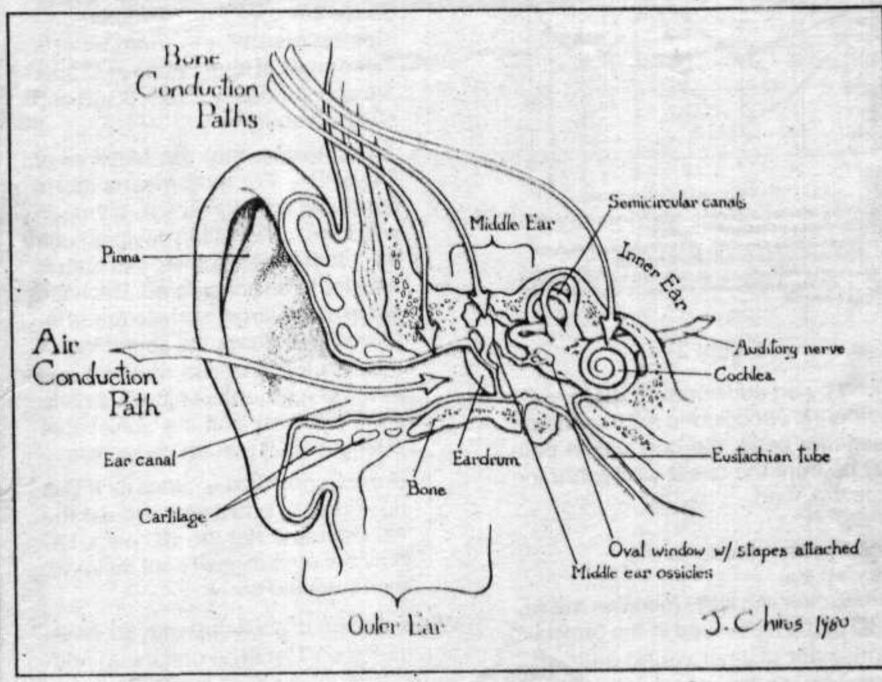
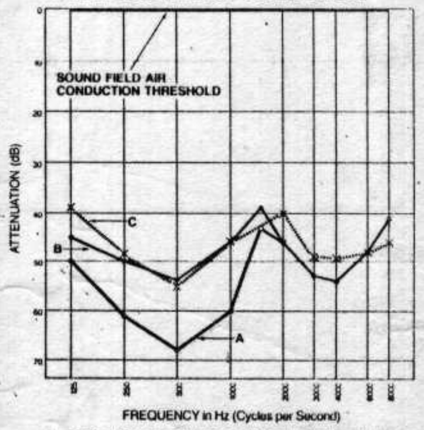


FIGURE 1. Basic Anatomy of the Ear with Illustration of the Air Conduction and Bone Conduction Sound Paths.

BONE CONDUCTION TO AIR CONDUCTION RATIO IN dB AND THE ATTENUATION FOR AN EARPLUG/EARMUFF COMBINATION.



FREQUENCY in Hz (Cycles per Second)

A — Ratio of Bone Conduction to Air Conduction Thresholds for Open Ear Canals (after Zwislocki[4]).

B — Ratio of Bone Conduction to Air Conduction Thresholds for Occluded Ear Canals (after Zwislocki[4]).

C — Real-Ear Attenuation (ANSI S3.19-1974) for Deeply Inserted E-A-R Plug in Combination with David Clark 19A Earmuff. 5 Subjects.[9]

Figure 2

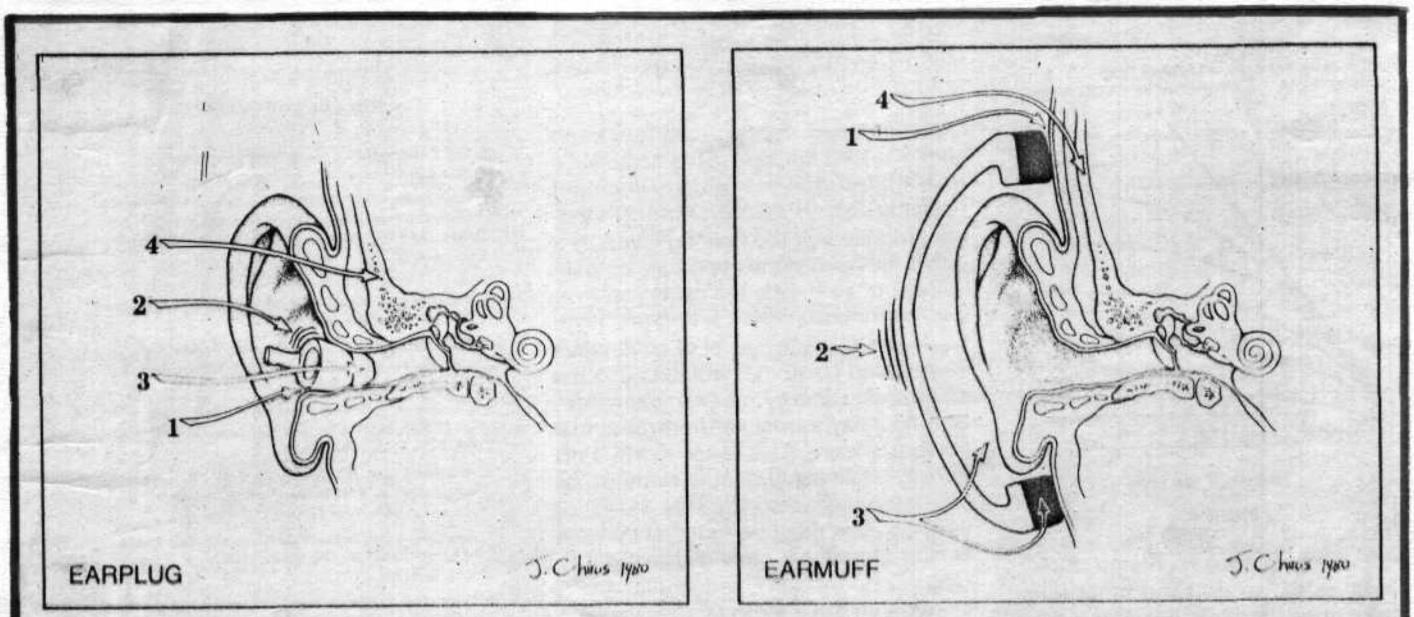


FIGURE 3. Illustrations of the 4 Paths by Which Sound Reaches the Occluded Ear.

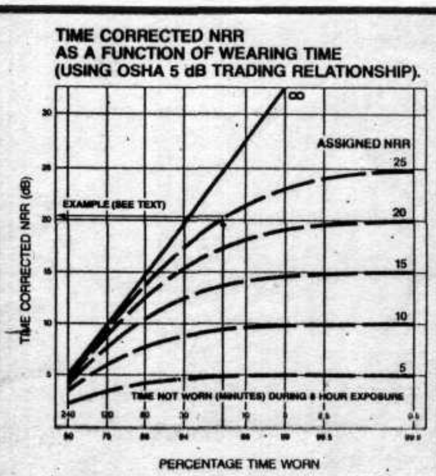


Figure 4

TYPSS OF EAR PROTECTIVE DEVICES

There are many brands and types of ear protectors available in the market today. But according to their position relative to the ear the personal ear protectors can be classified into four basic Types.

These are:

1. Ear Plugs
2. Semi - inserts
3. 5ar Muffs
4. Helmets,

1. Ear Plugs:

Ear plugs are a development over the cotton plug which has been Known to industrial workers and gunners for long. These are made of plastic material moulded to fit the outer Ear canal and usually remain there without any additional means of support. Ear plugs are unabstrusive and must be personally fitted for an individual end for each ear. In addition to it they should be always fitted under medical supervision. When compared to other ear protectors the earplugs are cheaper, smaller, they can he easily cleaned with soap and water and can he carried around in the pocket or hand bag, They will not become a problem when head covers, masks, goggles, or other devices are worn on the head.

Ear plugs can be made of materials such as cotton, paper, wax, glass wool, fibre glass down, plastic or expanding vinyl foam or some of the more recent plastic compounds. These plugs which can be shaped by the wearer, are usually made of non—porous, easily formed materials, and they are capable of providing attenuation that compares favorably with the best of the semipermanent molded variety of ear plugs. Fibre glass down plugs are the oldest form of personal ear protection on the market used properly it is very dense and attenuates selatively well, an average being about 15 dB (A). It has the advantage of being hygienic, as it is cheap and disposed of after each use. Plastic ear plugs consist of a central stalk with 2 - 4 flanges or an insert without flange. Since the shape of the plug is concial it fits most external auditory canals. The expanding vinyl foam ear plugs consist of a small cylinder which is compressed before insertion and which then slowly expands and seals the external auditory canal lightly.

Since each ear of a person differ from other in size and shape it is not uncommon for a person to require two different ear plugs, and no Single - sized molded ear plug has been found that would fit the large range of ear canal sizes and shapes. Most of the accepted molded ear plugs come in four or five different sizes. This variability in shape and size of ear canals do not offer a good fit and usually necessiates several sizes. This may inturn pose problem in the production and distribution of ear plugs an may result in the improper selection of the plug. Consequent of this the performance of earplugs is likely to be highly variable.

Ear plugs are not generally acceptable to residents who are affected by external noise- industrial, traffic etc. And also ear plugs are not usually tolerated, in the ear, for more than an hour or two at a time. Professional expertise is required in explaining the use of the earplugs to the individual, and in particular emphasizing the need to ensure pro er initial sealing and the need to reinsert the plugs from tine to time. Since they work loose, the seal breaks and they become in effective.

About the attenuation characteristic of ear plugs, different types of earplugs have different attenuation characteristics. When earplugs are of the proper size and inserted correctly t ey provide good attenuation. Usually, they give an attenuation between 15 and 35 d B, according to type and will often give better attenuation in the low frequencies than will ear defenders. A combination of ear plug and ear defender can be used to provide increased attenuation where necessary, but the attenuation acived by this combination will not generally exceed 45 dB.

Types of Earplugs

There are many brands and types of ear plugs available on the market. In selecting the most suitable type for any given situation, several factors such as comfort, cost, durability, chemical stability, availability, wearer acceptance and hygiene are to be considered along with the hearing protection they provide.

1) <u>Prefabricated Ear Plugs:</u>

These are made of Soft, flexible material that will fit readily to the many different ear canal shapes, thus giving a Snug, air tight and comfortable fit. For general industrial use the best prefabricated earplugs are available in three to five different sizes.

Prefabricated Ear plugs are nontoxic, and have got Smooth Surfaces that may be easily cleaned with soap and water. They are usually made of material that retains its shape and flexibility over extended periods of use and unaffected by the presence of ear wax. Prefabricated ear plug is available in a large number in different types. One of the most versatile end efficient types is the V - 51 R. It has got an asymmetrical shape and since it carries a single flexible flange it can be adopted to a large number of differently shaped ear canals. When fitted correctly, provides a reasonable protection along with a certain amount of comfort. It is usually available in five sizes from most manufacturers.

Prefabricated plugs are also avilable in large number with symmetrical shape providing sufficient protection along with the comfort under certain circumstances, however, for sharply bending or slit–shaped ear canals the round and stright types of ear plugs do not adopt generally.

Disposable and Malleable Plugs

Generally these types of Ear plugs are made from low cost materials such as cotton, ware, glass wool, and mixtures of these and other substances. Usually these materials are non-porous. Easily formable, reasonably comfortable and capable of providing attenuation values which will be similar to those afforded by prefabricated plugs when made correctly.

The amount of protection afford by these type of plug depends on the type of material used and how firmly the plug is fitted into the ear canal. Usually the most commonly used plug - the ordinary cotton wool by itself is extremely porous and offers very little attenuation. Because of its inefficiency and the fabe sense of security it gives rise to its user it is not at all recommended.

However there is an increasing demand in factories for an ear plug which can be inserted by the employee at such times as may be necessary and then removed and thrown away when no longer protection is required. One of the most practical a d efficient forms of disposable hearing protection is obtained by Glass wool which are microscopically thin glass fibres about one micron in thickness and provides reasonable attenuation when inserted according to the manufacturer's instructions.

These fibres are made into a down life felt, which is cut into strips and sold in packets. The employee removes about 25mm of the strip, folds it in an appropriate manner and inserts it in the ear before entering an area of high sound pressure. After leaving the area, the plugs are taken from the ears and thrown away one packet (3g), is sufficient for two weeks daily use. The material is very comfortable to wear and gives an attenuation of between 15 & 30 dB according to frequency.

Individually Moulded Earplugs:

The materials used in the formation of these type of ear plugs are some form of silicone rubber. These will have got their own permanent form and are actually moulded with the ear canal in their permanent form. Usually a curing agent is supplied along with the ear plug material and a putty like mixture of the two are used in their formation before being fitted into the ear canal of the person. Having cured, the Ear plugs are in a permanent form and there a will be provision for removing and reinserting it any number of times without affecting their performance. The expertise of the person making the plug plays a major role in determining the amount of protection provided by these individually moulded ear plugs.

The greater appeal to the wearer is the main advantage of individually moulded ear plugs. In situations w ere diff-iculty is encountered in persuading men to wear hearing protection, the provision of a personal and individually

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moulded device that will only fit the person for whom they are intended (Like Spectacles and false teeth) is a Psychological advantage.

Advantages: of Ear Plug

1. They are small, easier to store and easily carried.
2. Do not interfere with use of personal items like eye glass and can be worn conveniently.
3. Less expensive when compared to other ear protectors.
4. More comfortable to wear in hot environments Overall plugs are better accepted in all Environment.
5. Do not interfere with head movements and convenient to use when the head of the wearer must e in close, cramped quarters.
6. Hygine is maintained i.e. it can be washed or disposed.

Disadvantages:

1. Requires a tight ceiling to get maximum attenuation value which may often become uncomfortable to wear
2. They require more time and effort to fit.
3. The amount of protection provided is generally less and varies considerably among wearers.
4. Can become dirty and unsanitary through use.
5. Many of these materials may shrink or become hard so has to be changed frequently.

6. Difficult to see at a distance, making it difficult to insure that employees are wearing them.
7. Cannot be worn by individuals with external and middle ear infections.
8. It is almost specific to individuals.
9. Easily affected by jaw and neck movement so they have to be reseated frequently.
10. Requires good coordination.
11. Difficult to monitor its use.

2) <u>Semi - Inserts</u>

These are similar to ear plugs but are supported by a head band. These devices closes off the entrance to the ear canal without actually being inserted into the canal. They are not generally used for ear protection against noise but rather as part of a communication system. For this purpose there is a small receiver of the hearing aid type contained in each plug. One.size can provide high sound attenuation and are comfortable to wear for almost any person. The semi-insert is smaller mam than the earmuff and inteferes less with other devices worn on the head, however it requires a support in the form of a head band and therefore it is considered more cumber some than an ear plug.

These are also called concha - Seated ear protectors or canal caps. They usually consists of two conical soft rubber caps attached to a narrow head band which presses them against the entrance to the extrnal ear canal.

The Semi - Inserts combine some of the advantages of ear muffs and ear plugs and some of their disadvantages. They have the advantage that one size will fit the majority of ears, unlike prefabricated plugs. As they are captive and may be reinserted hygienically at any time, they are suitable for industries where the loss of an ear plug must be avoided (E.g. The food Industry) and for people who must frequently enter noisy Environments for short periods or remain in hot environments for long periods. However, this type of plug is often not as comfortable as other forms, of hearing protection as must be pressed firmly against the ear canal entrance to be effective.

3) Ear Muff

Ear muffs are in the form of covering for the entire outer ear (Pinna) and are held against the sides of the head by a spring loaded adjustable band and are sealed to the head with soft circumaural cushion seals. Sometimes for practical reason is incorporated into a protective helmet which covers the whole of the head(obviously including the face) Ear muffs are made from rigid cups which are usually formed of a rigid, dense, imperforate material. The cups are made of hard plastic or metalic cases line inside with polyurethane. Acoustic insulation between the outer shell and the skin is provided either by liquid filled or plastic-foam filled seal. Usually liquid - filled seals, all things being equal provide marginally better protection with less head band tension. But if treated roughly they suffer from the problem of leakage. On the other hand foam filled seals are almost as good as the liquid seal with the additional advantage of rebustness. However, ear muffs should be provided with seals that are easily and separately replaceable in the factory environment.

Most of the muff protectors are similar in design and come only in one size and their shape is less critical than ear plug. They can be fitted comfortably to all persons with little adjustment. For this reason the variability of performance is smaller and problem of comfort less critical.

The force with which the cups of the muff are pressed against the sides of the head plays an important role in determining the attenuation provided by it. Therefore it is important to maintain the correct head band pressure care must be taken not to bend the head band which may inturn reduce the attenuation value of the muff. Ear muffs provide maximum protection only when they are placed on a relatively smooth surface. Therefore when muffs are worn with safety equipment such as goggles and helmets and over long hair or spectacte frames we can expect less protection.

Generally speaking, the degree of attenuation is greater for low frequency when the volume of the muff is greater. And also greater the attenuation, greater is the force applied by the head band. But it becomes uncomfortable so optimum attenuation and person's comfort should be taken into consideration during its construction. All ear muffs doesn't give same value. Some gives batter protection at low frequency and some at high frequency. A volume of air enclosed within the cup is directly related to low frequency attenuation. And the inside of the ear cup is partially filled with material that absorbs high frequency resonant noises. Usually muffs offer greater protection with freq-uencies greater than 1000 c/s but, unless specially designed, muffs offer less protection below 1000 c/s and a combination of plug and muff usually offers optimum protection at these frequencies. For the one type of muff which Glorig tested the attenuation ranged from 20 to 34 dB at the above frequencies, with maximum attenuation at 2000/c/s. A combined plug and muff provided attenuation ranging from 34 to 38 d B at these frequencies. With maximum attenuation at 3000 c/s. If high level sound attenuation is required ear muffs can be worn underneath the helmet. Beside these, aircrew frequently use head phone with covers which act like ear muffs. The reduction in noise level afforded by these ear phones is not much at the lower frequency below 1,000 CPS, being of the order of 10 to 15 dB. They are, however efficient at higher frequencies giving attenuations of about 206B in the 1,200 - 2,400 CPS band and about 30dB in the 2,400 - 4,800 CPS band.

Some earmuffs are asymmetrical and thus can only be worn one way, i.e., only one cup will fit the left ear and only one the right. In these cases the correct way of wearning the muffs should be prominently indicated.

Advantages : of Ear muffs:

1) Provides the greatest protection, i.e., they are likely to give greater attenuation value than ear plugs and inserts.

2) The variability between individual to individual is less.

3) One size usually fit most people with different size and shapes of head.

4) Require very little manipulation. They are easily removed and replaced in a hgienic fassion. Even person with motor problem can use this without difficulty.

5) Eminently suitable for dirty and high level noise areas and for people who frequently move in and out of noisy environments.

6) They can also be worn by people with collapsed Ear canal and people who may suffer from minor diseases of the external Ear canal or in other circumstances when ear plugs cannot be worn.

7) Can be seen readily at a certain distance away, so the effectiveness of ear proector program can be easily monitored.

8) Move comfortable to use so usually more readily accepted by employee than ear plugs.

9) Not as easily misplaced or lost as ear plugs.

10) They last longer than ear plugs.

Disadvantages:

1) Bulky and not as easily worn in cramped quarters.

2) In general, more expensive than insert protectors.

3) Uncomfortable when humidity is high and they tend to make the ears hot and exacerbate perspiration.

4) Muff protection depends upon the spffng force of the head band. Through usage, the force may be considerably weakned and the protection significantly reduced.

5) Not as easily carried or stored as ear plugs.

6) Not compatible with other personal item like spectacles.

7) Not suitable when head movement is important to a large extent.

Helmets:

Helmets are the largest and usually the most expensive of all ear protectors. They have to be made in several sizes. Helmets cover most of the head sufface and either through a close fit or through integral earmuffs or other types of built - in - ear pieces supply hearing protection against noise. Helmets are not used for ear protection alone. They are rarely worn except by pilots and motor cyclists and are usually designed to safeguard the wearer against bump, crash, and cold-type injury. Another requirement for military helmets would we ballistic protection.

At present the acoustic action of ear muff does not seem to improve significantly the effectiveness of earmuffs. They do provide some sound attenuation but that is not its primary function. If high level sound attenuation is required ear plugs or ear muffs can be worn underneath the helmet. Helmet attenuation for the low frequency sound is comparatively poor. The acoustic importance of the helmet may increase when sound attenuation at the ear reaches such a high level that transmission through the skull becomes a controlling factor. In this situation a helmet covering the greater part of the head can introduce additional transmission loss.

Special Types of Ear protectors:

At present a number of earmuffs and earplugs are available which are designed specially for the purposes such as improved communication and the selective attenuation of high level transient noises. Among them are:

a) Frequency - Selective devices:-

An acoustic low-pass filter usually fitted with these type of devices emuring relatively small attenuation below about 2KHz.

This fitter allow the lower speech frequencies to be pass permitting slightly easier speech communication between wearers. However, only when all the external noise is at a higher frequency, there will be provision for improved speech, communication. This type of ear protector is usually unsuitable for use on the factory floor since all the external noise will not be at a higher frequency in the majority of industrial situations.

b) Amplitude - sensitive davices:-

These type of ear protectors are designed in such a way that they attenuate loud sounds more than quiet ones. A modified version of the V - 51R plug is so designed that it is possible to hear the normal speech and other sounds but for the high level transient noises, such as gunfire and explosive types of industrial noises. There are also earmuffs available provided with mechanical valves which close when high - level gunfire noise is impinging upon them. The main advantage of this type lies in the military aspects of noise.

However, earmuffs are available which incorporate an electronic peak-limiting device. These can be extremely valuable in industrial situation where people are exposed to impulse noise, or any high-level intermittent noise, but wish to communicate easily during the quiet periods between noise bursts. The disadvantages of this type of earmuff are that they are relatively expensive, require batteries, end must be handled with greater care than ordinary earmuffs.

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Attenuation characteristics of SPD:

a) **Acoustic:**

The primary function of an SPD is its capacity to attenuate sounds. The greater the attenuation an EPD produces the better it is. Each SPD has its own characteristic attenuation pattern. However the absolute limit of attenuation provided by EPD depends upon the sensitivity of the bone conduction pathway.

According to a study (R. Waugh, 1973) the dBA attenuation of an ear protector is a function of the C-A value of the noise spectrum in which it is used and may vary be more than 20dB in noises of different C-A value. However, in noises of similar C-A value a given SPD proviges similar amounts of dBA attenuation. The noise spectra may be sorted into five classes on the basis of their C-A values and any values of dBA attenuation, one for each noise class and ear protector's five dBA attenuation curve by meal&of a simple calculation proe@<8ure to ensure that each calculated dBA attenuation value is obtained or exceeded in a specified proportion of the spectra in the corresponding noise class.

Now considering the factors determining the sound attenuation provided by ear protector, the most important one is the insertion loss introduced by the ear protector between the sound source and the eardrum of the listener. This is accomplished by a change in the sound field which is usually considered negligible and the transmission loss between the outer and inner surfaces of the ear protector which can be defined as the ratio of the sound presure at the inner surface of the ear protector to the sound presure at its outer surface pil Po.

In case of physical measurements which appear to be the most accurate, particularly when tests are done under actual field conditions with living subjects variables such as differences in the anatomy cf the skull, the bows on a pair of spectacles and long hair, are known to affect attenuation. (Forrest, 1980, Smooren burg and Mimpen, 1982)

In case of ear muffs leakage between the custion ring and the skin is generally the most important factor reducing the acoustic attenuation. Small holes a few millimetres large drastically reduce attenuation, mainly in the frequency range 100-200 Hz. At low frequencies, the noise inside the earmuff may even be amplified, since the system constitutes a Helmholtz resonator (Alberti, 1982). Attenuation against connon shot was very low compared with that obtained against the rifle shot, because cannon shot was vary low compared with that obtained against the rifle shot, because cannon shot contains lower frequencies than rifle shot. Generally, the laboratory test valves of attenuation as well as the field experiments, with the earmuff, have shown attenuation values of 5-15 dB in the frequency range from 125 to 500HZ and 30-40dB in the frequency range from 2 to 5 KHz.

Another measure associated with acoustic attenuation is the degree of scatter of the attenuation as measured on different subjects. This is usually expressed as the standard deviation about the grand mean or as the inter quartile range about the median. This figure should accompany each attenuation datum. When expressing the attenuation. It provides a measure of the ear protector's ability to fit different individuals and a measure of the accuracy with which the attenuation determinations were carried out.

It should also be noted that external sound cannot be excluded completely from the ear even if the best ear protectors are used. Because acoustic vibrations are transmitted not only through the ear canal but also through the bone conduction. In such cases use of an ideal helmet make way for the transmission of Vibration through the rest of the body however these are secondary path ways which are often Ineffective and the exclusion of sound transmission through the ear canal should afford sufficient protection in most situations.

Transmission of the sound to the protected ear can be expressed by an electrical network analogous to the mechanical system however the electrical analogy do not represent the exact acoustic situation and has got limited validity to low frequencies, but it do helps in making out clearly what is happening.

It is impossible to totally isolate the inner ear from noise by means of an ear protector. Sound energy can reach the inner ears of persons wearing ear protectors by three different paths:

1) By passing directly to the cochlea through vibration of the bones and tissues of the skull (bone conduction).

2) By passing through leaks in the ear protector, or around the protector because of poor fit.

3) By vibration of the ear protector itself, which generates sound in the ear canal.

The last path way depends on the mechanical properties of the layer of flesh that separates the ear protector from the bony structure of the head. These properties, together with sound conduction through the body and the skull, control the sound attenuation at the ear. The sound attenuation depends not only on the impedance of the ear protector, but also on the impedance behind it.

Methods for the Evaluation of Ear,Protectors:

We use attenuation data as guidelines in the selection of the appropriate type and make of ear protector required. Thus it is also important to note the method by which this information is obtained and the laboratory carrying out the measurements. It should also be determined that attenuation data published by manufacturers are measured following a recognized standard procedure. Some of the recognized standard procedure are

1) The threshold shift Method of measuring ear protector Attenuation*

2) Single number measures of Ear protector noise Reduction.

3) A new ear protector attenuation standard - ANSI 512.6.

THE THRESHOLD SHIFT METHOD OP MEASURING EAR PROTECTOR ATTENUATION

One of the most common methods of reducing employee noise exposure Is the utilization of ear protective devices (EPDs) Selection of a suitable SPD is influenced by many parameters, one of the foremost being the protector's attenuation. In the discussion that follows, information will be presented that will explain some of the details of EPD attenuation measurements.

The most common method of measuring the attenuation of SPDs has been an absolute threshold shift procedure* Virtually all available manufacturer's reported data is derived via this method conceptually the idea is very simple - determine the minimum sound level of a sound that a subject can hear without wearing a EPD (open threshold) and then measure how much louAder the sound needs to be for the subject to hear it while wearing the EPD (occluded threshold). The difference in these two thresholds, the threshold shift, is a measure of the attenuation afforded by the device.

TWO AMERICAN NATIONAL STANDARDS:

Two american National standards have been written describing the absolute threshold shift technique of testing EPDs. Both standards require testing 10 subjects, 3 times each, at nine different frequencies. Since this results in 30 data points at each frequency, a measure of the dispersion of the measured attenuations at each frequency is available. Thus both the mean attenuations and the standard deviations are reported. The original standard ANSI Z24-22 - 1957 (R1971) required the subject be seated in a directional sound field, usually achieved of, and facing the subject. The test sounds used were pure tones.

It is apparent that pure tones at frontal incidence are not characteristic of typical industrial environments. Furthermore, earmuff attenuation can vary as much as l5dB as the angle of sound incidence vaties. Additionally, since resonances in the protector can cause attenuation to vary rapidly over small frequency increments, pure tone attenuations at actave band center frequencies may not accurately reflect the noise reduction afforded by the EPD in those actave bands.

The new standard, ANSI 53.10 - 1974 (ASA - STDI.1975), specifies stimuli that are 1/3 actave wide bands of noise, presented in a uniform, non-directional (diffuse) sound field. This circumvents the problems mentioned above, by more closely approximating typical industrial noise exposure conditions.

S3 19 and Z24-22 - Data Compared:

Attenuation measured via the two methods on the same BPD using the same subjects yields results which may differ by as 10 dB or more. Typically the agreement is closer. In fig.l the results for a representative muff are shown. The 53.19 attenuation is poorer than the Z24-22 valves in the 1-4KHZ region. Especially at 1KHZ and 4KHZ, where the differences are 5 dB, It is also noted that the trent also indicates slightly smaller standard deviations using the 53.19 test.

In figs. 2 and 3, two sets of 53.19/Z24.22 comparisons are shown for the E-A-R plugs, a user molded foam insert. In Fig.2, recent (1978) E-A-R data are presented. Both of these tests were performed in one, 2 week period using identical subjects. It is noted that the attenuation is virtually identical for the two tests with smaller standard deviations for the 53.19 data. Generally insert protectors show closer agreement between 53.19 and Z24.22 than do earmnffs, but usually the mean attenuation are 2-4 dB less using 53.19. Thus the agreement between the two sets of data shown in fig.2 is somewhat better than is normally found.

In Fig.3, the currently advertised data for the E-A-R plug is plotted. The Z24-22 test was performed in late 1974 and the 53.19 test about 1 year later. Thus the subjects were not identical for the two sets. It is noted that not the 53.19 attenuation data is uniformly lower than the Z24.22 data. These differences, larger than those shown in Fig.2, are not due to the different test methods, but due to other variables that can arise over a period of one year.

Variability in data is an important aspect of measurements involving human subjects, such as threshold shift tests. Only the intra-laboratory part of this variability is reflected in the reported standard deviations. Variability among different laboratories is not included in the reported standard deviations is not included in the reported standard deviations and may be greater than that found between the two sets of 53.19

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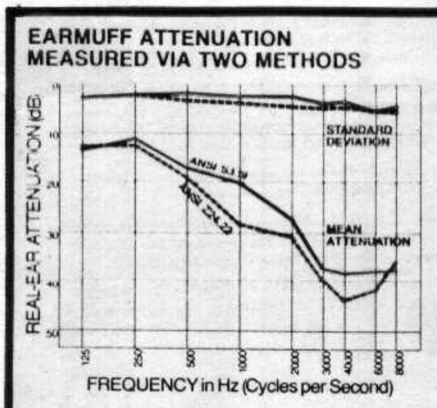

Figure 1

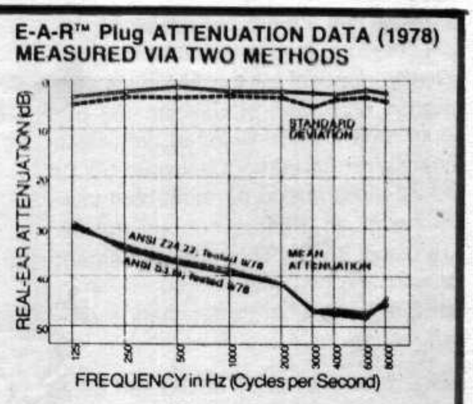

Figure 2

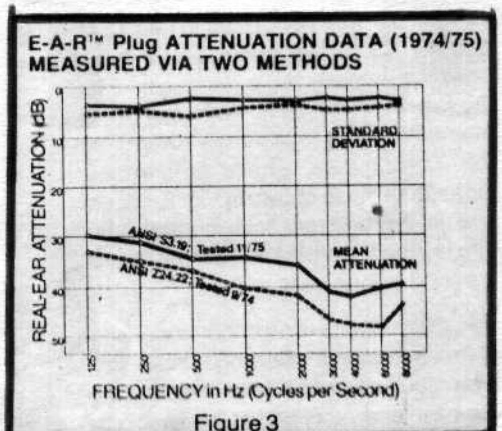

Figure 3

data shown above. E-A-R Division recognizes this and therefore advertises the 53.19 data shown in Fig.3, the lowest evsr measured on the currently produced E-A-R plugs,

SINGLE NUMBER MEASURES OF EAR PROTECTOR NOISE REDUCTION

In the previous section we discussed about the threshold shift method of measuring ear protector attenuation. The results of such a laboratory ear protector test consists of attenuation and standard deviation values at nine frequencies. Reduction of this data to a single number rating provides a simple and efficient means of choosing ear protective devices and determining their suitability for particular applications. So here will discuss single number ratings, their accuracy, calculation, and utilization.

The most accurate method of determining an employee's noise exposure under the protector (Effective exposure) is to utilize an actave band analysis of the actual sound spectrum to which the employee is exposed, in conjunction with the attenuation and standard deviation data. This will be labelled the long method. It involves computations similar to those necessary to determine a device's single number rating. The long method noise reduction must be individually calculated for each noise environment, whereas the single number rating provides a noise reduction value that can be supplied by the manufacturer and simply subtracted from the measured A or C weighted sound level in question.

There have been atleast eleven single number rating descriptors proposed since 1970. John Son and waugh among others have statistically evaluated the accuracy of these ratings Vs the long method! by examining the resulting predictions for large numbers of industrial noise spectra. The data indicate that a good single number rating scheme will provide a successful compromise between under - protecting a minority and over - protecting a majority of wearers in most environments.

THE NOISE REDUCTION RATING (NRR)

The Noise Reduction Rating (NRR), a variant of the NIOSH R_c factor, is the current EPA proposed single number descriptor A sample NRR calculation is demonstrated in Table 1. The key point to consider is that the NRR is subtracted from the measured (unprotected) C-weighted sound level to yield an effective A-weighted sound exposute for the employee. The idea of subtracting a noise reduction factor from a C-weighted sound level to find an A-weighted exposure was first proposed by Botsford in 1973. This "C-A concept " is the important common ingredient in all of the successful single number descriptors proposed in recent years.

As can be seen in Table 1, the NRR is the difference between the overall C-weighted sound level of a pink (flat by octaves) noise spectrum and the resulting A-weighted noise levels under the protector. The attenuation values used in the calculation are the measured laboratory attenuation values minus two standard deviations. This correction assures that the attenuation values used in the calculation procedure are actually realizable by the majority of employees who c o n t i o u s l y and correctly wear their protectors. This correction will not account for employee misuse or abuse of the protectors.

In figure 1, the ANSI S_3 19 laboratory data for three protectors are plotted. The associated NRRs are listed at the bottom of the graph. Although the NRR is most correctly computed using ANSI S_3.19 (Noise band) data, it can be useful to look at the range of NRRs computed from ANSI Z24 22 (pure tone) data since this is available in an existing NIOSH document. The range is approximately 7-31. The NRR - 31 is the value for E-A-R plugs tested according to ANSI Z24.22. That it is higher than the currently reported (ANSI 53.19) E-A-R plug NRR OF 29 is due primarily to laboratory testing variability.

Further perspective on the meaning of NRR values can be gained by calculating the maximum theoretical NRR possible. Swislotion to determine bone conduction thresholds, i.e. if the ear were perfectly sealed and covered, mow effectively could a device attenuate noise before sound conducted through the skull itself would become audible? calculations based on this data, assuming a very low standard deviation of 1.5 dB at each frequency, yield an NRR of 45. To the best of the knowledge, the highest NRR ever measured on a production protector was found in a 1980 test of E-A-R plugs. It was 35, or about 6dB greater than the currently reported (conservative) E-A-R plug attenuation data.

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HOW TO USE THE NRR:

As previously mentioned, the NRR is a dB noise reduction value that must be subtracted from the measured dBC sound level in the work place. Thus we have.

gffective exposive (dBA) = Noise level (dBC) - NRR.

According to existing federal regulations, employee noise expesive must be limited to an equivalent level of 90 dBA for 8 hours. Nevertheless there is ample data to substaiate the fact that levels of 85dBA will not be innocuous to all people. Furthermore it is likely that many employees will not fit hearing protectors as carefully as do laboratory subjects. Therefore there is a suggestion of targeting for an 80 dBA effective exposure level. Thus for the protectors illustrated in figure 1 the values in table 2 are the suggested maximum work place noise levels for 8 hour exposures.

Royster and lilley have recently developed new techniques of evaluating the performance of hearing conservation programs. Analysis of their data verifies that V-51Rs are only marginally suitable for noise levels of 96-98 dBA. On the other band, informal data, personal communications, and ongoing research indicate that the foam insert protectors are, as laboratory NRR values would suggest, measuratly more effective in actual industrial noise environments.

TABLE 1 - HOW TO CALCULATE THE NRR

Octave Band Frequency (Hz)	125	250	500	1000	2000	4000	8000
1. Hypothetical noise spectrum OB† sound levels (pink noise)	100.0	100.0	100.0	100.0	100.0	100.0	100.0
(level assumed is not significant)							
2. C-weighted OB sound levels unprotected ear	99.8	100.0	100.0	100.0	99.8	99.2	97.0
3. Overall C-weighted sound level (logarithmic sum of the seven OB sound levels in step 2)	108.0 dBC						
4. A-weighted OB sound levels unprotected ear	83.9	91.4	96.8	100.0	101.2	101.0	98.9
5. E-A-R™ Plug mean attenuation	29.6	31.3	34.1	34.0	35.5	41.4*	39.6**
6. E-A-R™ Plug standard deviations *x 2*	6.4	6.6	4.2	4.6	5.4	3.9*	4.8**
7. Protected A-weighted OB sound levels [Step 4 − Step 5 + Step 6]	60.7	66.7	66.9	70.6	71.1	63.5	64.1

8. Overall A-weighted sound level under the protector (effective exposure) ← 76.0 dBA
(logarithmic sum of the seven OB sound levels in step 7)

9. NRR = Step 3 − Step 8 − 3 dB††
NRR = 108.0 − 76.0 − 3 = **29 dB**

†OB-Octave band.

††This is a correction (safety) factor to protect against over estimating the device's noise reduction because of possible variations in the spectra of actual industrial noises.

*Numerical average of the 3000 Hz and 4000 Hz data

**Numerical average of the 6000 Hz and 8000 Hz data

ATTENUATION DATA FOR THREE TYPES OF HEARING PROTECTORS[16] (ANSI S3.19)

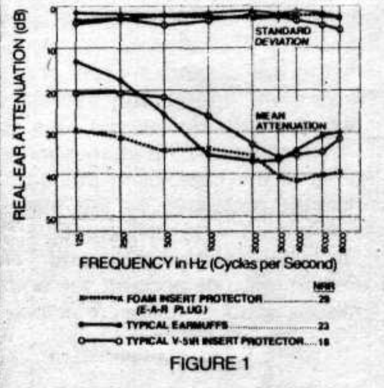

FIGURE 1

A Summary Table of Proposed Single Number Measures of Hearing Protector Noise Reduction

Single Number Rating	Proposed By	Date	Weighting Network For Noise Measurement[1]	Hypothetical Noise Spectrum[2]	User Variability Correction[3]	Spectral Safety Factor[4]	Sample Calculation[5]
R	NIOSH Criteria Document	1972	dBA	Pink	10 dB[6]	—[6]	26
AES[7]	R. Camp	1972	—	—	None	—	88%
K	ANSI Z137.1 Draft 3	1973	dBA	Pink	10 dB[8]	—[8]	36
SLC[9]	J. Botsford	1973	dBC	6 typical noise spectra	Optional	—	42
Two Number Method	D. Johnson C. Nixon	1974	dBA and dBC	6 typical noise spectra	Optional	—	—
R_c	NIOSH 76-120	1975	dBC	Pink	2σ	3 dB	29
R[10]	NIOSH 76-120	1975	dBA	Pink	2σ	8.5 dB	22
P-AR[11]	J. Tobias	1975	dBC	TTN[12]	$0, 1\sigma, 2\sigma$	Accounted for by shaped spectrum	1-1-1
SLC_{80}	R. Waugh	1976	dBC	Shaped spectrum[13]	1σ	Accounted for by shaped spectrum	34
NRR[14]	EPA 40CFR Part 211	1977	dBC	Pink	2σ	3 dB	29
S	ANSI Z137.1 Draft -1979	1979	dBC	NNS[15]	2σ	4 dB	28

A NEW EAR PROTECTOR ATTENUATION STANDARD - ANSI S12.6

The first American National standard describing a method of measuring ear protector attenuation appeared in 1957 ANSI Z24-22). It was significantly revised in 1974 with the publication of ANSI 53.19, and just recently has been revised again with the issuance of ANSI S12.6, "Method for the measurement of the real - Bar attenuation of ear protectors. Although currently available attenuation data primarily of the 53.19 type, some older Z24.22 data are still available, and in the 'hear future data in conformance with S12.6 will begin to appear. Now let us compare the three standards, with emphasis upon the latter two documents, so that hearing conservationists will be better able to interpret the various types of attenuation data with which they may have to contend.

AN OVERVIEW:

All three standards describe methods of measuring the laboratory attenuation of ear protective devices (EPDs) viz the use of a real-ear attenuation at threshold (RSAT) protocol. The standards do not specify minimum acceptable physical or performance characteristics for 5PDs, and in and of themselves do not provide for EPD certification or approval.

The REAT protocol specified in the American standards is the most commonly implemented and one of the most accurate method; of measuring attenuation. It consists of determining the difference in the minimum levels of sound that subjects can defect while atternately wearing (occluded threshold) and not wearing an BPD (open threshold). The change in hearing semitivity between the two conditions, the threshold shift, is an accurate indicator of the noise reducing characteristics of the EPD.

Certain requirements of the three standards are summarized in table 1. ANSI 53,19 and S12.6 bear a strong resemblance in that both specify 1/3 octave band noise stimuli presented at random incidence in a non directional sound field. The earlier standard, Z 24,22, differed in this regard since it specified pure-tone stimuli prevented directlonally in an anechoic environment.

Purpose of S 12.6.

ANSI S12.6 explicitly states that its protocol is "intended to yield optimum performance values" and then goes on to suggest that those values "may not usually be obtained under field conditions". In fact recent data suggests that "may not usually" might more appropriately read "are rarely "thus, without correction or adjustment, S12.6 data are unvitable for use in estimating typical or average "real-word" data.

"optimum performance values" were selected by the writers of the standard since they felt that such measurements could be "repeated consistently for reliable rank-ordering of protectors" Although that was the opinion of the majority of the committee based upon previous informal observations, there are little or no documental data available to substantiate or refute that position.

The strorigest caveat included in the standard is the statement that "(Optimum performance) values will depict the noise-reducing capabilities of ear protectors only to the

...42.

extent that users wear the devices in the same manner as did the test subjects. However, for those subjects that were tested and for the fitting of the EPDS that they utilized, the attenuation measured via S12.6. will be a very accurate indicator of the protection achieved.

applicability of S12.6.Data

Since REAT Evaluations are conducted at low sound levels (10-606B re20u pa), another area of concern with respect to such data has been its applicability to high level noise exposures. Numerous investigators have empirically examined this problem and the preponderance of their work suggests that REAT accurately represent the performance of linear EPDs (Those not containing valves, orifices, diaphragms, or active electronic circutry) regardless of sound level . However for nonlinear EFDs (devices designed to provida attenuation that changes, as a function of sound level) the standard "may not be applicaple" i.e. may underestimate actual attenuation.

Another small, but neverthless well defined limitation of the standard is that "Low frequency" results (below 500HZ) may be spuriously high by a few decibles as a result of masking of the odcluded ear theresholds caused by physiological noise.

Instrumentation and Measurement Details:

Many instrumentation and measurement details of S3.19 were revised in preparing S12.6. The revisions were intended to tighten up the specifications so that they were more accurate and less open to interpretation. Although these changes will probably have only minor effects on attenuation data, they should lead to reduced interlaboratory variability by helping to ensure that implementation of the standard is more uniform.

One important change in the measurement proceedures concern the reading and averaging of the avdoimentic traces. The hewer technique, which is more precise and less subject to sli-ghtly larger intralaboratory variability. Even though the affect on mean attenation values in expected to be negible, calculated was reduction Rating's (NRRs) should be reduced slightly since a subtractive two standard-diveation correction is included in such computations.

SUBJECT SELECTION:

Although Z24.22 states that subjects should be "randomly" selected, none of the three standards suggests or requires that the test population should be chosen in any particular way that would ensure its representative sample with a test group of only 10 subjects.

All three standards permit exclusion of subjects for whom "adequate" or "good" fits cannot be obtained. This re-quirements also stems from" limitations incurred by using small "representative" test populations. Although S12.6 explicitly requires the laboratory report to include a discussion of any subjects who were dismissed , it is in practice unlikely that such information will be passed on by manufacturers to buyers and end users.

FITTING THE SPD:

The Most critical aspect of an REAT evaluation is the

...44.

fitting of the EPD. To better define this procedure, S12.6 has eliminated the "subject fit* and "Experimenter fit" categories of the previous standard and replaced them with an "Experimentr supervised fit". The protectors are put on by the listener and then personally checked by the experimenter who has the option to have the subject refit the EPD "in accordance with the manufacturer's instructions as many times as necessary to obtain a 'best' fit prior to testing but not after the test has begun".

A Key point of this procedure is that the experimenter is not permitted to actually fit the protector, but rather must instruct the subject so that the "best" fit is one that is achievable by the subjects themselves. This impo- rtant restriction arises from the improbability of weakers being inclined to obtain physical assistance in doing their protectors in real—world environments..

Another key points pertains to the statement "after the test has begun." Whereas in S3 . 19 this statement was open to interpretation, S 12.6 includes an additional sentence that clearly indicates that once the actual audiometric testing begins no further manipulation of the EPD is permitted. Thus the experimenter cannot use the results of the audiometric testing to assist in determining when the best fit has been obtained. This has been included to try to assure that the "best" fit is indeed one that is potentially achievable in practice without the use of special instrumentation or techniques.

However, since the best-fit criterion is intended to yield optimum performance values regardless of comfort, such values will always represent an upper, and often unobta- inable, limit to actual real-world attenuation.

Summary

ANSI S 12.6 should prove to be a more precise standard for the measurement of optimum (Laboratory) EPD attenuation than was its predecessor, S 3.19. How- ever, it does not address the issue of the noncompara— bility of laboratory and real-world EPD performance. The principal procedural charges that it embodies are mo- dified ear protector fitting methods, and incorporation of a specified technique for the reading and averaging of automatic audiometer traces. A precise determination of the effects these changes will have on attenuation test results awaits implementation of this standard by practicing test laboratories.

Table I - **A comparison of three REAT standards**

SPECIFICATION	ANSI Z24.22-1957	ANSI S3.19-1974	ANSI 12.6-1984
Test Stimuli	Pure Tones	1/3-OB[a] Noise	1/3-OB Noise
Test Room Characteristics	Anechoic	Reverberant[b] 0.5 s< T_{60} < 1.6 s	$T_{60} \approx 1.6$ s
Sound Sources	1 spkr.	3 spkrs. min., 1 per plane	not specified
Allowable Ambient Noise:			
.125 / .250 / .500 / 1.0	34[c]/ 25 / 16 / 12	24 / 18 / 16 / 16	28 / 18 / 14 / 14
2.0 / 4.0 / 8.0 kHz	10 / 8 / 22	14 / 9 / 30	8 / 9 / 20
Subjects/Trials	10/3 (minimum)	10/3 (minimum)	10/3 (minimum)
HPD Fitting Criteria	Subject fit for best attenuation	Subject fit for best atten., or experimenter "best" fit	Experimenter supervised fit for best attenuation
Jaw and head movement after fitting and prior to testing	Yes	No	No
Subject Exclusion Criteria	Random selection, but may choose for good fit if explicitly stated in report	Subjects for whom adequate fit cannot be obtained should be noted, but should not be included in the evaluation	Subjects for whom good fit cannot be obtained shall be noted, but should not be included in the evaluation

[a] Octave band. [b] Reverberation time (T_{60}) - time required for steady-state sound to decay 60 dB.
[c] OB noise levels. Z24.22 data converted from old to new OB's re ANSI S1.11-1971

There are various studies regarding attenuation properties, Effectiviness, usefulness, problems and other subjective and objective factors related to various types of Ear proceivedivice.

Ear protectors are approved if they fulfil certain requirements as to mechanical properties and Acoustic attenuation (I So 4869. 3FS 4431, 4432, DiN, 13SI). Under working conditions, the protective effect of earmuffs seldom equals that measured in the laboratory (Smooren burg and Mimpen, 1982, chung Et.al., 1983). Becos of the wear and tear, poor fitting, weakening of the head band, use of spectacles and loose cushion rings, there is usually some leakage between the skin and the cushion ring. However, the protection is satisfactory at most work—places if protectors are used throughout the period of exposure, since the continuous sound pressure level seldom exceeds 100 dB & imposes above 140 dB peak level are rare (Pekkarinen & starck, 1984)

A well designed inflatable Ear plug provides attenuation equivalent or superior to a well-designed ear muffs. This plug also provides greatar attenuation than reported for other well designed fluid - filled ear plugs. When measured in a comparable manner (Zwis lock, 1955) Inflatable Ear plug exceeds Zwis lock's model upto 13 dB and is equal or superior at all frequencies (L.E. Marston & C.P. Goetzinger, 1972)

Investigators have found that ear plugs are more variable (Rice & coles, 1966). It is, however, likely that inflatable ear plug will provide less variable attenuation than most standard ear plug which are more prone to leakage, a common cause of ear plug attenuation variability. Inflatable ear plug is a superior form of insert ear protector worth consideration in some cases as an alternative device (L.C. Marston & C.P. Geetzinger. 1972).

Coles R.R.A.. & Rice. C.G. (1965) in their study reported that ear plugs lower the optimum level speech discrimination scores in parsons who already have high hearing losses. The reason given is plugs might alter the hearing losses, relationships of low frequency and high frequency components of speech sufficiently to cause difficulty in persons who already have high hearing loss.

Forest & Coles (1970) present data which indicate an increase in the attenuation properties of the ear plug as the level of the incident sound increases above 110 dB sound pressure level.

Gun defender provides the wearer with protection from high intensity impulsive type noise, while providing improved communication. In addition subjective reports from individuals who frequently fire rifles indicate their preference for the Gundefender plug (J.D. Mosko & John L. Fletcher, 1971).

Padilla (1976) attempted to evaluate the efficiency of standard pre-molded and custom-molded ear plugs by measuring the attenuation afforded by these devices. He suggested that custom - molded ear plugs were "... Significantly superior in effectiveness to the standard! — type. Ear plugs".

Based upon the results of studies conducted in actual industrial settings, several investigation have questioned the usefulness of the ear plugs (Padilla, 1976, Regan, 1977, edaward et al. 1978) others have indicated that ear plugs are advantageous in preventing more noise induced permanent threshold shift.

Regan (1977) Evaluated the real ear attenuation of 4 types of EPD worn by 32 male steel workers. He reported that custom — filled ear plugs were the "worst" type of real protector studied because they yielded the least attenuation of the devices used in the investigation. However, Regan also suggested that custom — molded plug

Kasden S.D & D. Aniello. A (1978) in their study showed a significant difference between the means for the intial and later tests for the regular plugs, leading to the conclusion that the Extra time and money for custom made plug is worthwhile.

Wichman. H, Mcintyre, M & Accomazzo (1978) have reported a significant in-flight measures of stress reduction due to waring expandable ear plugs.

A Report (Kasden & Daniello, 1976) indicated that the performance of custom — molded ear plugs may maice them a desirable alterative to pre-molded devices for use in hearing conservation programs However, this investigation is of dubious. Scientific value because of numerous flaws in experimental design (Nixon, 1979).

A study on custom - molded ear plug performance (Smith C.R., Wilmoth. J.N. & Borton T.E. 1980) suggested that custom fitted hearing protection was effective in preventing substantial changes in hearing threshold levels over a long period of time.

Sd wards. R.G., Broderson AB; Green W.W., Lempert B.L (1984) in their study about the effectiveness of ear plugs as worn in the work place found that the work place noise. Protection received from ear plug is dependent upon ear plug design, and that for a given protector there may well be large differences between attenuation values established in the laboratory and those received in the industrial setting.

Further, Regan D.E (1977) in his investigation to determine if manufacturer's attenuation specifications realistically reflected the actual attenuation provided by protective devices when worn by industrial employees in the work place, found that attenuation provided to the worker was significantly less than manufacturer's Specifications.

Recently interest has developed in custom made silicone - based ear plugs for canal eclusion. Similar occluding devices of various design, which often can be obtained in drug stores, have been used in industry for hearing conservation programs.

Protection by ear plugs from water borne infection was evaluated in 35 patients with "Tympanostomy" tubes tympanic membrane perforations, or mastoid bowls, stock and custom made ear plugs were found to be equally effective upto 4 months during a period of frequent swimming and bathing activities. Infections were only noted to occur in those patients who did not follow instructions on appropriate use of the plugs. (Johnson. D.W., Mathog, R.H & Maisel R.H. 1977)

Solomon R.E. (1975) in his study on the role of ear protection in reducing occupational hearing loss suggested that muffs were generally more protective than plugs, simply because of reduced possibility for improper insertion in the former.

Investigations have also shown that the effective attenuation of ear muffs are considerably reduced after a short time in practical use and is then almost the same as for ear plugs. (Johanson, 1978). These are general conclusions which can be drawn irrespective of their working place.

In a study on the effectiveness of EPDs in practice (Alberti P.W, Abel SM & Kristensen R, 1979), the results revealed that the muffs and most ear plugs produced similar attenuation levels at high frequencies, although the muffs produced less attenuation at low frequencies.

The variation in protection provided by different types of ear protectors is considerable. Generally, Ear muffs have an attenuation which is about 10 - 15 dB higher than ear plugs for frequencies between 0.5 &, 5 K Hz. The ability to protect depends not only on the type of protector (Ear plugs or ear muffs) but also on how and to what extent the protectors are used. If the subject for some reason or other does not use the protector. Even for a small period of the working day the effective attenuation is seriously reduced

(B. Erlandnon, H. Hankanson, A. Jvarson & P. Nilsson 1980? This has been pointed out by else (1973) & by karmy & coles (1975). The sound level is reduced from 110 dB (A) to 80 dB(A) when the protector with an effective attenuation of 30 dB (A) is used. If a subject working in such as environment does not use his protectors for 2% of the time, that is about 10 minutes in 8 hours, the effective attenuation has been reduced to 17 dB(A) and the noise level is reduced but not to 80 but to 93 dB (A).

' The attenuation efficiency of the ear muff which is used by military forces in many countries is dependent on the frequency of the exposing impulses from fire arms. The protection is good (about 30 dB) for pistol shets, moderate for rifle shots (about 20 dB) and poor (below 10 dB) for cannon fire. The differences are most probably due to the differences in the distribution of the energy at different frequencies. The small volume ear muff is not considered suitable for use as the sole ear protecter in connection with cannon fire. It gives proper protection only under optimal conditions in connection with rifle shooting. Ear muffs with larger cup volume or a combination of ear plugs with muffs are recommended for a large calibre weapon and rifle shooting exercises (Jukka. Vlikoski, Juss , Pekkarinen & Jukka starck, 1987).

Young man conscripted into the armed forces still run a risk of suffering hearing damage during their militery service. This risk could be reduced by effective personal hearing protectors. The standard tests to determine the attenuation values of ear protectors cannot be applied to high - intensity impulse has from fire arms, but the protectors should be evaluated under actual firing conditions. The attenuation values of the ear protectors (Ear muff) most commonly used in the Finnish Army were tested for impulse noise from different weapons. The attenuation was found to be good for pistol shots, moderate for rifle shots and very poor for cannon fire. The tested ear muffs gave only minimal protection against low frequency impulse energy.

Smith, C.R, Borton, T.E., Patterson L.B, Mofo B. 7 & camp R.T. (1980) in their study about the effects of insert hearing protector indicate that very small differences between measured ear canal diameter & actual ear plug size affect considerably the sound pressure levels in the ear canal during exposure to high levels of noise, the individuals typically select ear plugs that are smaller than their measured ear canal dimensions when the decision is left to them, and the most skilled technician cannot always determine ear canal sizes due to limitation of available measuring instrument.

The existing data on the intensity of various off-the road vehicles (ORVS) is sufficiently convincing to warrant advising the use of ear protection for all participants in these sports Interestingly enough most ORV drivers feel that their helmets provide them with adequate attenuation and reject the idea of any additional protection. There is evidence, however, which suggests that recreational head gear does not protect the ear from excessive noise levels. (Fred M. Bess, Denis W. Gale, John D. Aarni, Nichalas P. Redfield 1974) For Eg., helmet manufacturers admittedly design their product for the express purpose of crash & wind protection and give little or no consideration to their noise attenuating capabilities. Further support is provided by Zwislocki who has made the statement that "most helmets do not contribute to sound attenuation and indicated that they should not be used as ear protection alone. Thus it can be assumed that a tight seal around the ear will seldom be achieved with a helmet and that sound leakage will occur, particularly in the low frequencies.

Fred H. Bess Denis W. Gale, John. D. Aarni, Nicholas P. Redfield (1974) have also confirmed that the recreational helmet provides little ear protection from loud noise levels, especially at the lower frequency region. Further findings suggest that ORV on enthusiasts need to wear some form of ear protection in addition to their helmets.

Noise entails two effects on auditory function, hearing loss & auditory fatigue. The reduction of auditory fatigue without the use of protective helmets can apparently be used as an objective way of evaluating their efficacy. Two studies, one in an industrial the other in a lab environment show that for the same noise in the value of helmets differed.

A report on A.R.L tuned ear plugs reveals that these plugs offer advantages over conventional plugs for protection against harrow bands of noise. They may also be valuable as tools in general Psycho-acoustic - research. Attenuations of rrom 20 to 30 dB were found at the tuned frequencies. Speech has to be increased in level only 2 or 3 dB to be equally intelligible when the earplugs were worn. (Slliott.E. 1965).

Maas, R.B. (1964) in his paper on. Hearing protection in industry one way to solve the noise problem immediately discusses about the addition to state safety rules and orders in both wisconsion and calfornia, make the wearing of hearing protection mandatory under certain conditions. The logical time to acquaint a new worker with hearing protection is at the very beginning when he is also briefed on the physical examination, group health insurances, first—aid facilities, safety glasses, respirators etc.. It is explained that management provides this equipment for his protection and welfare. Hearing protection is much more successful if the nurse or doctor explains the purpose for wearing ear protection and its the worker properly. The nurse handles this type of protection the same way she promotes other safety and health measures. Like any other aspect of safety and health maintenance, the hearing conservation effort must have unqualified management direction. Management has much to offer the worker in providing hearing protection to its worker because no one gains more than the individual who protects his precious hearing ability from noise until retirement. The safety engineer should soon learn that the problems involved in the promotion of wearing.this type of protection is probably no different than the difficulties encountered in the promotion of all other safety devices and equipment. Most protective equipment requires long-range, educational emphasis.

General protection consists in the covering of factory walls, floors and ceilings with sound-proofing materials. Individual protection is achieved either with ear protections or with antiphons. The damping effect of an Italian and an American ear protector was tested, it was 30dB for both ears. The damping effects of a home—made ear protector was only 15 dB. The damping effect of two types of home-made antiphons were examined and this effect was very satisfactory for both types and the study emphasizes the importance of instructing workman in the correct use of these devices.

(Prazic,M; Greguric, M Salaj.B & Subatic R, 1966)

Psenickova.V. & Stikary 1966 in their study assessed the damping of noise by various mufflers produced in Czechoslovakia which were used as personal protection and reported that the muffers (stoppers made from a mixture of paraffin ceresin, vaseline & barium sulphate) & resonance protectors introduced into the auditory meatus are more effective than earphone protectors and suggested the construction of other types of protectors in case of very loud noises where the importance of bone conductivity is greater.

A variety of ear protectors are available, most offering adequate attenuation against harmful noise. Despite a wide selection employees frequently wear dry cotton in lieu of suitable devices provided. A Swedish material proved effective in Europe, composed of glass fibers with a diameter of 0.001 to 0.002mm was obtained for trial use. Excellent employee acceptance beyond expectation followed. Annual cost was estimated about 4 dollars per man per year. (Zenz.C & Berg.B.A., 1965).

Axelsson.K, Axelsson.A & Johmon.Ay 1978) in their study compared two groups of noise-exposed workers with respect to their use of ear protectors one group had a severe nois-induced hearing loss; the other group had normal hearing. Both groups were composed of workers of similar age and total duration noise exposure. It was found that those with normal hearing has used ear protectors considerably more than those with severe hearing loss. Interestingly, quite a few workers has normal hearing in spite of working in noise for many years without ear protectors. Also, quite a few workers had a severe hearing loss in spite of frequent use of ear protectors. The reason for not using ear protectors were analysed as also was the condition of the protectors and frequency with which they were replaced. Plastic ear plugs were preferred by 44% vinyl foam ear plugs by 26% libreglass down by 18% and ear muffs by 11% of the workers. In general, the condition of the ear protectors was good surprisingly 1/3 of the workers did not use ear protectors, many of them because they had not realized that the environment they worked in had a noise intensity level above the injury risk level.

Further, In order to explove the question of inter-laboratory variations in results of noise reduction Rating (NRR) tests of ear protectors, the environmental protection agency intlated a round robin test program* Four EPDs representing a wide range of currently available types, were tested. Seven laboratories participated directly, data obtained separately from an eigth laboratory also were included in the evaluation. The results showed significant variation in both mean values of attenuation and standard deviation, leading to substantial differences in reported NRRS among the different laboratories one source of the variability appears to be the uncertainly of obtaining the proper fit to avoid acoustic leaks other sources include subject selection and training as well as data reduction techniques. (E.H. Berger & J.E. Kerivan, F. Mintz; 1982).

ATTENTION OF EARPLUGS WORN IN COMBINATION WITH EARMUFFS

A combination of two types of ear protectors are sometimes used when the noise levels are high i.e., if the atteuation that can be provided by a single ear protective device (EPD) is inadequate for a given noise exposure and if noise control procedures are impracticable which is likely to be the case if equivalent 8—hour A—weighted exposures exceed 105 dB, the only remaining alternative is to use dual protectors i.e. an earplug plus an earmuff. Such a combination can provide additional protection, but however the total attenuation provided by such a combination of protective devices is not the sum of the attenuations produced by each of them individually, but is considerably less. (Elliott.H. Berger, H.C. Gan guli, M.S. prakash Rao, M. Rodda, Katz. Duerden.K).

A combined plug and muff provide attenuation ranging from 38 to 34 dB at frequencies between 250 to 2000 c/s with maximum attenuation at 3000 c/s. (M.Rodda). But the attenuation achieved by this combination will not generally exceed 45 dB (K. Duer den).

Elliott H. Berger in his study reports that the attenuation of the combination at individual frequencies is atleast 5 dB better than either device alone, but significantly less than the algebraic sum of the individual values. This is due both to mechanical coupling of the plug and the muff via the body tissues and the volume of air trapped between them.

and to limitations on attenuation created by the bone conduction pathways.

Bone conduction (BC) refers to flanking sound paths that permit transimission of energy to the inner 6ar through the bones and tissue of the skull, thus bypassing the EPD. It imposes a limit on the real-ear attenuation that any protector can provide since regardless of how well the device seals the ear canal and prevents sound from entering, energy can still reach the inner ear one estimate of the BC limits to EPD attenuation is shown by the bold line in Fig.3.

Although combination of other devices were found to perform similarly to those dipicted in Fig.3, no easy rule of thumb tould be devised to predict combined attenuation based on the results for single devices. The incremental performance gain at individual frequencies was found to vary from approximately 0-15 dB over the better of the individual EPDs, except at EKHz where no combination exhibited a gain of greater than 3 dB. The gain in the noise Reduction Rating (NRR) for the double protection combinations ranged from 7-17 dB when compared to the plugs alone, 3-14 dB when compared to the muffs alone, and 3-10 dB when compared to the better of the two individual devices.

An example of the performance of each of the earplugs worn in combination with muff is shown in Fig.4. For the lower and middle frequencies the attenuation varied by approximately 20 dB across the different combination as a function of the attenuation of the earplug. In contrast, above ZKHz the net performance was BC limited (Fig.3) and was equivalent for all combinations, when the performance of different muffs worn over selected earplug was examined, it was found that the net attenuation was essentially independent of the particular earmuffy suggesting that in such cases the choice of earmuff was relatively unimportant.

In the recent literature, the attenuation of EPDs in real word environments falls short of laboratory predications. To assess the effects of field fitting on the performance of dual EPOs, one test was conducted with a purposely misfitted device, a partially inserted foam earplug. (Elliott H. Berger)

The partial insertion test was designed to approximate utilization that is attainable in the field with limited instruction and motivation. This was validated by measuring the laboratory attenuation of E-A-R foam earplugs using 92 untrained listeners who fitted the plug themselves according to the manufacturer's instructions, but without supervision* Many of them had not previously worn SPDs. The figure 3 data for the partially Inserted E-A-R plug assumed to provide an indication of what can realistically be obtained with a comfortable combination of light weight protectors.

All of the double SPD data will reflect an upper bound on the values attainable under field conditions, especially since one must consider both the reduced comfort of dual

EPDs and the fact that when an earmuff is worn over an earplug, observation and enforcement of the correct usage of the plug becomes more difficult*

So in conclusion, when the real-world attenuation of a single EPD is inadequate, the utilization of double EPDs is an alternative that should be considered. This is especially important when the noises are dominated by lower and middle frequencies, since it is in this frequency range that the attenuation of single EPDs will be the lowest, making the extra protection provided by the combination most necessary. The performance of the combined devices is relatively unaffected by the earmuff that is selected but at the frequencies below ZKHz is strongly influenced by the choice of earplug. At and above ZKHz all plug-plus-tnuff combinations provide attenuation that is limited only by the flanking bone conduction pathways to the inner ear.

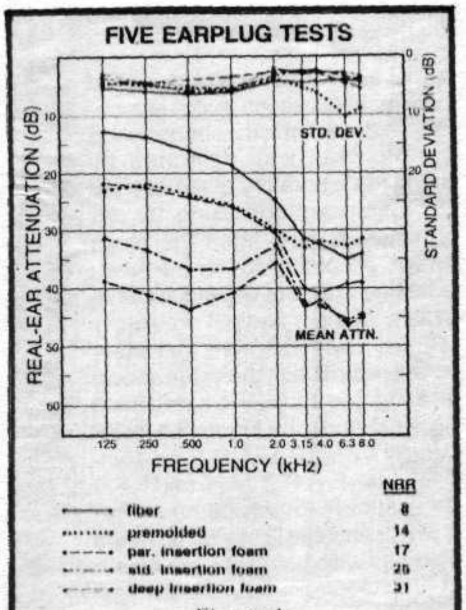

Figure 1

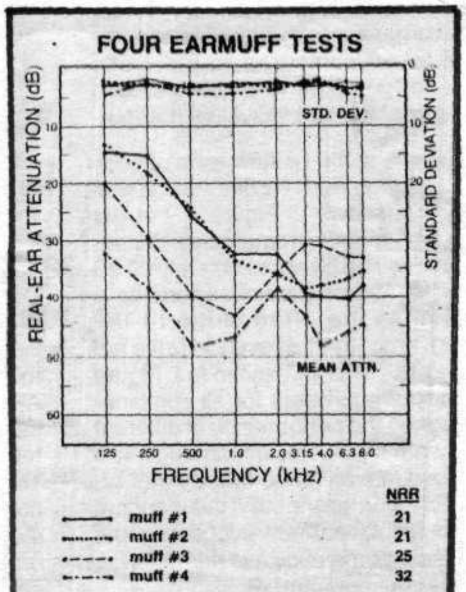

Figure 2

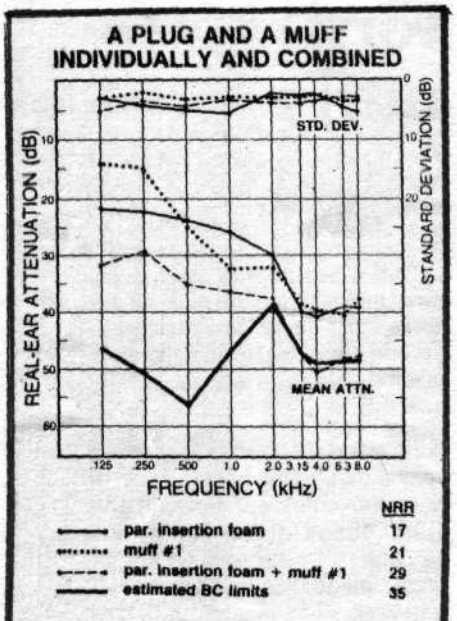

Figure 3

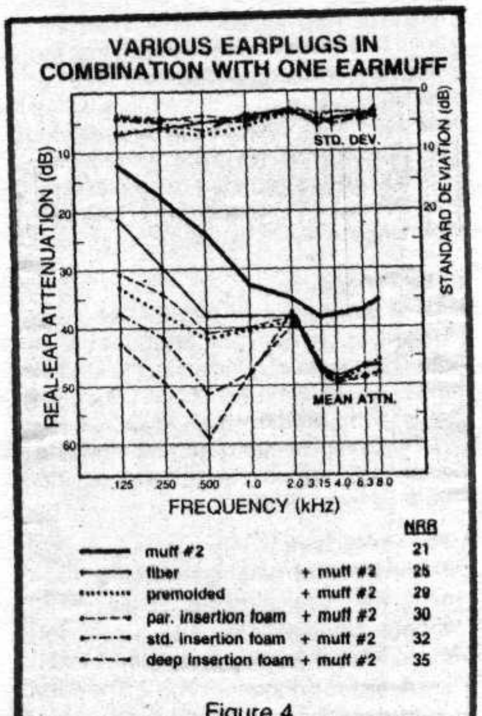

Figure 4

C H A P T E R IV

PRATICAL CONSIDERATION AND SELECTION OF EAR PROTECTORS

Each ear protector inspite of different types must fulfill the following requirements:- 1) Sound Attenuation, 2) Comfort 3) Absence of adverse effect on the skin (Toxic effect of ear protectors) 4) Speech communication noninterference 5) Ease of use and Handling 6) Hygiene, 7) Durability 8) Cost. The importance of the 4, 5 and 7 depends on the conditions of use.

1. SOUND ATTENUATION:

The primary function of an ear protector is its capacity to attenuate sound. It determines the amount of protection of the ear as well as the extent to which an ear protector can furnish noise reduction. The greater the sound attenuation capacity of an ear protector, the greater its ability to provide hearing protection against a harmfull noise. The degree of sound attenuation necessary depends on the sound pressure, the kind of noise, and the duration of exposure. Even though the exact nature of these interrelations is still indistinct, quite generally it is stated that the amount of sound attenuation provided by an ear protector should be sufficient to keep the noise level below the safety limit whenever such limit has been established. The ear protector will not always be capable of attaining this limit. Each protector has its own characteristic attenuation pattern. It has been noted that the attenuation characteristic of even the best ear protectors will not be more than 25 to 35 dB on the average, eventhough under certain circumstances an attenuation of 40 to 50dB may effective at the high frequency end than at the low frequency end. However, the ideal ear protector is one which cuts out the lower and higher frequencies equally. This prevents distortion of speech.

Generally the ear protector's attenuation characteristics are determined by means of a "Threshold shift" procedure. During which each individual wearing ear protector under study are tested to find out their hearing threshold levels for different pure tone frequencies. Later the same listener's threshold is redetermined when no ear protector is worn. The resultant threshold shifts or differences in decibels between thresholds obtained with and without the ear protector in place at the various test tone frequencies serve to show the attenuation characteristics of the protective device.

The attenuation values given for earplugs and earmuffs are fairly equivalent. However the difference between the two indicate earplugs to be better suppressors of low frequency sounds, but poorer high frequency suppressors. The helmets are the good high frequency suppressors whose attenuation values are either equal to or greater than the earplugs and ear muffs at the high frequency. At the same time they are poor in suppressing low frequency sound when compared with other protectors cotton plugs, in contrast to all other ear protectors Show little attenuation for all frequencies. However, cotton impregnated with wax or plugs made from glass-down material can cause significant reduction in sound transmission. But however these later items are of value for one-time use.

Except cotton plugs, the attenuation capabilities of the ear-plugs, ear muffs and helmets would be sufficient to reduce many noise conditions found in industry to safe exposure levels when ear protectors are worned in combination still greater suppression of sound can be gained For eg. Ear plugs and Ear muffs, ear plugs and helmets. The combined attenuation at the various frequencies is less than the sum of the individual attenuation values for the two items. This is due to the fact that the sound energies deeded for threshold response when wearing the combination are intense enough to enter the ear directly via bone conduction, thus bypassing the abstructed air conduction pathway into the ear.

2. COMFORT:

At the first glance comfort may appear to be a secondary requirement but it is the next important factor to be comi- , dered, because as these are meant to be worn for long periods they should fit in properly and not exert undue prossure or lead to any discomfort. Even slight discomfort gets aggravated and the wearer develops an antipathy toward it.

Some of the apparent discomfort caused by an ear protector may be nullified if the noise conditions are quiet excessive and represent a clear hazard to hearing. Given less

Intense but still potentially harmful noise conditions. The user may be less likely to tolerate any discomfort associated with protector. Consequently, it becomes useless even if it provides a high initial sound attenuation. There have been instances where industrial workers provided with ear protectors preferred to go without them even at the risk of considerable amount of hearing loss. Pressure applied by the ear protector on the skin is the most direct cause of discomfort. Reducing total pressure and/or distributing the total applied force over a large area so as to minimize pressure at any given point will promote comfort. Earplug and earmuff designs are guided in part, by this principle plugs come in a wide range of sizes and have soft, pliable outer layers to take account of the various sizes, shapes and contours of the ear canal found in the user population. The sealing cushions of earmuffs make contact with a fairly large area of the skin surface circumscribing the ears and also are composed of a soft material, so as to fit individual variations in anatomy. Actually, earmuffs do not pose a fitting problem since their basic dimenssions will fit all ears. Because of the large size of the ear cups, however, they may be considered as bulky or cubersome. Also the large surface area of contact between ear muffs and skin may cause overheating of the skin particularly in not environments.

When earplugs are worn correctly for long periods of time the majority of them are a little uncomfortable. But inspite of this the wearer should become used to them after a few days on the other hand earmuffs may tend to feel not and sweaty in certain environments even though absorbent seal covers may somewhat alleriate this problem. Helmets distribute their pressure all around the head* but generate discomfort through their weight and bulk.

It should be noted that there is only a fine dividing line between these types of ear protectors that are effective and unacceptable to the wearer. Consequently those properties of ear protectors that affect comfort should be considered as important as those that provide protection. 18 addition to it the requirement of comfort, is most acute in a noise of moderate sound pressure, where ear protectors are used for psychological rather than for phyiological reasons, for example, to eliminate the distraction caused by irregular noise, or to fecilitate sleep.

3. SPEECH COMMUNICATION NONINTERFERENCE:

It is a common complaint that ear protectors interfere with conversational speech when worn in quiet environment. The ear protectors should be designed so that it interfere minimally with speech communication in the noise situations where the protectors are being worn. The acoustic performance of the ear protector should ensure the highest possible speech intelligibility. If the ear protector has a flat frequency characteristic then speech will be most intelligible in a continous noise.. But special devices have been developed for intermittent noise. However, wearing conventional earplugs or earmuffs in noise levels above about 85dB (A) should not interfere with and in may improve speech intelligibility and the reception of warning signals for normally hearing ears.

Contrary to popular belief ear protectors fecilitate speech communication. Besides offering protection from noises, which is their primary function, especially when the ambient noise levels are high. It has bean observed that at high noise levels the intelligibility of speech is better with ear protecters than without them. The reason is that even though the signal-to—noise ratio remains the same, over loading of the auditory system and the consequent distortions are avoided resulting in better perception of speech. Also, since for any S/N ration there is an optimum intemity for speech intelligibility, the attenuation provided by the protecting device may bring the speech0 intensity nearer the optimum and thus fecilitate its understanding. Ear protectors, however, tend to reduce intelligibility of speech at low signal to noise ratios if the level of the marking noise is less than 75 db.

Decided impairment in speech reception will occur, however, if ear protectors are worn continuously in an intermittent or variable noise exposure,special devices have been designed into ear protectors in an attempt to offset their sound attenuation should the receiver wish to hear ambient sound more readily. Earmuffs have been made with ports that can be opened or closed depending upon need to near ambient sound plugs have been designed with diaphragms and values that will transmit a sound unattenuated to the ear provided that it is below a certain intemity level. If this level is exceeded, the diaphragm hits a stop which impedes or attenuates sound transmission to the ear. Unfortunately, these latter devices when in an attenuation state leak sound to the ear, consequently offsetting their ability to provide effective noise protection.

Still some way reject the use of ear protectors since this gives them a feeling of isolation and difficulties in communication.

4. ABSENCE OF ADVERSE EFFECT ON THE SKIN:

One justification for discarding an otherwise satisfa-ctory ear protector is that it causes a toxic effect on the skin. An ear protector may cause inflammatory condition of the skin which can be controled only by discontinuing its use. Fortunately, nontoxicity in ear protector materials is probably the easiest requirement to fullfill. Indeed most of the materials used in their manufacture are chemically neutral. Another factor to be considered about the EPD is it should be soft to wear and should be able to stand all weather conditions.

5. HYGIENE:

In general, the condition of ear protectors are acceptable even if ear plugs are often dirty. This does not necessarily mean that the noise reducing effect of these devices is impaired but if may contribute to irritation in the external ear canal however ear plugs are the type most likely to cause problems of hygiene. So before any form of earplug is issued, the user should be asked about and examined for any ear troubles such as irritation of the ear canal, earache and discharging ears or whether he is under treatment for any ear disease. In such cases medical opinion should be sought to ascertain whether earplugs can be worn with safety. Obviously, ear plugs should be kept absolutely clean and free from chemicals, oil, or grease when being inserted into the ear canal. Earmuffs rarely cause injection or sensitization of the ear canal and are a good alternative where this occurs with earplugs. However frequent changes of ear protectors of the insert type and of the sealing rings of the muffs would probably guarantee an acceptable condition of the ear protectors.

6. EASE OF USE AND HANDLING:

Ear protectors are more assured of being effective if their application is uncomplicated and only when usec correctly. More specifically, an ear protector which required a good degree of precision and effort in its proper usage will probably give poor performance results in the field. This can be achieved more easily when their application is simple. The probability of incorrect use increases of EPOS are difficult to handle including the variability of their performance. In addition to it EPD should be of small size capable of being taken from palce to place conveniently and of being stored away when not in use. It should be able to stand all weather conditions, frequent use ad even some rough handling.

In particular. Ear plugs require more deftnen in handling and use than any other type of protector, which makes them more vulerable to poorer performance. They have to b more effedtive earplugs should only be inued with the plant physician or nurse making the proper size selection and giving instructions as to how they should be worn and cared for. Careful spot-cheks to issue their correct use are necessary.

(7) DURABILITY

The durability is an economic factor of an Ear protector and is of much importance when large quantities are purchased. Ear protectors should be reasonably rugged and resistant to ageing Since many factors such as Ear wax, perspiration, humidity, light and active chemicals contained in the air speed up the aging process.

Generally speaking more durable devices are more economical in the long run. This is especially true of the more expensive earprotectors such as earmuffs and helmets. On the other hand earplugs designed for repeated use are composed of materials whict can resist most of the aging factors and can last for no or more years without objectionable changes. Most of the Soft resistent materials, however, show a tendency to contact or harden with with time or to expand and become soft.

(8) COST:

Cost becomes an important factor when Ear protectors are to be supplied in large quantities. The total cost invalved in providing Ear protectors to a group of personnel working under noisy situation may be divided into three basis categories.

a) Expenditure due to initial purchase.

b) Expenditure induding cost of supplying spare parts and replacements.

c) Expenditure involving cost of time spent in administering the Ear protectors.

Among these three it should be noted that the initial cost may not necessarily be the greatest figure. But replacements and administration costs are often the largest factors involved.

Existing Noise-induced Hearing loss:

It is unfortunate to know that persons with NIHLs when they wear EPDmit results in an added impaiment. In such cases the presence of EPD results in slight impairment in the speech communication. Neverthless, in a person who already has a hearing loss, there is a greater need to protect his hearing; He requires greater protection since has so much to speak, bat less hearing to loose than normally hearing persona. There are many workers who might have worked many years in a nosily environment without wearing EPD and thus have gradually adopted to the implications of hearing loss on his work and social life. Still there is a need to persuate him to wear EPD there after, thereby preventing further increase in any social handicap he might have in future.

SELECTION OF EPD

The decision about choosing the type of protector depends on the noise, environmental conditions in the industry, the needs of the worker, obviously, we have to consider the noise level to which the worker is exposed. The higher the sound level, the more effective is the protection needed. Another factor that has to be considered is how well the earprotector is accepted. A device which is less effective but is used frequently and is well accepted is preforable to a more effective Ear Protector used reluctantly Also the cost has to be taken into account. Muff type EPD are more expensive than the other protectors. In the long run, however, the ear muff is the least expensive. Since is is changed insuch less often than the other types. There are apparently many different factors which have to be taken into account when it comes to recommending personal Ear protector. It is often difficult to recommended any particular Ear protector. It is disirable and advantageous to offer a many types as possible so that each employee can choose the one he likes best and which he will use continuously or frequently from a range of different types of potentially adequate protection. (C.E.Marston & C.P Goet Zingle, 1972)

The adoptation of dBA-type hearing damage risk criteria and the consequent use of A. Weighted sound levels to identify areas of auditory hazard have created a need for a measure of the dBA attenuation of Ear protectors. In a study(R.Wagh,1973) it was found that the same EPD might offer 20dB more dBA attenuation to one noise than to another but-that noises of like C-A value were subject to approrimately the same dBA attenuation. Thus the expression of EPD performance in terms of dBA attenuation. Enables appropriate ear protectors to be selected on the basis of simple sound level measurements and eliminates the need for octave band survays farmely required for this purpose.

It is doubtfull whether ear plugs or ear muffs alone can satisfy all the needs of a ear protector program in any one organization. In a study (K. Axelsson, A. Axclesson and A. Johnson - 1978), where the employees in a particular car painting department had a choice of 4 different ear protectors, the results revealed that the most common type was the plastic ear plug, which was prefered by 44% The vinyl foam ear plug was used by 26% fibre glass down by 18% and ear muffs by 11% of the workers. Thus obvious advantages of each should be utilized wherever possible, so that a hearing protection program may be made as acceptable as possible to the potential wearers.

It should also be pointed out that the fitting suitable, EPD calls for as much skill as the previous methods of noise control. But this will be excercised by a specially trained audiometrician rather than by an acoustic engineer. Since EPDs vary in their attenuation characteristics, a suitable device must be matched to the noise from which the worker is being protected (M. Rodda 1967).

The chief function of an EPD is to reduce the noise reaching the inner ear. The persons responsible for EPD programs should be aware of the amount attenuation provided by the various types of protectors they intend to use. The attenuation properties of the protectiors are usually the specification listed! by the manufacturer are the results obtained under relatively good laboratary conditions. It is a good rule of thumb to reduce the reported attenuation characterstic by 5 to 10 dB to get an estimate of actual performance in the field. Frequently, the manufacture also provides an estimate of variation of effectiveness of the EPD in terms of aound deviation. When this information is available, the effectiveness of the ear plug in the field can be better estimated by reducing the specified performance by one or two standard deviation.

Piesse R.A. (1962) in his study on ear protectors found that in many instances a number of ear protectors will be suitable for use in a particular noise and, in these cases, selection of an appropriate device can be made on mechanical features or price.

Thus selection of appropriate 5PD plays an important role in the Hearing conservation programme.

Hearing Conservation Programme and SPD

1. Extra-Auditory Benefits of a Hearing Conservation Program.

Proper operation of any program requires the active support of all concerned. Not only must employees be convinced of the program's merit, but so too must all levels of management. An effective Hearing conservation program may not only prevent industrial noise— induced hearing loss, but also improve general employee productivity and safety.

Extra- Auditory, Effects of Noise.

It has been clearly established, the habitual exposures to noise levels is excess of 90 dBA will cause significant hearing loss in a sizeable portion of the exposed population. Additionally, there are ample data to suggest that levels of 85 dBA or even 75 dBA will be injurious to some. Beyond these obvious and well documented deleterious effects, noise has been linked to many other physiological and behavioral effects, although the evidence is inconclusive. These extra auditory effects are very difficult to quantify. Since they are often non specific in nature and since many other noxious stimuli and/or stressful circumstances often cocxist with high sound levels.

Analysis of the proceedings of the 1973 and 1980 International Congresses on Noise as a Public Health Problem leads one to conclude that although extra- auditory effects have been frequently hypothesized, there is widespread disagreement as to the validity and interpretation of the supporting data, often, for every study that correlates noise exposure with a particular extra auditory effect, another study finds contradictory results. In general, the data tend to support the following statements, applicable to the industrial setting.

1. Levels of noise necessary to produce adverse Psychological effects are high   95 dB.

2. Noise affects tasks requiring accuracy rather than speed.

3. Noise deterimentally affects demanding tasks especially those requiring attention to multiple signal sources, however, it may actually improve the performance of monatonous, routine tasks.

Studies which tend to demonstrates the extra - auditory benefits of HCPs have been conducted on a number of industrial populations. For example, Jansen examined the health records of 1,005 iron and steel workers in "very noisy" industries. He found from 5 to 15% greater occurrence of peripheral circulation problems, heart problems, and equilibrium disturbance in the "very noisy" group. It is useful to highlight these possible advantages to management, since, of course, they too must be motivated to actively participate in the HCP.

Recent Industrial studies:

An even more direct approach to substantiate the beneficial aspects of reduced employee noise exposures is to examine employee health and safety records before and after the advent of an HCP. Cohen reported on such a study involving 434 noise exposedd (95dBa) boiler plant workers. Data were compared for two- year periods, before and after the advent of an HCP involving the use of EPDs. Results indicated fewer job injuries, medical problems, and absences in the Post -HCP period, as typified by the results in Figure 1. For comparison, the data for a control population of 432 low noise (80 dBA) workers from the same plant are also shown since the control population exhibited no pre/post HCP reduction in absente- cism, but the high noise group did, it is likely that reduced noise exposure, as a result of EPD usage, was the controlling variable.

Cohen also attempted to rate each employees degree of EPD usage and correlate these findings with the degree of reduction of the various problems. That analysis indicated no significant relationship, and thus tempered somewhat the strength of any conclusions relating EPD usage to extra-

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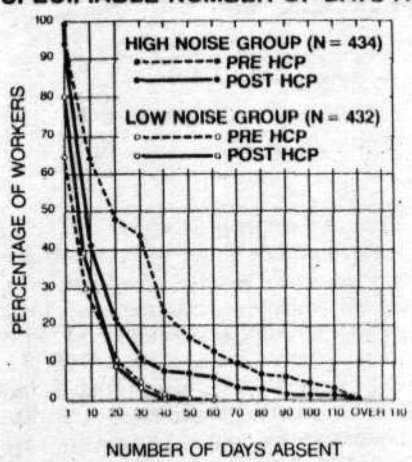
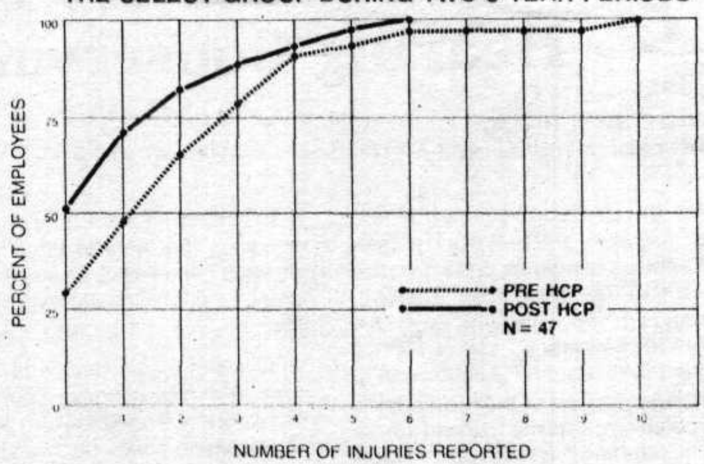
CUMULATIVE FREQUENCY DISTRIBUTION OF WORKERS FROM HIGH AND LOW NOISE GROUPS WITH SPECIFIABLE NUMBER OF DAYS ABSENT



This curve is plotted in an inverse manner. Each point represents percentage of workers having had *as many or more* days absent as read off the abscissa. After Cohen.[15]

FIGURE 1

COMPARISON OF THE CUMULATIVE FREQUENCY DISTRIBUTION OF REPORTED INJURIES FOR THE SELECT GROUP DURING TWO 5-YEAR PERIODS



Each point represents percentage of workers having had *as many or less* reported injuries as read off the abscissa. After Schmidt et al.[16]

FIGURE 2

auditory problems.

Another significant finding in cohen's study was that comparisons of injury data before and after the advent of the HCP, evidenced that the use of EPDs reduced rather than increased the number of mishaps. "This appears to connter the notion that wearing EPDs could increase the likelihood of accidents by attenuating not only noise, but also the audibility of sound signals depicting danger".

Recently, schmidt et al. conducted a study very similar to cohen's, wherein they examined industrial injury data for five years proceeding and five years following the institution of an HCP at a North Carolina cotton yarn manufacturing plant. They utilized two test groups totaling approximately 150 subjects. No Hygenic or other major environmental changes other than the HCP occurred during the study years. They found a significant reduction in reported injuries for both groups after the advent of the HCP. The data for the "Select group" are shown in Figure 2

The Hearing Conservation Amendment

Since octaber of 1974, OSHA has been working on revisions to the occupational noise exposure standard. After years of oral and written public testimony, resulting in an unwieldy public record of almost 40,000 pages, OSHA promulgated revisions to the noise standard in January, 1981 This was followed by deferrals, stays, revisions, further public hearings, and a multipliplicity of lawsuits, all of which culminated in the occupational Noise Exposure; Hearing conservation Amendment; Final Rule, issued March 8, 1983, with an effective date of April 7, 1983. In this section a little effort is made to summarize briefly principal components of this important new noise regulation, elucidate its key aspects, and clarify issues it has raised that are often musunderstood.

Background Information

It is estimated by OSHA that there are 2.9 million workers in American production industries with equivalent 8 — hour noise exposures in excess of 90 dBA and an additional 2.3 million whose exposure levels exceed 85 dBA. The Hearing conservation Amendment (HCA) applies to all those 5.2 million employees. Except for those in oil and gas well drilling and servicing industries which are specifically exempted. Additionally, the Amendment does not apply to those engaged in construction or agriculture, although a construction industry noise standard exists (29 CFR 1926, 52 and 1926. 101) which is essentially indentical to paragraphs (a) and (b) of the general industry noise standard described below.

The Occupational Noise Standard

Prior to promulgation of the HCA, the existing noise standard (29 CFR 1910. 95 (a) and (b)) set a permissible exposure level of 90 dBA for eight hours, and required the employer to reduce employee exposures to that level by use of feasible engineering or adminstrative controls. In all cases where the sound levels exceeded the permissible exposure, regardless of the use of hearing protection, "a continuing, effective hearing conservation program" was required but the details of such a program were never mandated.

Paragraphs (c) through (p) of the HCA supply OSHA's definition of an "Effective hearing conservation program." They replace paragraph (b) (3) of 1910. 95, but do not alter the law as defined in paragraphs (a), (b) (1), and (b) (2). As long as the permissible exposure level for unprotected ears is exceeded, feasible engineering and administrative controls must still be implemented regardless of the existence or quality of a company's other hearing conservation efforts.

Terminology

The noise standard and the HCA define the permissible exposure level (PEL) as that noise dose that would result from a continuous 8 – hour exposure to a sound level of

90dBA. This is a dose of 100%. Doses for other exposures, either continuous or fluctuating in level, are computed relative to the PEL based upon a 5 dB trading relationship of level vs duration (See Table 1)

<u>The 8 hour time — weighted average sound level (TWA)</u>

Is the sound level that would produce a given noise dose if an employee were exposed to that sound level continuously over an 8 hour work day. This is true regardless of the length of the actual workshift. For example, workday exposures of 4 hours at 90 dB, 8 hours at 85 dB, or 12 hours at 82 dB, all correspond to a TWA of 85 dBA or a noise does of 50%. If a noise level is constant for an entire 8 hour workshift, the TWA is simply equal to the measured sound level. The Procedure for converting doses to TWAs is demonstrated in Table 11.

A noise dose of 50% is designated as the action level, or the point at which the HCA requires implementation of a continuing, effective hearing conservation program.

<u>Summary of the HCA</u>

All workers receiving noise exposures at or above the action level are to be included in a hearing conservation program comprised of five basic components. Exposure monitoring, audiometric testing, hearing protection, employee training, and record keeping. The requirements of the standard are primarily performance oriented, allowing the employer to use judgement in selecting the best methods of compliance*

MONITORING:

Employers shall monitor noise exposure levels in a manner that will accurately identify employees who receive daily noise doses at or above the action level. All continuous, intermittent, and impiassive sound levels from 80 — 130 dBA must be integrated into the computation. Noise levels must be remeasured whenever any change relating to production is suspected of increasing exposures to the extent that additional employees may receive doses at or above the action level, or the attenuation provided by the selected ear protectors is rendered adequate.

Monitoring may be accomplished by an area survey technique in which sound level meter readings are combined with estimates of the length of exposure of individuals to particular sound levels in order to calculate the TWA (as in Table 1), or may be measured by personal sampling methods via the use of a noise dosimeter. However, employers must justify the particular monitoring technique they choose to utilize. OSHA inspections will in most cases be be conducted via the personal noise dosimetry approach.

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All initial noise surveys were to have been completed by April 7, 1983, but in general, property executed and documented existing surveys are in acceptable alternative.

The noise dose that is to be reported for complicance purposes is the daily noise dose that could be measured by an 0SHA inspector on a particular survey day. It is not permissible to average doses over a number of days to compute a long term average noise dose. Unless an employer can fully document the infrequent nature of particular exposures, and unless management wishes to rely upon the latitude that might be permitted by a particular inspector, the prudent course of action and the one that would be more protective of the employee's hearing, would be to account for infrequent higher level exposures by using such values to compute noise doses.

The noise standard (Paragraphs (a) and (b) and Table G – 16) does not permit exposures to steady sound levels above 115 dBA, regardless of duration (although the exact meaning of "steady sound" and the types of impulsive or impact noises that might be excepted from this prohibition are une clear). OSHA still considers the 115 dBA limitation to apply even though Table G – 16 a of the HCA, which is to be used for compulation of employee noise exposures, incorporates levels up to 130 dBA. Those higher levels were listed in table G - 16 a to indicate explicity that they be accurately assessed and included in the dose computation, but they were italicized to avoid giving the impression that levels above 115 dBA are permitted.

AUDIOMETMC TESTING:

Audiometric testing not only monitors employee hearing acuity over time, but also provides an excellent opportunity to (re) educate employees about their hearing, (re)motivate them to protect it, and (re) train them in the use of their ear protectors. The audiometric program consists of baseline audiograms against which future tests are compared, and annual audiograms which are the tests used to identify changes in hearing acuity in order to take protective actions.

All current employees must have baseline audiograms taken sime months from their first exposure at or above action level, whichever is longer. An exception is provided when mobile test vans are used to meet the audiometrie testing obligation, in which case the employer has one year to obtain a valid baseline when this exception is invoked, employees must wear ear protectors jor any period exceeding six months after their first exposure, until the baseline audiogram is obtained.

Baseline audiograms must be preceded by 14 hours without exposure to work place noise; however, ear protectors may be used as a substitule for this requirement. Annual audiograms may be obtained at any convenient time during the workday. Although an audiologist, otolaryngologist, or physician must supervise the audiometric testing and must review problem audiograms, testing and evaluation in general may be conducted by a technician who has been certified by the council for Accreditation in occupation Hearing Conservation, or who has otherwise demonstrated competency to the supervising professional.

Changes in hearing acuity that exceed an average of 10 dB or more at 2000, 3000, & 4000 Hz in eirther ear, relative to the baseline audiogram, are considered to be a standard threshold shift (STS). In determining whether an STS has occurred, allowance may be made for the contribution of aging to the change in hearing level (Presbycusis) by correcting the annual audiogram. when an STS is detected, the employee must be notified, and unless a physician determines that the shift is not work related or aggravated by occupational noise exposure, the employee must be fitted or refitted with ear protectors as needed, and referred for a clinical evaluation as appropriate.

It is important to distinguish between an STS and a compensable hearing loss, the latter being defined according to each state's worker's compensation formula. The presence of an STS indicates a change in hearing acuity as defined by the HCA, but it has no relevance with respect to the determination of hearing impairment or handicap. It is possible for an STS to develop for employees whose hearing threshold levels are still considered "normal", and conversely, it is possible for persons to develop considerable hearing loss at the frequencies of 4000 and 6000 Hz before detected by the STS criterion.

The necessity of reporting STSs on 0SHA from 200 is undear at this time Although 29 CPR 1904. 2 clearly specifies that "work related" injuries and illnesses are to be recorded on from 200, OSHA has not stated whether an STS is to be considered a work related injury, and the HCA has specifically relieved the employer of the burden of determining the "work relatedness" of particular hearing losses.

Ear Protectors:

Ear protectors must be made available to all workers exposed at or above the action level. Additionally, for those exposed at or above the PEL, and for those exposed at or above the action level who either incur an STS or who have been exposed in excess of six months without having had a baseline audiogram established ear protector utilization is mandatory. Ear protectors must reduce exposures to 90 dBA* or to 85 dBA for those exhibiting an STS.

The employer must provide a "variety of suitable ear protectors" from which the employee can choose, and must provide training in the use and care of those devices, as well as ensuring proper initial fitting and supervision of continued correct use. OSHA interprets "Variety" to mean at least one type of plug and one type of muff, although a somewhat larger selection is considered preferable The ear protectors are to be furnished to the employees at no cost, and replaced as necessary. However, employeers are not expected to pay for an unlimited supply of protectors or to replace devices that are lost or damaged due to employee negligence or irresponsibility.

TRAINING:

Employees exposed at or above the action level must be trained at least annually regarding the effects of noise, the purpose, advantages, disadvantages and attenuation of the ear protectors being offered? the selection, fitting, and care of protectors; and the purpose and procedures of audiometric testing. This training does not have to be acco-mplished all in one session, and infact portions of it may be ideally reviewed during the employee's annual audiometric test.

RECORD KEEPING:

Noise exposure records must be retained for two years, but data older than two years should not be discarded unless remonitoring has been performed. Audiometric test records are to be retained for the duration of the employee's service. However, consideration of future possible compensation claims suggests the advisability of maintaining such data for an indefinite duration.

So far we discussed about the Principal components of the Hearing conservation Amendment, Now the following discussion inculde examining the portions of the regulation specifically pertaining to ear protective devices. With the emphasis placed upon the OSHA prescribed methods of estimating the adequacy of ear protector attenuation.

EAR PROTECTOR ACCEPTABILITY:

We have already discussed in the previous section, the Amendment defines when a hearing conservation program must be established, when EPDs are to be made available and/or their use ia to be enforced, and to what levels EPDs must reduce employee noise exposures. However, the decision concerning which protectors to utilize is up to the program administrators. Since OSHA does not approve or certify particular devices. A product is acceptable for use if it is shown to be adequate by any of the methods utilization of those methods requires the availability of the manufact-urer's published Noise Reduction Rating (NRR) and/or octave band attenuation data at the frequencies from 125 Hz to 8 KHz.

The Methods:

There are six primary methods and three alternative methods for estimating ear protector adequacy. They are.

1) NRR with C - Weighted dosimetry.
2) NRR - 7 dB, with A - weighted dosimetry.
3) NRR with representative sampling using C - weighted sound level meter.
4) NRR - 7dB, with representative sampling using A -weighted sound level meter.
5) NRR with area sampling using C - Weighted sound level meter.
6) NRR - 7dB, with area sampling using A - Weighted sound level meter.
7) NIOSH methods 1.
8) NIOSH method 2.
9) NIOSH method 3.

Examination of the first six items reveals that they represent only two different methods of utilizing the NRR, each paired with three separate methods of estimating employee time - weighted average noise exposures (TWAs). The two NRR - based procedures will be referred to as the NRR method and adjusted NRR Method, as illustrated in Table 1.

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The list may be further simplified when one realizes that the NRR and Adjusted NRR Method, were derved from the work of NIOSH and are equivalent to NIOSH Method 2 & Method 3 respectively.

NIOSH Method I. is significantly more complex than the single number methods such as the NRR or Adjusted NRR, since it requires octave band noise data and detailed calculations for each protector/noise spectrum combination. By comparison, the NRR that is utilized in the single number methods is precalculated by the ear protector manufacturer, and is independent of the noise spectrum in question.

Comparing the Methods:

The three distinct methods for estimating the adequacy of EPDs are summarized in Table 1. They are listed in order of descending accuracy. The octave. Band Method provides a greater potential degree of precision than is afforded by the single number methods. This potential is often limited due to the poor estimate of real world attenuation that is typically provided by laboratory data.

The NRR method, as taken from NIOSH Method 2, Embodies the most accurate type of single number rating procedure, in that it requires the subtraction of the single number from a C-weigted workplace measurement to estimate an A - Weighted exposure. It is essential to use this "C minus A concept" to estimate EPD adequacy when utilizing single number rating, since the A - Weighted noise reduction provided by an EPD is inversely related to the difference between the C - and A - weighted noise levels (C - A value) in the particular environment.

Considerable accuracy is lost in estimating protected noise exposures when, as in the Adjusted NRR Method, a single number rating is subtracted from an A - weighted sound level The 7 dB adjustment that is made in the NRR Method arises from the mathematics of this less accurate computational procedure. The adjustment ensures that the errors arising from this approach are more likely to underestimate rather than overestimate the protection that would be predicted using the more precise octave - Band Method. The 7 dB adjustment has nothing to do with the differences between laboratory and real world perforamance. It is not to be confused with any constant decibel or percentage deratings of the NRR that have been proposed to account for such discrepancies.

Alternative to the Adjusted NRR

Due to the Poor accuracy of the Adjusted NRR Method it ia advisable to use the octave - Band or NRR Methods.

However, the method of noise monitoring that is preferred by OSHA is personal dosimetry, and no commercially available dosimeters currently provide C — Weighted dose assessments. A solution to this dilemma is to estimate the C - weighted noise dose from the A - weighted dosimetry - derived TWAs. Although this procedure is not explicity presented in the Amendment, it is scientifically acceptable and has been implemented elsewhere.

The Procedure is as follows:

1) Obtain an A - weighted noise dose.

2) Using a Sound level meter possessing C - and A Weighting, develop a C — A value for typical processes, areas, or job descriptions.

3) Add the C - A value to the measured A - Weighted TWA to calculate the estimated C - Weighted TWA.

4) Subtract the NRR from the estimated C - Weighted TWA.

To the extent that an accurate C - A value can be estimated, this procedure will provide enhanced accuracy over the Adjusted NRR Method for those situations in which C — weighted TWAs are unavailable.

EPA Labeling Requirements:

A point of confusion exists between OSHA's Appendix and the information which according to EPA regulations, must accompany ear protection packaging. The confusion arose since EPA chose to accomodate those users whom it feared would lack C - weighted measurement capabilities. It did this by effectively developing a two - number rating system, without ever explicity stating that fact.

The EPA method requires that the user subtract the (unadjusted) NRR from an A - weighted sound level to estimate the wearer's protected exposure. A cautionary note is included which rates: "For noise environments dominated by frequencies below 500 Hz the C -Weighted environmental noise level should be used". Thus, depending upon the particular C — A value Of the noise environment, which will increase in proportion to the amount of lower frequency energy present, the NRR is to be subtracted from either an A - or a C - weighted sound level. In practice, it matters little from which weighted sound level the NRR is subtracted when C - A values are near zero, but for noise with significant low frequency energy and therefore higher C - A values, errors of 10 dB or more can arise if the NRR is mis applied*

Unfortunately it is precisely those individuals for whom the EPA method was intended who are most likely to misuse the NRR. Since they lack C - Weighted instrumentation they will be unaware when dominent energy is present below

500 Hz, and thus will be unable to judge from which weighted sound level the NRR must be subtracted. In comparison to the NRR method, or even the adjusted NRR method, the EPA s procedure is less accurately defined, more easily misapplied and less effective at estimating EPD adequacy.

REAL WORLD ATTENUATION:

0SHA does not require that an employer estimate the actual attenuation that its workers obtain from the devices as worn. This actual or real world attenuation is known to be significantly less than published laboratory data for a number of reasons primarily involving differences in training, motivation, and utilization, between users (the noise exposed work force) and testers (laboratory subjects). The problem is well recognized by rxperts is the field, and devatings such as substracting 10 dB from published NRRs have been proposed. But, thus for there has been no consensus in the professional or regulatory communities on how to derate laboratory data, or how to otherwise account for the discrepancies.

In the hearing conservation Amendment, acknowledgement of disparities between laboratory and real world data is limited to a short note which states;

The employer must remember that calculated attenuation values reflect realistic values only to the extent that the protectars are properly fitted and worn.

This warning is crucial, since proper fitting and wearing of EPDs by the industrial work force is probably the sigle

TABLE I

Abbreviated version[9] of Table G-16a for computation of employee noise exposure.

Sound Level (dBA)	Permissible Time (hrs.)
80	32
85	16
90	8
95	4
100	2
105	1
110	0.5
115	0.25
120*	0.125*
125*	0.063*
130*	0.031*

*Exposures above 115 dBA are not permitted regardless of duration (see Table G-16), but should they exist, are to be included in computation of the noise dose.

Dose (D) = $100\,[C_1/T_1 + C_2/T_2 + \ldots + C_n/T_n]$ where C_n is the time exposed at a specific level and T_n is the time permitted at that level.

Example (1): Workday consists of 7 hours exposure to a constant level of 95 dBA; $D = 100\,[7/4] = 175\%$

Example (2): Workday consists of 1 hour @ 95 dBA
2 hours @ 90 dBA
4 hours @ 85 dBA

$$D = 100\,[1/4 + 2/8 + 4/16] = 75\%$$

TABLE II

Abbreviated version[9] of Table A-1 for conversion from Dose to TWA.

Dose (%)	TWA (dBA)*
10	73
25	80
50 (action level)	85
75	88
100 (PEL)	90
115	91
130	92
150	93
175	94
200	95
400	100

*Values rounded to the nearest dB. The exact conversion from Dose to TWA is given by:

$$TWA = 16.61 \log_{10}[D/100] + 90$$

Table I

Summary of OSHA Approved Methods for Estimating Hearing Protector Adequacy

Technique	Description
Octave-Band Method / Long Method / NIOSH Method #1 *	Mean attenuation less 2 standard deviations is subtracted from workplace noise levels at each frequency from 125 Hz - 8 kHz. Resultant values are A-weighted and summed to yield estimated dBA exposure.
NRR Method / NIOSH Method #2 **	dBC (workplace noise level or TWA) − NRR = dBA (estimated protected exposure)
Adjusted NRR Method / NIOSH Method #3 **	dBA (workplace noise level or TWA) − [NRR − 7] = dBA (estimated protected exposure)

*Three alternative names for the same technique.

**These two methods are identical except for minor mathematical differences which result in NRRs being approximately 0.5 dB less than the corresponding NIOSH methods.[5]

most difficult element to execute in a hearing conservation program. It requires not only education, training, and the selection of comfortable and effective EPDs, but perhaps more importantly, motivation, enforcement, and responsiveness to the needs of the ear protector employee.

WORKER'S COMPENSATION FOR OCCUPATIONAL HEARING LOSS

One of the most significant factors influencing the past growth in awareness of and concern for hearing protection has been the promulgation of the hearing conservation Amendment. In the future, as a result of the litigious nature of our society and recent trends in hearing loss claims, an important additional consideration may become worker's compensation (We) costs for occupational noise—induced hearing loss (OHL). This section provides a perspective on the situation by summarizing available data on the current costs of We claims for OHL, and by developing estimates of potential future costs.

STATS WORKER'S COMPENSATION PROGRAMS:

Although we programs were initially established in the early 1900's, it was not until the late 1940's that claims for OHL were first filed, and not until 1953 that proposals were drafted (in New York State) for provisions dealing spec- fically with OHL-Today, most states treat OHL as an occupa- tional disease with scheduled awards bases upon the degree of loss, although nine states still require a claimant to show "incapacity to work", "disablement", "inability to earn normal wages", or some other synonym for economic disability.

In addition to the question of whether to compensate workers based on their hearing impairment alone or to require an attendant loss of job or earnings, states also vary widely in dealing with other critical compensation considerations. These include the hearing impairment formula, waiting periods fof filling, the presence of harmful noise, presbycusis corre-ctions, choice of physician, filing time limits, apportionment of CHL among employers, and whether willful failure to use hearing protectors voids an employee's right to file for com-pensation as is now the case in certain states such as north Carolina, New Jersey, and Georgia.

IMPAIRMENT FORMULAS:

The principal factor determining worker's eligibility to fite for compensation is their audiometic profile compensation formulas include a specification of the frequencies that will be averaged, a low and high fence (The criterion hearing threshold level(HTL) at which impairment is assumed to begin and the level at which it is assumed complete), and a method of averaging the better and poorer ears. Since OHL typically first appears in the 3-6KH2 range, the aritical factor is whether or not frequencies above 2KHZ are included in the ave-raging process. This can influence the percentage of a given population that is compensable by upto a factor of three.

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Although sixteen states still employ the old AAPP (1959) formula which averages 0.5,1, and ZHKZ (Low fence = 25 dB re ANSI.53.6 - 1969), nine states have adopted the new AAO (1979) formula which averages 0.5,1,2, and 3 KHZ (same fence) in an attempt to better reflect the difficulty of hearing - impaired individuals in understanding speech in every-day listening situations. The remaining 25 states leave the formula to the discretion of the examining physician, who in most cases will follow the recommendation of the American Medical Association and utilize the AAO (1979) formula.

ESTIMATES OF ACTUAL STATE COSTS:

Most we agencies have devoted marginal resources to record keeping or statistics, only a few states publish data on compensable injuries and fewer still provide data on claims paid or denied. And the situation is even more bleak in the case of claims for OHL. The best available data on WC claims for OHL indicate that in 1977 total payments amounted to $13 million (MM) distributed across, 6,095 claimants. This was less than 3 tenths of 1 percent of the $ 6 billion (B) total U.S. costs for worker's compensation.

Shampan reported that by 1983 claims activity began to change significantly. Based upon a nationwide survey of We administrators and responses from almost 40 officials, he estimated that claims had increased in over 13 states. Nine states reported in excess of 100 claims, versus only 5 states reporting that many in 1977. Natable exceptions were New Jersey

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and californea (the states with the largest claims activity in 1977) which actucally reported fewer claims in 1983, probably due to changes in the New Jersey filing and payment procedures, and in californea due to data collection and reporting methods.

ESTIMATES OF POTENTIAL FUTURE STATE COSTS:

A few authors have estimated the potential future costs of state We claims for OHL. Their estimates, which typically can be assumed to be cumulative totals for the next 40 years have varied from $6B, to $9, 63, and as high as $20B (unclean, but probably aho includes federal employees). The best documented value was Ginnold's 10 year projection of $365 MM was based on estimates of actual We payments in 1977. Due to scant available data and the different assumptions invoked by the various authors, the diveragence is not suprising.

This section illustrates one method of estimating the potential We liability. Data have been assembled from the most current sources and estimates developed bases upon the AAO (1979) impairment formula which is likely to become the most widely adopted state We formula in the coming years.

Presented as Table 1 are various estimates of the total noise-exposed U.S. work force (minus those employed in agricuture and by state and local governments). Approximately 7.9MM production workers are exposed at or above a TWA of 85 dBA. Since 40 years represents a typical working lifetime and it can be assumed that an equal propotion (1/40) of the work force is likely to file for We benefits each year, the number of workers must be divided by 40 to estimate annual potential costs.

The percent of the noise-exposed population that is compensable is estimated from the data of Royster, et.al., for 10,000 North Carolina production workers. The population, with mixed racial and sexual proportions, was drawn from environments that included engineering shops, power plants, metal working, furniture, textiles, printing, and tobacco manufacturing. A representative portion (10%) of office workers and other low noise exposed employees were also part of the data base.

The Royster, Et. al. data indicate that about 6.2% of the noise-exposed work force are compensable by the AAO (1979) formula, vs 3.6% by AAOO (1959). By comparison, Heffler found 12.5% of 8,953 industrial employees in nine different states were compensable under the formulas of their states, and in one selected population of high-noise-exposed white-males as many as 27% were found to be compensable. Thus, the Royster, Et.al data are probably conservative, and an upper estimate of potential compensation can be obtained by multiplying their figures by a factor o/ from two to four.

The Royster, Et al. data, reproduced as Figure 1, provide an exect determination of the potential dollar cost of

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compensation per employee per $1000 of maximum allowable compensation for the work force they studied. Assuming that the noise exposures and hearing protection practices of that work force are representative of overall industry their, data may be used to compute compensation costs for any group by determining the relevant impairment fence and the maximum allowable compensation for total impairment.

The value read from the Y-axis in figure 1 can be converted to estimated dollar costs for a target population by multiplying it by the number of employees in the target group and then multiplying that product by the ratio of the maximum allowable compensation divided by $1000. For example, using the AAO (1979) formula, the Y-axis value is $8.5/ employee/$1000.

The average value of the maximum compensation for total binaural hearing loss was computed from data for the 43 states with scheduled payments that value, $37,000, has been growing at about 17% year over the past 10 years; a conservative increase of 9% year was used for the 10-year projection.

Thus the estimated potential WC costs in 1984 are?

$$\$8.5 \times \frac{7{:}900{,}000}{40} \times \frac{\$37{,}000}{\$\ 1{,}000} = \$62\ MM$$

This will rise to $112MM in 1993 for a 10-year projected cumulative total of $871MM. The estimated potential costs for 1977 would have been $34MM, compared to estimated actual payments in that year of $13MM. This suggests that about 40% of those who could have filled in that year, did so. Assuming the estimated potential costs may be conservative by a factor of up to four, the actual percentage of those who could have filed claims in 1977 that actually did so may well have been only about 10%.

STATE WORKER'S COMPENSATION TRENDS

Factors not yet accounted for that could tend to affect future claims are:

a) Waiting periods to file have and are being reduced in many states, and/or the use of hearing protectors is being considered the same as being removed from the noise. This dramatically minimizes a significant impediment to filing.

b) In the short term, hearing conservation regulations and the consequent increased concern for the hazards of industrial noise exposures are likely to increase claims activity by heightening awareness of employees and attorneys regarding WC for OHL. However, the long-term results should be the apposite as more effective hearing conservation programs decrease the incidence of OHL.

A RSCENT EXAMPLE:

A unique approach to evaluating WC claims was recently implemented in Georgia, where 22 potentially compensable former employees filed claims after the shut-down of their plant. Two technical experts used the proposed 150/DIS 1999 hearing loss model to estimate the potential total hearing losses of the exposed population. The observed losses among the exposed workers were consistent with the predictions of the 150 model based upon their known industrial noise exposures.

Analysis of the hearing conservation program established that the employer had not provided adequate hearing protection or sufficient user training, nor enforced its utilization. Therefore, the population was judged to have been inadequately protected. Based upon this conclusion, all of the potentially compensable employees who filed claims were awarded compensation as calculated under the Georgia hearing impairment formula.

FEDERAL AND MILITARY WORKER'S COMPENSATION:

In the government, WC is and will probably continue to be an even costlier program than for industry, and unlike the state programs actual costs are readily available. OHL compensation for nonmilitary federal employees and civilian military exmployees is covered by the Federal Employee's compensation Act (FECA), and for longshoremen, maritime workers, and private shipyard workers by the longshoremens and Harbor worker's program, although claims data are only available from the former program. Military compensation is covered by the veterani's Administration (VA).

An indication of the civilian and military noise-exposed personnel is given in Table 1. They amount to about 13% of the private sector noise—exposed work force.

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CONCLUSIONS:

The estimated future hearing-related worker's compensation costs, which are summarized in table II, amount to $3.4B over the next 10 years. According for the conservative nature of the state-Wc estimate, this figure could rise to nearly $6B. For individual high-noise industries, particularly those with poor or nonexistent hearing conservation programs, the costs can be considerably higher than would be predicted from these averaged data, especially if mass filings occur subsequent to layoffs or plant closings.

Thus, the potential financial costs of worker's compensation are likely to provide an additional incentive for improved hearing conservation practices. And finally, as has been repealedly illustrated, when. Employees learn to annual testing (i.e., the "learning effecr) the potential costs of compensation can be reduced, highlighting yet another benefit of hearing conservation programs and industrial audiometry.

TABLE I

Number of people (in millions) exposed to occupational noise levels at or above a TWA of 85 dBA and/or 90 dBA.

	NIOSH[1]	OSHA[2]		EPA[3]	
	≥90	≥90	≥85	≥85	Total
Manufacturing, utilities	2.5	2.9	5.2	5.1	14.9
Construction	0.4	—	—	0.5	3.5
Mining	0.1	—	—	0.4	0.8
Transportation	0.4	—	—	1.9	2.6
Subtotal (production workers)	3.4	—	—	7.9	21.8
Dept. of Defense (military & civilian)	—	—	—	1.0	3.0
Grand Total	—	—	—	8.9	24.8

1 From ref. 18; NIOSH estimated that 15% of production workers were exposed > 90 dBA.

2 From ref. 1, based on 1975-76 Bolt, Beranek, and Newman (BBN) study and updated by OSHA using 1980 Bureau of Labor Statistics employment data. Estimated that 19% of manufacturing workers were exposed ≥90 dBA and 34% exposed ≥85 dBA.

3 From ref. 19, also based on 1975-76 BBN study. Manufacturing and utilities data are the same as OSHA's. Independent estimates for other categories. "Total" represents entire specified group without regard to noise level.

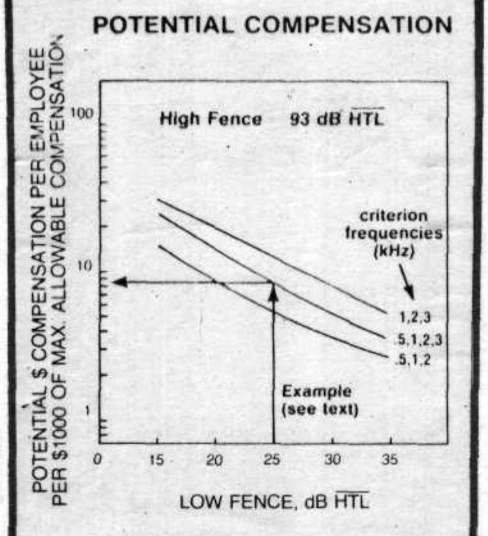

Figure 1

TABLE II

Estimated 1984 and cumulative 10-year projection for occupational hearing loss claims.

Payer	Costs (in $ millions)	
	1984	1984-1993
States[1]	62	871
FECA[2]	27	339
Military[2]	166	2,158
Total	255	3,368

1 Estimated potential costs; see text.
2 Projected from 1977-1983 data; see text.

MOTIVATING EMPLOYEES TO WEAR HEARING PROTECTION DEVICES

There are evidences suggesting that reduced employee noise exposures could have tangible health and safety benefits in addition to protecting employee hearing. Although this could provide an incentive for stronger management support of hearing conservation programms (HCPs), other approaches are necessary to motivate employees to conscientiously utilize hearing protection devices. A review of the literature suggests that the pivotal chara-cteristics of a successful HCP are support of management, enforcement. Education, motivation, comfortable and effe-ctive EPDs.

Support by all levels of management is crucial since it sets the tone for the entire program. It demonstrates to employees that hearing conservation is important to their company and to their cbs. Hearing conservation should be viewed as an important and integral part of the overall safety program. Further more, management must be responsive to employee problems and complaints so that they can be sincerely and effectively answered.

The next three elements of an HCP are inextricably related. Education and motivation modify employee's behaviour, and enforcement provides a constant reminder about that which is deemed acceptable. Enforcement alone can engender resent-ment and attempts to circumvent HCP requirements, as for example, modifying EPDs, for greater comfort and less protection

Enforcement must be firm and consistent. A four step disciplinary procedure for failure to wear EPDs might consist of (3) Verbal warning, (2) Written warning, (3) brief suspension, no pay, and (4) termination. Although the latter steps are necessarily a form of discipline, the verbal warning can and should be handled in a +ve manner. Front line supervisors should also be held responsible for the performance of their employees and must set a good example by regularly wearing their EPDs when in posted areas. In fact, all personnel in hearing protection posted areas should wear EPDS, be they visitors, managers, or temporary employees.

Education should consist of topics pertaining to the function of the ear, how it is damaged by noise, and training on use of EPDs. Many short films are available which are useful to highlight these topics and maintain employee interest. Posters are also useful as reminders and training aids. These are generally available from EPD manufacturers. An example appears in Figure 1.

Unfortunately, education alone is of little value unless it is integrated into the employees' daily experiences. This can be accomplished by making their education personally relevant, either by demonstrating how noise directly affects them or by inducing them to use hearing protection for a long enough time to become adopted, and to appreciate its benefits.

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MOTIVATIONAL TECHNIQUES:

The best motivational resource is the person or persons in the HCP who are responsible for direct employee contact, those who fit HPDs, and administer monitoring audiograms. The annual or biannual audiomtetric Examination provides an excellent opportunity for this person to reinforce good EPD utilization habits. The employees should bring, or preferably wear, their ear protectors to the test where they can be examined for fit, cleanliness, and signs of deterioration or abuse. After the audiogram is administered, it should be shown to the individual and the result's explained. If, for example, the hearing levels are normal and unchanged from previous tests, and the EPDs are in good condition, the individual should be complimented, on the other hand, significant hearing level shifts, should they occur, can be pointed out. This provides an ideal opportunity for reinstruction of EPD fitting procedures and a reminder of the importance of their use. Worn out or abused EPDs should also be replaced at this time (and generally more often).

A very successful behavioral modification approach utilizing employee audiograms has been discussed by Zohar, et al. Workers underwent audiometric testing at 500, 2000, 4,000, and 6000 Hy. Testing occurred on randomly selected dates, at the beginning and end of regular shifts. Results were discussed with the employees immediately after the second test, with significant shifts being explained as representing a temporary

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noise-induced hearing loss. Employee participated in these tests on two separate days, wearing hearing protection one day and none on the other. Audiometric results were also posted on the department fulletin board. This information feed back procedure demonstrated to the employees the effects of noise on their hearing. The feed back lasted only one month, but successfully modified employee behaviour end continued working after cessation of the treatments as shown in figure 2. A control group at the same plant, which recieved only educational sessions without feedback, showed no change in their EPD utilization rate.

Schmidt etal, reported a significant observation that provides additional support for their results. They had access to employee audiometric records for the ten years that were studied. Analyses of these data indicated that the females were wearing their EPDs more effectively and receiving better protection than were the males. Therefore, it would be expected that they should show a greater reduction in industrial inries than did the males. The data confirmed this hypothesis, thus closely linking EPD usage to the rate of industrial injurie

CONCLUSION:

Only tenative conclusions may be drawn from the available literature, but the inference exists that elevated noise exposures may cause extra-auditory physialogical and/or psychological disorders. This suggests that affective HCPs may not only prevent noise induced hearing loss, but also improve general employee health and productivity.

FIGURE 1

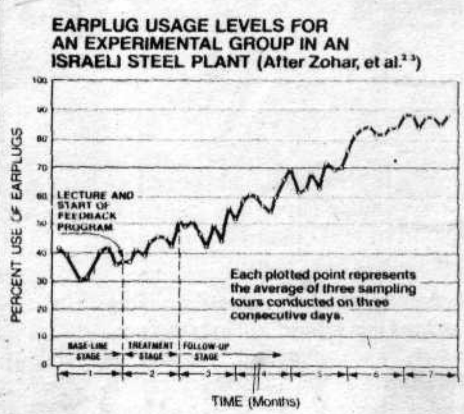

FIGURE 2

THE EFFECTS OF EAR PROTECTORS ON AUDITORY COMMUNICATIONS

Ear protective devices reduce user sound exposures when properly worn. This means that all sounds may be attenuated, both unwanted sounds (noise) and useful sounds such as speech and warning signals. Thus wearing EPDs may affect speech discrimination, and the perception of warning signals.

SPEECH DISCRIMINATION:

Speech discrimination (SD) is a measure of one's ability to understand speech. It is greatly affected by such factors as a persons* hearing acuity, the signal (speech) - to - noise ratio, the absolute signal levels, visual cues (lip and hand motionl,) and the context of the message set. SD is measured by presenting to subjects one of a number of prepared word lists, and determining what percentage correct responses they achieve. The effects of EPDs on SD can be evaluated by establishing a set of test conditions, and measuring SD with and without SPDs on the subjects. The results of such tests conducted by many investigators may be summarized as follows:

1. EPDs have little or no effect on the ability of normal hearing listeners to understand speech in moderate background noise 80dBA, but EPDs begin to decrease SD as the background noise is reduced even further. EPDs will decrease SD for

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hearing impaired listener's in law-to-moderate noise situations,

2. At high noise levels 85 dBA EPDs actually improve SD for normal hearing listeners. This is clearly demonstrated in Figure. 1 For hearing impaired listeners the effect of BPDs on SD at these high noise levels is not unequivocal, but the results seem to indicate no significant effect.

3. The literature is not extensive enough to differentiate between the effects of earmuffs and earplugs on SD. Never-thless, it may be said that the higher attenuation devices, be they earmuffs a earplugs, offer greater potential for degrading SD at lower sould levels.

The beneficial effects of EPDs on SD can be partially explained by referring to figure 2 in which the spectrum of a male voice is superimposed upon a typical industrial noise spectrum of 91 dBA. It can be noted that although the EPDs attenuation increases with increasing frequency, at any one frequency both the speech and the noise are reduced equally. The signal to noise ratio is consent, but importantly the overall signal level is reduced. This prevents the ear itself from distorting the signal, a phenomenon which occurs even at levels well below 90 DBA. Thus as long as speech signal is maintained above audibility, intelligibility can be improved by restricting signal levels to those that will not overload the ear.

The proceeding generalizations may be modified in practice by three important factors. Typically, in real work environment

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communications will be accompanied by visual cues and/or be limited in scope. Missed words can be "filled in" and intelligibility maintained. Howell and Martin have shown that when the person speaking wears EPDs his speech quality is degraded and this will adversely effect communications. And finally, Acton has demonstrated that employees get accustomed to listening in noise and can perform better with respect to SB than do laboratory subjects with equivalent hearing levels. The interaction of these three effects has not been fully evaluated by any one author, but RinK has shown that visual cues do improve SD for hearing impaired persons wearing EPDs, especially in noise.

LOCALIZATION:

Another effect that EPDs can have is to confuse one's ability to locate the direction of origin of sounds. The data indicate that earmuffs, which necessarily cover the entire ear, can interfere with this localization accuracy whereas inserts, which generally leave virtually the entire outer ear exposed, do so to a much lesser extent. Furthermore, experiments with earmuffs indicate that subjects cannot adopt to this effect, 1.$., they cannot learn to compensate for the adverse effects of the muff.

AMPLITUDE SENSITIVE INSERT HEARING PROTECTORS:

Amplitude sensitive or nonlinear inserts are designed to provide attenuation that increases with increasing sound level, so that for low level noise conditions there is little attenuation and SD can be improved. Basically these devices are insert protectors provided with a small orifice running longitudinally through the body of the plug. The orifice may contain values or acoustical damping materials.

At sound levels below 110 dB these devices simply behave as a vented earmold with almost no attenuation below LKHz and attenuation increasing to as much as 30dB at higher frequencies. At high sound levels (140 dB), steady-state or impulsive sound waves generate turbulent air flow in the orifice which impedes the passage of sound. Measurements of gunfire impulses in cadaver ears have verified that the peak noise reduction increases from approximately 10dB for 140 dB peaks to 20 dB for 180 dB peaks. For one particular nonlinear device. Combining this information with impulse noise damage risk criteria indicates that these devices should be effective for limited exposures (20 rounds per session) to gunfire noise upto 175 dB peak SPL. Measurements of the human subjects exposed to such noise, in nonreverbernt spaces, verify this supposition. Unfortunately these devices are of little value for many occupational and recreational noise exposures wherein the noise is levels are rarely the appropriate type or sufficient level for these devices to become functional.

In summary, the proceeding data indicate that EPDs can be effectively utilized for the preservation of hearing in

SPEECH DISCRIMINATION AS A FUNCTION OF NOISE LEVEL AND SPEECH LEVEL, FOR EARPLUGS vs. NO EARPLUGS

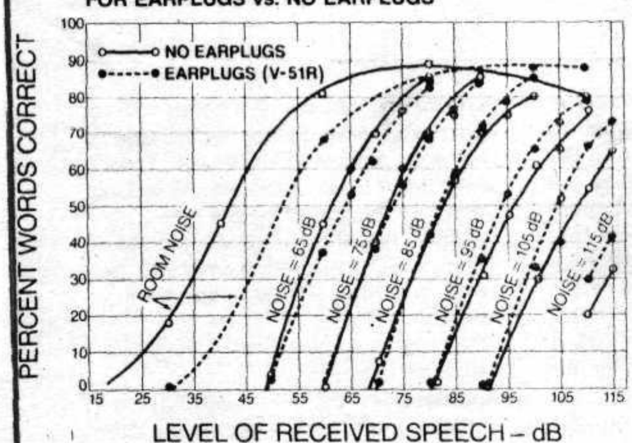

Figure 1

EXAMPLE OF THE REDUCTION OF SPEECH AND NOISE LEVELS THROUGH THE USE OF A PRE-MOLDED INSERT HEARING PROTECTOR

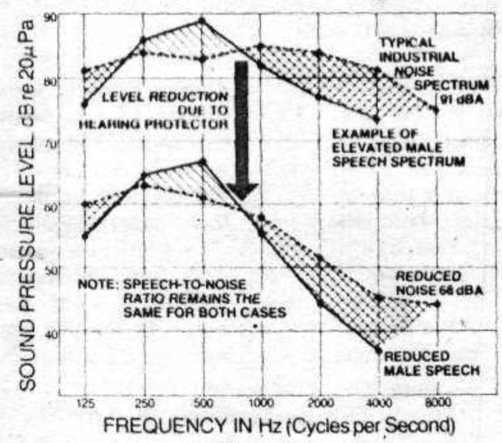

Figure 2

high noise level environments with minifal effects on SD. For hearing impaired. The utilization of EPDs in lower noise level environments should be carefully considered. If localization capabilities are important then inserts should be chosen instead of earmuffs. And finally the use of amplitude semitive devices may be advantageous for use on firing ranges where they have been 3hown to provide adequate protection for limited exposure.

THE PERFORMANCE OF HEARING PROTECTORS IN INDUSTRIAL NOISE ENVIRONMENTS

Characterization of the attenuation properties of hearing protection devices (HPDs) or Ear protective devices (EPDs) is most often accomplished in the Laboratory by examining the performance of trained and motivated subjects using optimally fitted EPDs. The crucial question is - How does this relate to the real world? And the obvious answer- poorly. Employees are seldom adequately instructed in the correct utilization of TPDs and even less often properly motivated to wear them. And if devices come in multiple sizes or are uncomfortable to wear, the problem is compounded.

In the past few years a number of studies have been conducted that shed some light on the matter of real world (RW) performance, i.e., performance for employees in industrial noise environments. In this section we can discuss some of the more significant findings, and integrate the data to yield some interesting conclusions.

LABORATORY APPROXIMATIONS OF REAL WORLD PERFORMANCE:

When a EPD is tested in a laboratory, the procedures, if modeled after actual usage conditions, can yield results indicative of RW performance, waugh, of the National Acoustical laboratories (NAL) in Australia, has attempted to do just that* In a recend publication, the NAL reports attenuation data for 75 earmuffs and 19 inserts that were all tested at that facility.

The NAL has a subject pool consisting of 35-40 of its employees. The EPDs are tested on 15 people, 1 time each, Devices undergo a series of physical tests (vibration, impact, temparature cycling, etc.,) prior to being tested for attenuation. Subjects are given the manufacturer's instructions and very little experimenter supervision. The test procedure is an absolute threshold shift method similar in detail to the ANSI Z24, 22 standard, with the data corrected to 1/3 octave band values.

The NAL tests yield lower mean attenuations and higher standard deviations than data gathered for manufacturers in U.S. testing laboratories. As the following discussion will show, the data from NAL can be used to make good engineering approximations of the RW performance of EPDs.

IN-FIELD MEASUREMENTS OF RSAL WORLD REFORMANCE:

An alternative approach to answering the question of how well EPDs actually perform in use, is to take the threshold shift experiment to the subject. Alleast three experimenters have done this by setting up their measurement facilities at industrial plant sites and using noise exposed employees as their subjects. Although the employees were aware that they would be subjects, they were not aware of the exact times of their tests and were carefully monitored to assure that they did not readjust their protectors once they had been notified to proceed to the test booth.

The three studies that will be considered included 613 subjects at 7 different plant sites using 5 inserts and 1 earmuffs. Although the 3 studies varied in their exact measurements techniques, appropriate controls were incorporated to insure the validity of the results.

In Fig. 1-4 mean attenuation data for 4 devices as measured via different methods is presented* In figure 1 we see very good agreement between the NIOSH-and Padilla field studies at 500 Hz (Padilla only measured at 500 Hz) we see that the field attenuation data are only about 40—60/ of the decibel values of the manufacturer's reported attenuation data. NAL's data fall between these two data sets, only about 5 dB above the field data, except at the two highest frequencies. Remember although NAL uses very minimal subject Iinstruction, they do fit multi-sized plugs correctly whereas it is likely that missizing often occurs in the field.

Figure 2 shows similar results, this time for Swedish wool, with very good agreement between NAL and field data, except again at 4Kz and 8KHz.

Figure 3 compares Regan's field data for an earmuff to NAL data. This time, agreement is again good (within 4dB) except at 500 Hz where NAL data are low. It is important to note that this result shown that standard laboratory data also overestimate the RW performance of earmuffs. This has also been confirmed in a soon to be released MSHA study that used miniature Microphones to measure earmuffs performance in the field. The results indicated performance at only 20-75% of the decibel values of the laboratory data with larger discrepancies at lower frequencies.

Figure 4 shows comparison data for foam earplugs. The field data, from Regan, are for foam earplugs that were early prototypes, sold in limited quantities, and considerably more difficult to use than the present model available since 1974. His data were corrected by 1 to 5 dB, by using laboratory data comparing the prototype and current model foam plugs. The "corrected" foam data agree well with NAL data and demonstrate attenuation of 60—90% of the manufacturer's reported data. Also of interest in Fig. 4 are the three points marked by diamonds. These are preliminary data for 30 subjects from the E-A-R. Division Acoustics laboratory. The data were gathered in strict accordance with ANSI 53.19 procedures but with instructions and subject selection intended to simulate RW conditions. Note the excellent agreement with the NAL data and very good agreement with Regan's field data.

Figure 5 and 6 depict standard deviation data for the various devices measured via the four feat methods. The general trend is for the field and NAL data to be in reasonable agreement and both somewhat higher than manufacturer's laboratory data. That this is not always the case is partially explained by the fact that the standard deviation tends to vary in promotion to the mean attenuation, so that devices with lower mean attenuations have a reduced expected range of attenuation values as well.

OBSERVATIONS:

1. Manufacturer's laboratory data overrate the RW performance of HPDs. For a comfortable protector, this data can indicate the protection that conscientious, well trained users will receive. For an uncomfortable device it is virtually meaningless.

2. Manufacturer's laboratory data are useful for research and development and may yield an indication of the rank ordering of various EPDs.

3. Laboratory experiments such as the NAL work, which are designed to simulate RW performance can provide useful indications of the actual attenuation typically provided by EPDs.

ANOTHER ESTIMATE OF REAL WORLD PERFORMANCE:

Another method of investigating the actual protection afforded employees by the EPDs that they are using, is to measure their hearing levels before and cyter a workday's noise exposure. Royster has just completed and reported on such work. His subject population consisted of 101 employees in two very different acoustical environments at two different plant sites. Seventy of the subjects (population A) worked in a textile paint with steady noise levels at an Leq=95 dBA. The other thirty-one subjects (population B) worked in a steel plant with intermittent noise levels, but the same Leg=95 dBA. During the experiments, the textile workers wore either a V-SIR type insert or a foam plug. The steel workers wore either a foam plug. The steel workers wore either a 3-flange plug (Norton) or a foam plug (E-A-R plugs) for the first four hours of each work shift. Population B employees wore no hearing protection in the afternoons as per company policy.

All subjects participating in the study had been wearing the pre-molded inserts for atleast 4 years as part of the ongoing hearing conservation programs at these two companies. On the day of the test, the subjects that were selected to wear E-A-R plugs instead of their standard EPDs, were handed the plugs and given only 15—30 seconds of instruction on utilization of the device.

A comparison of the measured change in mean hearing level over an 8 hour shift (i.e. temporary threshold shift (TTS) for population A for the two SPDs is shown in figure 7. The comparison for population B is shown in Fig. 8, this time using date for a 4 hour shift. Notice the differences between the performance of the foam plug and the pre-molded inserts, which are significant at 2,3, and 6KHz for population A and at 2,3,4 and 6KHz for population B (P .05). The fact that population B employees who used the foam ear plug show

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improved hearing due to the elimination of TTS. This small residual TTS could be due to the in-adequate protection received from the 3-flange inserts combined with the unprotected 4 hour afternoon exposures which these employees received.

Royster concluded from this data that the V-51R and 3-flange inserts were unacceptable for use in noise environments with daily A-weighted Leq Equal to or greater than 95dB. Analysis of the existing 4-9 years of audiometric data.for those two populations supported this contention. Furthermore Royster determined that the foam earplug would be acceptable for use in these 95dB environments and is currently conducting a longitudinal survey at one of the plants to verify this supposition.

SINGLE NUMBER RATINGS APPLIED TO REAL WORLD DATA:

Already the concept of single number EPD ratings has been discussed and an explanation of the EPA proposed NRR values are presented. The NRR incorporates a 2 standard deviation (20) correction and a 3dB spectral safety factor. These corre- - ctions are intended to insure protection for 98% of the population who "correctly" wear the SPD in 98% of the environments where the devices will be used .Correctly" have means, wear the EPD in the same manner as did the subjects who were used to generate the test results.

In Table 1, the NRRs for the four EPDs that have been discussed namely V-51R, Swedish wool, Earmuff, Foam Insert are presented. These NRRs were calculated using the manufacturers laboratory data as well as the NAL data. It has been noted that for two devices the NRR based on the NAL data is 1. This simply says that if we wish to examine the least possible protection we are likely to find (i.e. only 2% of the population will receive less protection than this) that the overall protection provided by these two devices is virtually zero.

It may be that with RW or estimated RW data, a20 correction is too severe and that we should examine a 1 correction (84% protection, i.e. 16% will get less than this number). These values are also shown in Table 1. (In fact, the single number rating listed in the NAL report is the SLC, which is very similar in concept to the NRR, except that it uses a 1 correction and lacks a spectral safety factor). Even these more "optimistic" values demonstrate that certain insert protectors may be suitable for noise exposures only slightly greater than 90 dBA, a supposition substantiated by the Royster study cited above.

CONCLUSIONS:

There appears to be a less than adequate correlation between manufacturer's (laboratory) attenuation data and the RW performance of EPDs. Suitably designed laboratory tests, such as the work performed by the NAL, can provide reasonable estimates of RW performance comparison between NAL data and in-field data from three authors substantiates this fact. This is an important point, because it suggests that existing EPD test methodologies, such as FINSI 53.19 1974 can be effectively utilized with only simple modifications regarding subject selection, training, fitting and LPD preparations procedures.

The NAL and in-field data suggest, for example, that the E-A-R foam earplug should be more effective in use than other insert hearing protectors. This was confirmed independently by an in—field TTS study which found that E-A-R plugs performed significantly better than V—SIR and 3—flange inserts in a 95 dBA noise environment.

Finally, if a single number rating is to be used with RW type data, such as the NAL data, perhaps a 1 insetead of a 2 correction is more appropriate. This suggestion is reasonable, since an attempted 98% protection criterion may be leasible if unrealistically high laboratory data are utilized, but is certainly extreme if RW estimated data are developed and used for NRR calculations.

ATTENUATION DATA FOR V-51R INSERT PROTECTOR BY FOUR METHODS

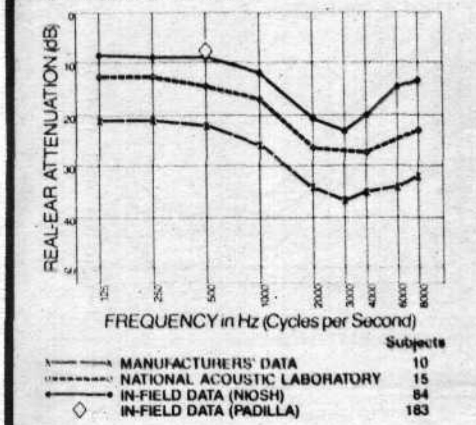

Figure 1

ATTENUATION DATA FOR SWEDISH WOOL INSERT PROTECTOR BY THREE METHODS

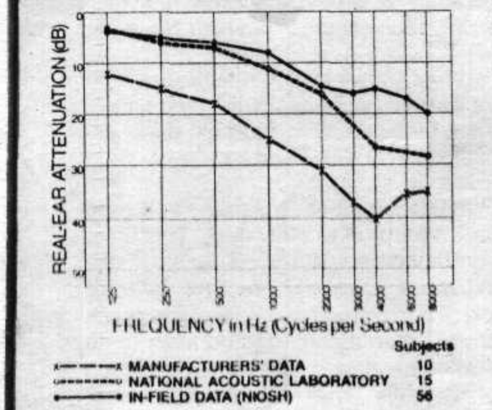

Figure 2

ATTENUATION DATA FOR EARMUFF PROTECTOR BY THREE METHODS

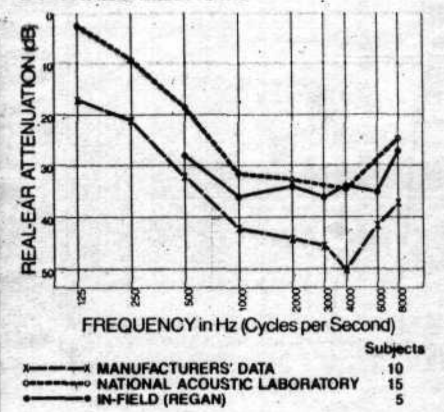

Figure 3

ATTENUATION DATA FOR FOAM INSERT PROTECTOR BY FOUR METHODS

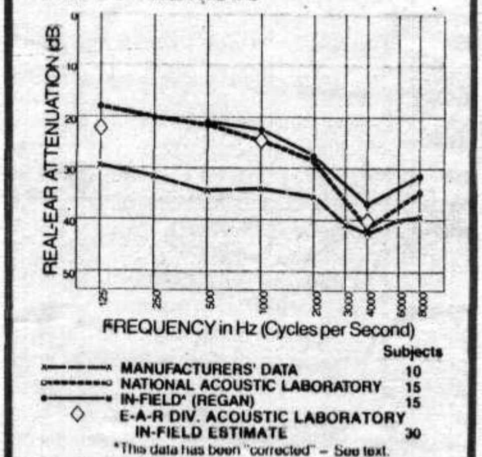

Figure 4

STANDARD DEVIATION DATA FOR TWO INSERT PROTECTORS BY FOUR METHODS

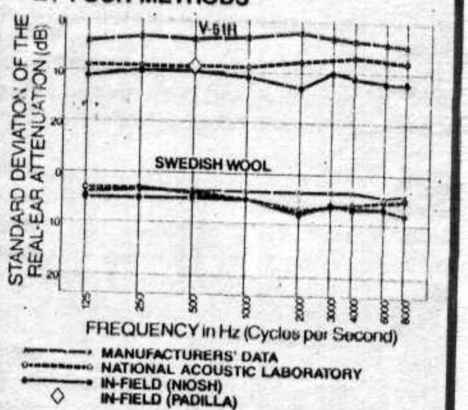

Figure 5

STANDARD DEVIATION DATA FOR AN EARMUFF AND AN INSERT BY FOUR METHODS

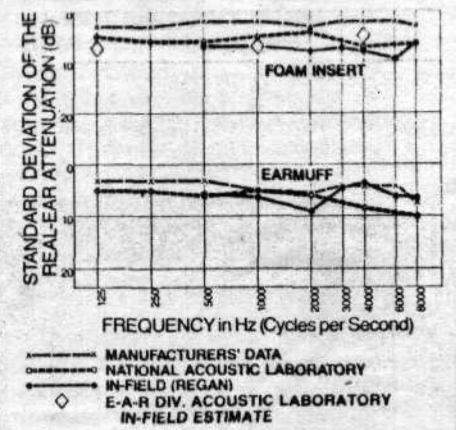

Figure 6

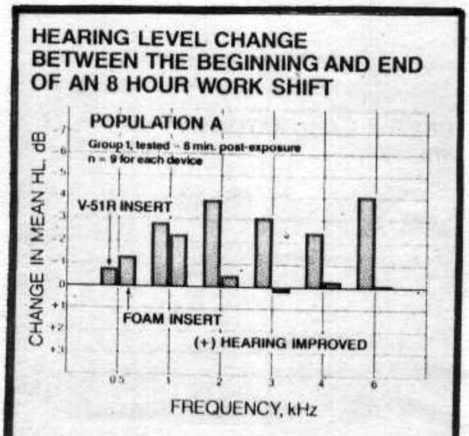

Figure 7

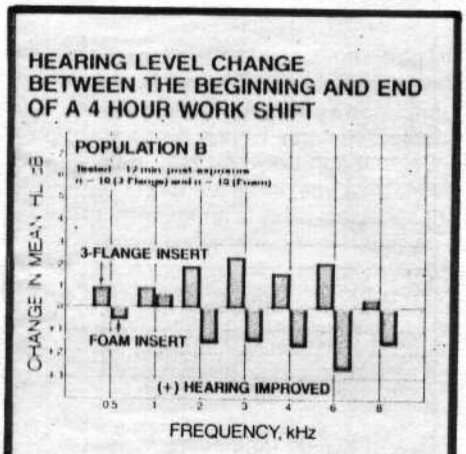

Figure 8

TABLE 1

NRR VALUES BASED ON MANUFACTURERS' LABORATORY DATA AND NAL DATA

HEARING PROTECTOR	NRR^{*}_{MFG}	NRR^{**}_{NAL}	$NRR^{***}_{NAL,\,1\sigma}$
V-51R	18	0	9
Swedish Wool	16	1	6
Earmuff	25	6	13
Foam Insert (E-A-R Plug)	29	14	19

*NRR based on manufacturers' laboratory data with 2σ correction.
**NRR based on NAL data with 2σ correction.
***NRR based on NAL data with 1σ correction.

PROTECTION FROM INFRASONIC AND ULTRASOMIC NOISE EXPOSURE

When noise is assessed for its hazardous and for annoying effects attention is normally limited to frequencies within the range of audibility. However, there are situations that arise in which acoustical energy outside the nominal audible range may become important. If at those times the use of hearing protection devices is required, hearing conservationists are at a disadvantage since EPD attenuation measurements conducted in acordance with standardized methods are normally limited to the frequency range of 125Hz—8KHz. So here a small attempt is made to address the problem by not only providing extended-frequency attenuation data for a representative sample of devices, but by also briefly discussing suggested limits for exposure to very low and very high frequency acoustical energy.

DEFINITIONS:

Although the range of audible frequencies is classically defined as extending from 20Hz to 20KHz, sounds of sufficient intensity can be aurally detected at both lower and higher frequencies. Acoustical energy falling outside the "audible" range is designated as either infresonic (below approximately 20Hz) or ultrasonic (above approximately 16-20KHz).

Infrasound can be generated by both natural and man-made events. Examples of the former are thunder, volcanic activity, winds, large waterfalls and the impact of ocean waves, whereas examples of the latter are high-powered aircraft and rocket propulsion systems, explosions, sonic booms, bridge vibration, ships, and air beating and cooling equipment. Airborne ultrasound can be generated by a wide variety of industrial processes, including cleaning, drilling, welding plastics, mixing, and emulsification. Infra-and-uitrasonic acoustical energy do not usually occur in the audible range due to the nature of the processes by which such sounds are generated.

EXPOSURE LIMITS:

Currently, there are no U.S. or international standards defining permissible exposure limits to infrasound. However, von Gierke and Nixon present an excellent review of the topic area. Since they found that "infrasound, which is not subjectively perceived in some way, has no effect on performance, comfort, or general well-being", they developed proposed limits with respect to the safety and preservation of the auditory system. Their 8-hour. Exposure limits range from 136 dB at a low frequency of 1Hz to 12d dB at the upper end of the infrassonic range (20 HZ). The limits may be approximately adjusted for shorter or longer duration expsoures using a 3-dB exchange rate, i.e., if the duration is halved, the level may be increased by 3dB, and vice versa.

Exposure limits to airborne ultrasound have been recommended by a number of national and international organizations.

The available data and the exposure criteria have been reviewed and summarized by Acton. The criteria are similar, typically limiting exposures to 110 dB SPL for the frequencies at and above 20KHz, which has been trnslated to a 1/3 actave band criterion of 110 dBSPL for the bands at and above 25 KHZ, and 75 dB SPL for the 20-KHZ 1/3 octave band.

The criteria for the high audio frequencies (upto approximately 18 KHZ) are based upon subjective and psychological rather than auditory effects-an unpleasant sensation of fullness or pressure in the ears, headaches, in-head localization, and possibly nausea and fatigue-since they are the more sensitive indicators of potential harm in that range. Above 18KHZ the limits are intended to avoid potential hearing loss in the audio frequency region that could result from the generation of lower frequency aural distortion phenomena result from nonlinear processes. Thus it is questionalble whether ultrasonic exposure criteria are amenable to adjustment via an exchange relationship such as the 3-dB rule, although some groups have made such proposals.

EPD ATTENUATION AT LOW AUDIO AND INFRASONIC FREQUENCIES:

In the frequency range below 50HZ available attenuation data appear to be limited to only one study. The authors utilized both subjective (real-ear attenuation at threshold, 35-500 Hz) and physical (Microphone in earmuff, 1-500 Hz) measurement methods. Representative data are shown in Fig.l

They indicate generally constant attenuation from 30 Hz to 100 Hz, with very limited protection or even amplification for the infrasonic frequencies. The data confirmed subjective impressions also reported by the authors.

No measurements were conducted on insert-type protectors, but subjective reports that were cited. Suggested that a tightly sealed eanalug could provide appreciable attenuation, as would also have been predicted based upon early thoretical studies.

Although most test standards do not require testing below 125 Hz, many authors have reported data in the 50-125 Hz range. Data from our laboratory are depleted in Fig. 2,3 and 4 for insert, semi-aural, and circumaural EPDs. The results, extending down to the 80-Hz 1/3 actave band may be compared to the standard test frequency results which are also shown. All of these data, measured in conformance with ASA STD 1, indicate that the 80-and 125-Hz values are substantially similar.

EPD ATTENUATION AT HIGH AUDIO AND ULTRASONIC FREQUENCIES:

At the upper end of the audio range hearing sensitivity decreased at the rate of approximately 100 dB/octave, compared to 10-20 dB/octave (as frequency decreases) for low audio and infrasonic frequencies. This fact, combined with the relatively good inherent attenuation of SPDs at high frequencies, makes generation of ultrasonic acoustical stimuli at at levels sufficient to be detected! by hearing protected test subjects very

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difficult. As of this writing there do not appear to be any studies reporting EPD performance at ultrasonic freque-ncies and only two that even discuss the range above 8 KHz.

Representative published data combined with recent results from laboratory are platted in Fig. 2-4, EPDs were fitted by the subjects under experimenter supervision. The fitting of the vinyl foam earplug was an exception in that it was tested with two distinctly different experimenter insertions; partial (about 15-120% in thea ear canal) and standard (typical laboratory fit with 50-60% in the canal).

The data extend upto the 16-KMz 1/3 octave band, which includes energy to 17.8KHz. The bold line at the bottom of the graphs represents an estimate of the bone conduction (BC) limits to EPD attenuation.

Except for the 3-flange earplug, standard-insertion foam plug, and semi aural data, the 8-KHz attenuation appro-ximates that at 12.5 and 16KHz. For the two earplug mentioned, the highest frequency test are 8-9 dB less than at 8—KHz. This is probably attributable to the nearness with which the atten-uation of those plugs approaches the BC limits which exhibit the same apparent behaviour in that test range.

Berger also evaluated an earplug plus earmuff combination and found that in the frequency range from 2-16KHz the measured performance was essentially equal to the BC limits.

CONCLUSIONS:

EPD attenuation at low audio frequencies (down to 50Hz) cam be estimated to an accuracy of approximately 5dB by anuaning it is equal to 125-Hz data. At high audio frequencies(upto 17.8KHz) all EPDs tested were very effective, providing atleast 32 dB noise reduction. Thus, at those frequencies, exact esti— mation of attenuation becomes somewhat academic.

At infransonic frequencies earmuffs provide little or no protection and may even ampily sound, whereas properly fitted imperforate earplugs should provide appreciable protection. No ultrasonic EPD attenuation data are available, but it would be resonable to asume that the general behavior observed in the high audio range should prevail & frequencies up through 32KHz.

LOW FREQUENCY EARMUFF ATTENUATION*

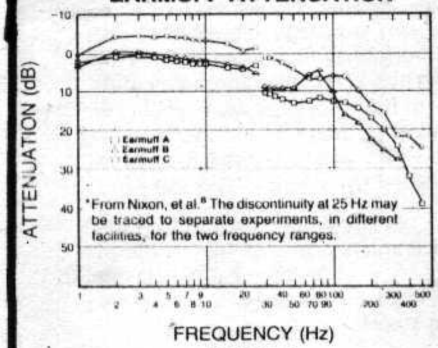

Figure 1

EXTENDED FREQUENCY DATA: EARPLUGS

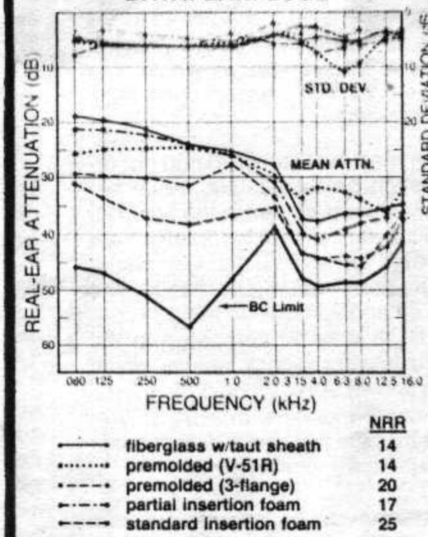

Figure 2

EXTENDED FREQUENCY DATA: SEMI-AURALS

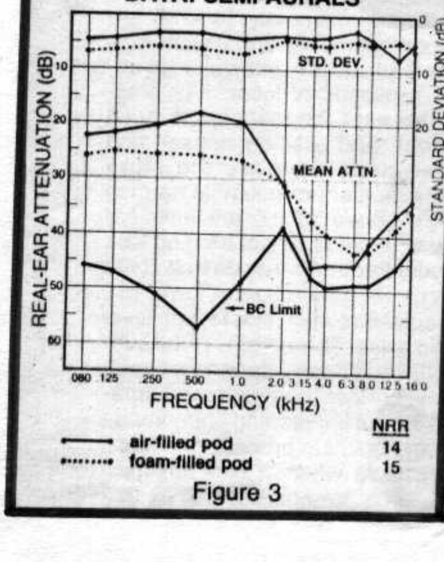

Figure 3

EXTENDED FREQUENCY DATA: EARMUFFS

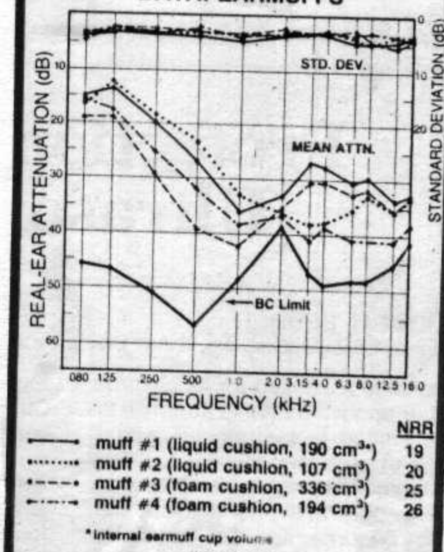

Figure 4

EAR INJECTION AND THE USE OF HEARING PROTECTION:

Documented instances in which hearing protection devices have been shown to create avral hygience problem or are the causative agent for injections of the ear canal are rarely described in the literature. Nevertheless, it is not uncommon for hearing conservationists to express concern regarding the potential for EPDs to cause ear injection, particularly in the case of earplugs. This apprehension probably arises as much from misinformation, as from observation of the fact that the ear canal, is an ideal culture environment warm, moist and dark. Now let us address such concerns by examining ear canal anotomy, discussing the etialogy and prevalence of external ear injection, and providing recommendations to minimize potential problems that can arise within occupational hearing conservation programs (HCPs).

BASIC ANATOMY:

The external ear consists of the auride (pinna), the external auditory meatus (ear cabal) and the tympanic membrane (ear drum) as illustrated in Figure 1. The pinna is a cartilaginaous shell—shaped structure attached to the skull by muscles and ligaments which ae covered by skin. The ear canal is a generally eliptical S-shaped tube, approximately 25mm(linc) long, with an average diameter of 8mm at its entrance. It is directed inwards, upwards, and slightly for words. The eardrum, which terminates the ear canal, forms an airtight and watertight barrier separating the middle ear from the external ear.

The auter half of the ear canal is cartiliginous, with an epithelial layer(skin) possessing numerous hair follicles and associated ceruminous and sebaceous glands. By contrast, the inner or medial half of the canal is asseous(bony), with skin that is only about 1/5 as thick(0.2mm) and hearly devoid of hair follicles and glands. The differences between the auter and inner portions of the ear canal in terms of pore structure and hairiness are similar to those found between the back of the hand ad the palm.

The secretions of the ceruminous and sebaceous glands, together with dead epithelial cells which are regularly cast off and replaced, combrine to form cerumen (ear wax), a water repellent substance that coats and impregnates the skin of the ear canal. This coating is one of the most important protective mechanisms of the ear. It acts as a mechanical brainer which shields the skin from exposure to excessive moisture, and its acidity provides an antibacterial "acid cloak" that inhibits the development of many of the bacteria responsible for ear canal injections.

Since the skin that lines the inner portion of the canal ia continuous with the external layer of the eardrum, the ear canal can be taught of as a skin-lined tube. This "lining migrates outwards from the center of the eardrum towards the entrance of the ear cabal at rate of about 1.5mm/month. Skin migration, combined with jaw movement, are additional self protective features of the ear in that they tend to keep the canal clear of excess cerumen and other debris.

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WHAT IS AN EXTERNAL EAR INJECTION?

The medical term that describes an inflammatory condition of any portion of the skin of the ear canal is otitis externa. This need not necessarily be an injectious process, i.e. one involving an vasion of the body by microorganisms. The infla-mmation may be caused by mechanical means(scratching) or che-mical (caustic or allergic) substances, or by biolcgic(bacterial and fungal) agents. Once he skin has bean abroded or inflamed it is easier for microorganisms to become implanted in the follicles and glands of the ear canal and for an injection to develop. Since the hair follicles and glands are almost exclu-sively found in the outer third of the ear canal, injections are also primarily limited to that region.

It is important to distinguish soreness or irritation from the above conditions. For example, irritation may develop when a new user begins wearing EPDs for extended periods of time (for this reason nes users should gradually increase their wea-ring time over a period of a cauple of we<=?ks). This type of irritation is similar to the discomfort many people experience on the bridge of the nose when they intially begin wearing glasses. The irritation will sub-side without treatment when either the irritant is removed, or the skin has adopted to its presence. In contrast, the resolution of ear canal injec-tion generally requires medical treatment.

SIGNS AND SYMPTOMS OF OTITIS EXTERNA:

Observable signs of otitis externa includes swelling and reddenning of the ear canal, a greenish-tinted discharge, and sometimes a foul adour to the ear. Symptoms include itching, pain, tenderness upon manipulation of the pinna, a feeling of "fulness to the ear" and hearing loss in those cases in which the swelling and/or discharge is serve enough to have fully, obstructed the ear canal. However, etitis externa may often be present in the absence of one or more of these signs and symptoms.

THE ETIOLOGY OF OTITIS. EXTERNA:-

The incidence of otitis externa in the general population is related to environmental or seasonal conditions, being more prevalent whan temperature and humidity are elevated and/or when recreational water. Sports are common. It has been hypathesized that prolonged exposure to water removes the protective ceruminous layer, allowing the skin to soften and absorb moisture. This leads to swelling and obstruction of the sebaceou and ceruminous glands, thus preventing replacement of the cerumen. Itching results, which may give rise to scratching and more itching, and the situation worsens.

Another common cause of etitis externa is excessive cleansing and scratching digging at the ear canal. This not only removes the protective caruminous layer and creates itching, vut may result in trauma or abrasion which further breaches the skin's protective barriers. In two separate studies of patients with otitis externa it was found that from 63-87% reported cleaning their ear canals with cotton swabs, matches, fingernails or he like.

When the surface barriers to microbial penetration are removed. Organisms that are normally found in the ear(such as staphylococcus epidermis) as well as external pathogenic bacteria(such as pseudomonas aeruginosa and staphylococcus aureus) and to a lesser extent fungi-are able to penetrate and thrive in the arifices of the epithelial glands. The inflammation then becomes more ax severe and the injection progress.

Other predisposing factors for otitis externa include allergs to chemicals or hair dyes and sprays, dermatitis, chronic draining middle ear injections, excessive cerumen(which can trap water in the canal), and systemic conditions which lower the body's resistance, such as anemia, vitamin deficincies, diabetes, and endocrine disorders. Wearing ear plug has also been suggested as a possible predisposing factor, since, their use can increase the temperature and humidity in the canal, create the potential for skin abrasion or local trauma, remove cerumen, and provide a verticla for the introduction of organisms into the canal. In one study of 139 patients with otitis externa, 9% were found to have been wearing hearing x aids. However, as discu-ssed below, available epidemoilogical studies do not generally substantiate concern regarding the potential for earplugs to increase the likelihood of developing an external ear injection.

PREVALENCE-ANECDOTAL EVIDENCE:-

As early as 1956, expert opinion syggested that "cases of external otitis resulting directly from wearing ear protectors are exceedingly rare provided the material in the ear protector is an inert non-tocic substance. Those few cases reported are more often due to failure to keep the ear protectors reasonably clean. The author's cited as evidence reports from the medical directors of three different major aircfft manufacturers. They also pointed out there were overll. million hearing aid wearers who were using their aids for periods of 12 to 16 hours per day, and among that group as well, external was quite rare.

Even today when one reviews the literature or interviews hearing conservation authorities to gather data on the prevalence of external in occupational HCPs, one is struck with the dearth of factual information. Anecdotal comments abound, but controlled studies are "conspcious by their absence". By implication the problem is neither significant nor wide spread, otherwise it would have drawn greater attention and research interest. This qualitative assensment of the situation was recently reinforced by audiologits from the workers' compersation board of British, Columbia, Where audiometric records for over 60,000 noise,exposed workers in that province have been reviewed annually for the past five years. Although they had considered conducting a study on the incidence of otitis external, the plans were never implemented due to the lack of feedback from employees and employees alike that any such problems existed.

PREVALENCE-THE AVAILABLE DATA

Table 1 summarize the date that provide a numerical estimate of the prevalence of otitis externa. Data on "excessive" cerumen are also listed, when available, although the definition of excessive is often unclear and varies with prevalence since all of the otoscopic exams were conducted by one or more physicians using both pneumatic and microscopic otoscopy. The report contains comments, by subject, for all otological abnormalities that were observed. Unfortunately, data on EPD utilization are not provided.

Forshow and cruchely reported on a study of sixty long-range patrol-aircraft crew members who were randomly divided into three groups, one wearing premoded ear, plugs, the second using foam earplugs washed after each use, and the third using foam earplugs washed only once per week. The study lasted eight weeks and included examinations by a medical officer as well as skin scrapings for bacterial culture and fungal examinations. The results indicated no fungal injections or clinically significant bacterial injections, and no differences in positive bacterial cultures across the three groups of users.

Foltner reported data from two investigations. Unfortunately in the larger of the two studies in which otoscipy was conducted by audiometric technicians(68,647 subjects), "ear disease, perforation, and occlusive wax", were grouped together. Since the other data in table 1 indicate a higher prevalence of excessive was than of or disease, it is likely that her 6% figure which is cited in the Table is dominated by that factor. This is substantiated by her other study(101 subjects) in which one audiologist conducted all of the otosclpic examinations and individually reported the data 2% otitis externa and 9% excessive("occlusive") cerupen.

Royster and Royster conducted a unique study in which they interviewed EPD fitters and issuers, or in some cases

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HCP administrators, at 3 218 sites across the continental U.S. interviewees were asked to "describe any type of problems you have observed with the wearing of hearing protection by your employees" They were then aked for estimates of the frequency of occurrence of the problems they specified and whether they attributed them to the use of EPDs No effort was made to specifically elicit comments regarding canal irritation or otitis externa, and likewise due to the nature of the study it was not possible to verify the occuracy of the assertations or perceptions of those who were intervlwed.

At 51 of the 218 sites surveyed by the Roysters, externa otitis was mentioned as a problem for the warers of insert EPDs, but at only 38 of those sites was the interviewee able to provide an estimate of the number of accurrences. It was from those 38 dstimates based on espence with over 24,000 employees that they computed an annual prevalence rate of 2.5% It is also important to note that of the 51 interviewees mentioning otitis externa as a problem, 28 (55%) did not attribute its indidence to the use of EPDs.

The most recently reported data are from cooper, who studied 587 employees at five midwestem industrial fecilities. Otoscopy was conducted by audiometric technicians. Information on EPD usage and medical histories were recorded. Subjects reporting infrequent BPD use and those to wore hearing aids were excluded. The subjects were divided into premolded earplug users, foam earplug users, and those no didn't wear EPDs. The prevalence of otitis externa was less that 0.3% across al groups, with no satistically significant differences among the groups.

Cooper also reported data on the presence of cerumen. She defined a partial blockage as a 50E or greater abstraction. and a total blockage as 100%- The prevalence of partial blockage did not vary significantly across groups. It averaged about 5%. The only satistic that varied significantly accross groups was that of total cerumen blockage, which was that reported as 7.4% ,2.0%, and 6.0% for the premolded users, foam users, and honusers respectively. The author suggested that foam the fact that they are inserted into the ear canal in a compressed state, can actually penetrate and achere to excessive wax to facilitate its partial removal.

RECOMMENDATIONS:

Prior to insuring EPDs the fitter should visually examine the extenal ear to identify any medical or anatmoical conditions which might interfere with or be aggravated by the use of the protector in question. If such conditions are present, EPDs should not be warn until medical consultation and/or corrective treatment can be obtained, or the suspected condition has been shown not to sonstitute a problem. Areas of concern include exterme tenderness, vedness or inflammation (Eigher in or around the ears), sores, discharge, congenital or surgical ear malformations, and additionally in the case of erplugs, canal obstructions and/of impacted or excessive cerumen. The latter condition. However, is difficult to judge since few data are available on the effects of earplugs on the formation, buildup, and possible impaction of wax.

As with all clothing and equipment that comes in repeated and intimate contact with be body and the work environment.

the cleanliness of EPDs must be considered. EPDs should be cleaned regularly in accordance with manufacturers, instructions and extra care is warranted in environments in which handle potentially irritating substances. Normally, warm warm water and soap are recommended as cleansing agents. Solvents and disinfectands should generally be avoided.

Ear plugs should be washed in their entirety and allowed to dry thoroughly before reuse or storage in their carrying containers. Ear muff cushions should be periodically wiped or washed clean. Their foam liners can also be removed for washing but must be replaced since they do affect attenuation. Ear plugs and earmuff cushions should be discarded when they cannot be adequately cleaned or no longer retain their original appearance or resiliency.

Stressing hygiene beyond practical limits, however, can compromise the credibility of the EPD issuer/fitter. It is often difficult enough to get employees to replace or repair worn out EPDs, 1 et alone clean them routinely. And in spite of this, the epidemiological data previously discussed give no indication that the use of EPDs significantly increases the prevalence of External ear disease.

If an ear irritation or infection is reported the exact extent snd etiology of the problem should be investigated first and by medically trained personnel to determine whether the causative agent is an EPD or one of the other

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predisosing factor cited above. When EPDs are implicated, a common cause has been found to be earplugs or even earmuffs that are contaminated with caustic or irritating substances, or sharp or abrasive matter. If such contamination is likely or unavodabale, and repeated, insertion and removal are required during a work- shift, formable earplugs that are manipulated by the user prior to insertion may not be the best choise.

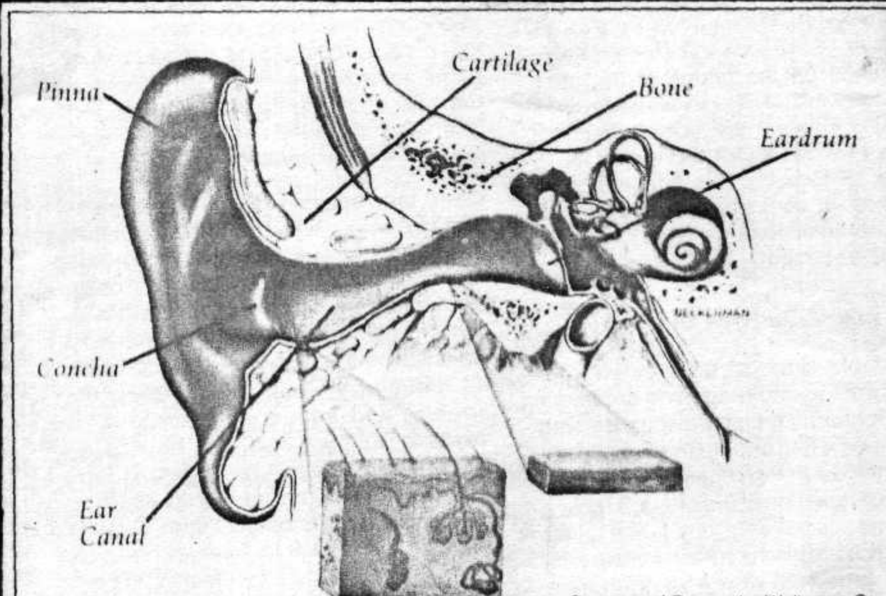
In one reported case of earplug contamination, more careful hygiene practices, combined with the use of corded plugs to allow removal without touching the protector, eliminated the problem. In another situation, in which underground miners in a warm and humid environment were experiencing otitis externa, switching from a premolded vinyl plug to a foam plug decreased the incidence.

Canal irritations can also arise due to the use of missized or inappropriate EPDs, omission of a "break - in period " for new users, or the use of worn out EPDs whose once resilient parts are no longer soft and flexible. For example, one reported cause of ear irritation has been the continued wearing of V - 51R (Premolded PVC) earplugs beyond their useful life, i.e., after they have hardened from exposure to cerumen and sweat. In rare instances individuals may develop circumaural or canal inflammation as a result of allergic reactions to the materials from which earmuff cushions or earplugs are composed rectification of the above problems involves resizing or issuing alternative EPDs, retraining of users, and periodic replacement of worn out devices.

If incidences of external ear problems are detected, it is important to determine if they are limited to a particular department or operation, to one or more brands or types of EPDs, to a change in the EPDs being utilized, to a particular time of year, or if they are perhaps due to some other policies or procedures that may have been modified within the work environment. This will allow a reasoned approach and help to avoid an overreaction which could compromise the HCP, without necessarily resolving the problem at hand.

Closing Remarks

Examination of the physiology of the typical healthy ear canal suggests that its natural defence mechanisms render it exceedingly resistent to infection. This observation is substantiated by the available anecdotal and epidemiological data on the prevalence of otitis externa among both users and non—users of EPDs. For both groups prevalence was found to be approximately 2%. Although hearing protection devices should not be worn in the presence of some preexisting ear canal pathologies, and care must be exercised regarding selection and use under certain environmental conditions, regular wearing of EPDs does not normally increase the likelihood of contracting otitis externa.



Courtesy of Burroughs Wellcome Co.

Figure 1. Frontal section of the ear canal with magnification of the skin of the cartilaginous and osseous (bony) portions (from reference 2).

Table I – Estimates of the prevalence[a] of otitis externa and excessive cerumen

Date	Author	Otitis Externa		Excessive Cerumen	Wearing HPDs	Comments
1946	Jamieson	1.5%		—	no	65,000 RAF and army troops; medical diagnoses of in- and out-patients seen by military hospital during 3-year period.
1948	Johnston	2.6%		—	not specified	Survey of factory workers.
1952	Carpendale	0.3%		—	no	1000 "normal young men;" Royal Air Force candidates.
1953	Akroyd	6.0%		—	no	Incidence data for military personnel in tropical climate.
1957	Senturia	1.1%		—	no	551 newly enlisted Marines in Florida; incidence during 2-1/2 month period.
1965	Cambon et al.	3.0%		—	no	504 Indians on reservation in British Columbia.
1981	Hopkinson	2%		6%	not specified	350 noise-exposed coal miners.
		2%		2%	not specified	150 industrial noise-exposed controls. Otolaryngic exam w/microscopic otoscopy.
1982	Forshaw & Cruchley	0%		—	yes	60 aircraft crew; 8 weeks usage; exam by physician including skin cultures.
1984	Foltner	—	(6%)[b]	—	yes	68,647 industrial workers; prevalence of "ear disease, perforation, or occluding wax;" otoscopic exam by CAOHC technicians.
		2%		9%	no	101 industrial workers prior to HCP; otoscopic exam by certified audiologist.
1984	Royster & Royster	2.5%			yes	24,212 noise-exposed workers, yearly prevalence of "otitis externa, fungus, drainage and nonspecific reports of infection," based on estimates by HPD fitters/issuers at 38 out of 218 sites interviewed.
1985	Berger & Nuss	0%		14%	few	63 industrial workers; TWA > 85 dBA; excessive wax – 75% or more obstruction.
1985	Cooper	0.3%		3.5%	yes	362 industrial workers from 5 plants.
		0.2%		6.0%	no	225 controls from same plants. Prevalence of inflammation, drainage, or perforation; otoscopic exam by CAOHC technicians.

a) Rates in this table are prevalence, except as noted under comments.

For a given period of time, prevalence = # existing cases (old & new) / population at risk and incidence = # newly diagnosed cases / population at risk

b) Doesn't fit in either column; see comments

CAN HEARING AIDS PROVIDE HEARING PROTECTION?

When employees who wear hearing aids work in noise, they may request to wear their aids, turned off, in lieu of standard industrial hearing protection devices. This may be due to comfort (Since they are accustomed to their custom hearing - aid earmold). or convenience (since their hearing aids are available for use when needed), or reduced attenuation (which may help them hear better under certain conditions), or because they may wish to occasionally use their aids in the noise. The latter is uncommon since it is generally observed that present day hearing aids are of little value in noisy environments.

The question is : can an earmold that is part of a hearing — aid system provide adequate hearing protection? If so, the wearer could quickly and easily turn on and use the aid when needed, and yet turn off the aid and continue wearing it to obtain noise reduction as required.

A study which examines the feasibility of such an approach is as follows.

Six different types of earmolds were evaluated. Three consisted of a standard lucite shell custom earmold with a vent which was either fitted with a plastic plug containing a 0.030"or 0.150" diameter hole, or with one containing no hole at all (unvented). The remaining devices, all of which were unvented, were a full – size in - the ear aid (ITE), an earmold manufactured from a soft elastomeric material commonly used for high - gain hearing aids (Power mold), and a standard 3 - A - R plug center bored with a 0.108" diameter hole and fitted with #13 hearing aid tubing. The lucite, power, and foam - plug earmolds were connected to a behind - the ear aid (BTE) that was fitted with a battery and turned off.

The Procedure

One group of 10 subjects participated in all measurements One audiologist using a syringe and foam ear dams took all of the earmold impressions. Real – ear attenuation was assessed by the E - A - R division Acoustical Laboratory in conformance with ANSI S 12.6, except as noted below.

To minimize the number of molds that were manufactured only right ears were tested. The non – k test (left) ear was occluded with a deeply inserted E – A – R plug covered by a large volume earmuff cup. This procedure was assumed acceptable since the dual – EPD combination provided at least 6 dB more attenuation at all frequencies than did any of the earmolds in the study.

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In certain ear canals temporomandibular - joint motion may cause custom ear - molds to imperceptibly back out of the canal, breaking their seal, and thus losing much of their attenuation. Therefore, to provide more realistic data, all subjects exercised their jaws after fitting and prior to actual testing.

The Results

The real - ear attenuation values (Fig 1) can be separated into three categories - vented earmolds, which provide less than 20 dB of protection below 2 KHz. unvented earmolds, which provide approximately 20 dB or more protection at all frequencies; and the foam "Earmold" which provides approximately 30 dB or more protection at all frequencies.

The foam earmold is compared with an unmodified foam earplug in figure 2. The loss of attenuation due to the penetration by the tube is from 2 to 4 dB at all test frequencies. A likely cause is sound conduction into the BTE aid or through the walls of the connective tubing, with subsequent transmission into the occluded ear via the orifice in the earplug.

In figure 3 the average results for the three unvented earmold t pes in this study are compared to data from our laboratory for a standard high - quality custom earmold

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designad specifically for hearing protection. The performance is similar as would be expected.

Also shown in figure 3 are the average data for a group of six different types of custom earmolds (half were lucite and half were viny flere) that were fabricated and tested by Frank. The average results are shown since the range of mean attenuation values accross all six devices was never greater than 8 dB at any one frequency and was typically less than 6 dB Although all of the earmolds in Frank's study were unvented, the measured attenuation is much closed to that found for the vented earmolds tested in this study.

Since earmold attenuation is so strongly influenced by the tightness and accuracy of the initial ear canal impression, it is likely that the lower values of attenuation reported by Frank reflect different procedures and criteria for earmold fabrication. He suggested that the primary reason for the reduced attenuation "was Belated to sound passing through leaks around the traditional earmolds". Thus, depending upon the impression and fabrication procedures, even unvented earmolds may fail to provide adequate noise attenuation.

The data in this report indicate that for the typical vented earmold, and even unvented earmolds depending upon how they were fabricated, attenuation is insufficent for all but the most marginal occupational exposures. However for a tightly fitted unvented ear-mold or when foam earplugs are used as hearing aid earmolds, protection equivalent to standard commercially available earplug is achievable. If possible, it is best to validate the level of protection by asking the audiometry, i.e., measuring the difference between the individual's unaded, unoccluded thresholds and the occluded thresholds with the aid turned off.

Related Issues

Regardless of the amount of attenuation that is provided by the hearing aid ear mold, the aid itself, which usually supplies from 20 to 50 dB of maximum gain, can potentially cause additional noise induced hearing loss when used in the presence of sustained high – level noise. Although no definitive answers are available, a prudent recommendation is that employees should never operate their aids without the addition of an earmuff when the sbund levels exceed 80 dBA. Whenever hearing aids are worn in noise, careful employee orientation is necessary, and more frequent audiometric monitoring (twice annually) is adviced untill the stability of the individual's hearing threshold Levels can be varifled.

When a hearing aid user is required to remove his or her aid and wear a hearing protector, speech messages and some warning signls may be attenuated below the hearing treshold. This effect may be minimized by providing a low attenuation EPD, one with the minimum attenuation necessary for the exposures in question. Individual couselling is required as well as evaluation of the suitability of the person for the job. For example, in the Air Force iminimum hearing sensitivity is specified for certain noise haxardous occupations.

Alternative strategis, but ones that should only be considered with caution, involve the use of hearing aids (Primarily ITE versions) worn under earmuffs. Presuming the earmuff is in good condition and properly worn, in certain cases the aid may be adjusted (for reduced gain) to partially compensate for the predomintly high frequency hearing deficit arising from the combination of sensory loss and earmuff attenuation. The aid may also be used under the earmuff. in a honoperational mode, but if the earmold is well fit and has minimal enting, the combined attenuation from the two devices can be great enough to ren er the already hearing - impaired individuals unable to hear the sounds about them.

Whatever decision is made concerning the suitability of the earmold for use as a hearing protector* the hearing - impaired individual should be protected. Exceptions may include and individual with a hearing loss so severe that the noise is inaudible, or persons with a conductive loss that exceeds in magnitude the attenuation th t a ear protector could provide.

Decisions regarding the disposition of hearing - aid users and others with substantial hearing impaired ments are not clearcut. Even with individual counse- ling, comprehensive audiological workups, and expect consultation, ideal solutions are elusive. Develop- ment of an informed consensus on suitable strategies for protecting the already hearing impaired awaits further laboratory and field research, as well as frank and open scientific exchange.

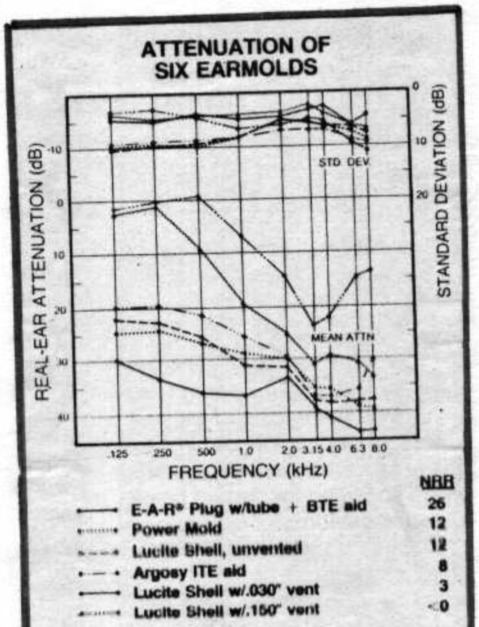

Figure 1

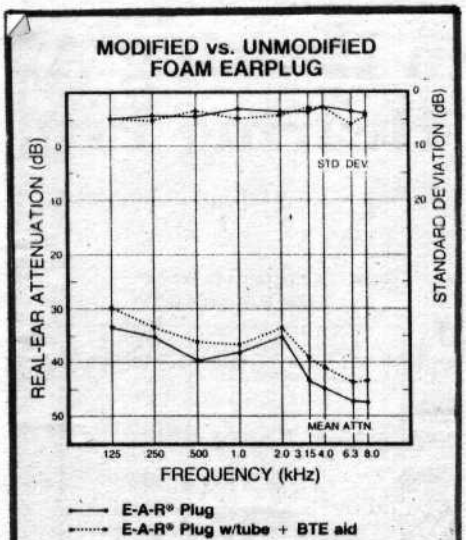

Figure 2

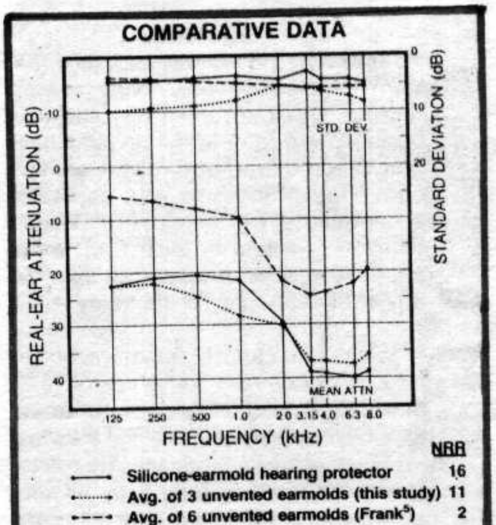

Figure 3

RESPONSES TO QUESTIONS AND COMPLAINTS
REGARDING HEARING AND HEARING PROTECTION

Program administrators of a Hearing conservation program must sincerely and accurately deal with questions and complaints regarding the utilitization of hearing protection devices and the purpose of the hearing conservation program so here we can look on to the summary of the more common areas of concern that are expressed by supervisors and employees, and information that can provide the basis for appropriate responses.

COMPLAINT:

Ear protectors are confortable.

RESPONSE:

EPDs are often uncomfortable initially, but hearing loss due to noise exposure is uncomfortable permanently, like a new pair of shoes or glasses, ear protectors do require a reasonable period of adjustment. Since not all ear protectors adapt equally well to all head shapes and ear canals, it is important to give the employee the final choise in what he or she will wear. If after a couple of weeks of daily use the employee is still experiencing difficulties or discomfort, the protector should be resized and/or refitted, or another ear protector should be issued.

EXCUSE: I don't need ear protector. I am used to the noise.

RESPONSE: Ears do not get used to noise they "get deal" (and unfortunately a deagened ear may often seem to get used to the noise). Repeated exposure to noise does not toughen ears nor does having an existing noise induced hearing lass prevent you from losing the hearing you have left. Although individual susceptibility to hearing loss from noise exposure varies widely, there are currently no standardized tests that can defect the more noise sensitive members of the population.

QUESTION:

I've already lost some or most of my hearing? why should I have to wear ear protectors.

RESPONSE: The existence of a noise induced hearing loss does not protect one from losing further hearing due to noise exposure. Fig. 1, illustrates the typical progressive nature of noise induced hearing loss. Initially the hearing is damaged in the higher frequencies and as the unprotected exposures continue, this damage spreads to the lower frequencies, eventually affecting those essential to the understanding of speech (500 Hz to approximately 3000 Hz). Although EPDs cannot restore a noise induced hearing loss, which by its nature is permanent and irreversible, they should prevent additional losses from being incurred. Furthermore, proper use of EPDs will prevent employees from developing a temporary hearing loss, and allow existing temporary losses to recover before they become permanent

COMPLAINT: I can't hear my fellow workers if I wear ear protectors.

RESPONSE:

When the ear is bombarded with high level sound, it overloads and distorts, reducing its ability to occuratly discriminate different sounds. Wearing EPDs reduces the overall sound levels so that the ear can operate more efficiety. The effect is similar to the improved vision that sunglasses provide in very bright, high glare conditions.

For those with normal hearing, EPDs will usually provide improved communications when sound levels are greater than approximately 85 dBA. For moderate to severely hearing impaired individuals, the situation is more complicated? for them, ear protectors may not provide a communications benefit and actually be a liability. But, if these individuals do not protect their hearing, they may suffer additional impairment and then will have even greater difficulty communicating regardless of noise level.

COMPLAINT: My machine sounds different to me when I wear ear protectors.

RESPONSE:

True, machines will sound different, but for the reasons outlined above, most employees will still be able to effectively monitor their operation once employees become accustomed to the new sound of their machine, chances in its operation will usually be as easy to defect as without the EPD. Also, since they won't be acquiring progressively increasing amounts of temporary hearing loss throughout the day, employees will be able to hear their machines as well as the end of their shift as when they started in the morning.

QUESTION: Do earmuffs black out noise better than earplugs?

RESPONSE: No. The misconception that earmuffs are better than earplugs at reducing noise is partly due to the "bigger is better" school of thought. Actually, whether or not an earmuff or an earplug is better is dependent upon the device and user in question.

In figure, 2 the real-ear attenuation data for two muffs and two plugs are plotted. The data are all from one laboratory. Earplug A are among the best commercially available EPDs this facility has ever tested, whereas earplug B is a low attenuation insert and ear muff B is a typical "popular" model We can notice that the better earplug out perform the better earmuffs at all frequencies except 2.0KHz, where the earmuff offers approximately a 8dB advantage. But both earmuffs outperform earplug B at all frequencies. Thus although some earmuffs do outperform some earplugs, it is not true to state that all earmuffs outperform all earplugs.

It is important to remember that although the above discussion focused on attenuation, other factors such as comfort and the intended application significantly affect the choice of a muff or a plug for a particular situation.

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QUESTION: Can earplugs cause ear infection?

RESPONSE: Based on the experience during the past decade, and information gleaned from consultation with experts in the field of otology and audiology, as well as preliminary data from an ongoing survey of U.S industries, it appears that the likelihood of earplugs causing outer ear infections (otitis externa) is minimal. Although it would seem that placing a dirty or gritty foreign object in the ear canal could easily lead to irritation or infection, the data from existing HCPs seem to indicate that the external ear is fairly resistant to such abuse. Nevertheless cleanliness should be strpssed and certain individuals such as diabeties or others who are prone to infection should be more carefully monitored.

When an ear infection is reported, earplugs should not necessarily be assigned the blame. Other causative agents may be excessive cleaning of the ear, recreational water sports, habitual scratching and digging at the ears with fingernails or other objects, environmental contaminants, and systemic conditions such as anemia, vitamin deficiencies, endocrine disorders, and various forms of dermatitis.

QUESTION: Once I put on my heqring protector, can I forget about it until I take it off for my break?

RESPONSE: No. Ear protectors may work loose or be fostled out of position and need readjustment. Certain pre-molded and user molded inserts are particularly prone to this problem and

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must be periodically reinserted or reseated properly fitted custom ear molds and user formable foam earplugs are among those devices that are best at maintaining position throughout the use period.

QUESTION: Will I hurt my ears if I blow my nose while wearing an earplug?

RESPONSE: No. Since the earplug is inserted in the esternal ear canal* which is separated from the middle ear by a membrane (the ear drum), if will not affect the pressure changes in the middle ear which may arise due to blowing of the nose Sometimes, if the eustachian tube, which vents the middle ear to the back of the throat, is blocked or otherwise, not functioning properly, air or fluids can be forced into the middle ear and cause discomfort or other problems. However, this will not be affected or aggravated by the use of ear plugs.

QUESTION: Can hearing protectors cause head aches, nosebleed, ulcers, insomnia, or eyestrain?

RESPONSE: Headaches may be caused by an EPD (Primarily circumnural devices) that fits too fightly, or is in some other way uncomfortable. The EPD should be resized, refitted or another device issued.

There are no known medical or physiological reasons why EPDs should be suspected of causing any of the remaining maladies listed above. However, when an employee voices such compalints, this indicates dissatifaction with the EPD he is wearing, a misunderstanding, of the need for its use, or a real

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health problem that has been mistakenly attributed to the use of the EPD. The best response will be a patient and accurate assessment of the actual cause of the disorder.

QUESTION: Can I use stereo earphones for protection against noise and enjoy the music at the same time?

RESPONSE: In figure 1 the attenuation of a circumaural radio head set and also of a more popular set of light weight foam supraural stereo earphones is plotted. The foam earphones offer almost no protection. Even the circumautal device provides no more than approximately 20dB of attenuation at high frequencies, and actually significantly amplifies sounds at some frequencies. This protection is inferior to that of a well designed, properly fitted EPD. Furthermore, these devices alone, can generate equivalent noise exposures upto approximately 100 dBA.

Since these devices offer so little attenuation, a greater concern is that employees might turn UP the music to mask (i.e., "down out") the factory noise. Products are available which have been specifically designed to offer adequate protection and at the same time play music or transmit voice communications Although generally expensive, such devices are suitable for use, especially when they have built - in signal limiting circuitry so that they are not capable of presenting hazardous sounds to the ear.

EXCUSE: I don't need to worry about losing my hearing since I can always get a hearing aid.

RESPONSE: Although eyeglasses can in most cases correct a vision problem to a nearly normal condition, it is a misconception that hearing aids can do likewise for a noise induced hearing loss correctable vision problems not the loss of the optic nerve cells, whereas noise damage is due to destruction of the nerve (hair) cells in the cochlea that enable us to hear. Hearing aids can restore the ability to defect and discriminate sounds to a certain extent, but when insufficient hair cells are present to receive the amplified sounds that the aid provides, the results are not fully satisfactory and if wearing an EPD 8 hours/day is objectionable, will it be any more acceptable to wear a hearing aid for all of noa's waking hours?

QUESTION: **I**sn't it important to wear earmuffs rather than earplugs at high sound levels. Since,at such intensities the sound transmits directly through the bones of the skull and can bypass an earplug?

RESPONSE: Sound transmission around as SPD via bone conduction is present regardless of sound level and limits the maximum attenuation that a perfect hearing protector can provide to about 50 dB. It may be compared to keeping the light out of a dark closet by shutting its colored glass door. Light enters through the open doorway as does sound through the open ear canal. Shutting the door is akin to putting on a EPD, with more heavily tinted glass representing a better protector.

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Light passing through the key-hole is analogous to the bone conducted sound. It will control the illumination of the closet if the glass door is very dark or opaque. When the glass is less tinted or even clear, however, the keyhole light is insignificant.

As the illumination outside the closet increases, additional light enters the key-hole, but the ratio of the keyhole light to the light passing through the door remains constant.

Similarly, bone conduction is insignificant compared to normal air conduction unless the EPD's attenuation approaches the 50 dB limitation imposed by bone vibration, a limitation which is constant regardless of sound level. Thus, if a muff or a plug offers bone conduction limited protection at a low sound levels, the same will hold true at a high sound level.

Since the areas of the skull arand the external ear are only a small portion of the total bone conduction mechanism, covering them with an earmuff is of small significance, perhaps 3-4dB in the 1-2 KHz region. Thus the relative performance of plugs compared to muffs is not, in practice, determined by the bone conduction paths but by factors inherent in the design of the EPDs and their interface to the head. In fact, a well designed insert such as a foam earplug, can offer attenuation comparable to or exeeding that of, earmuffs at most frequencies.

QUESTION: Since my entire head is affected by the sound and can transmit energy to my inner ear, does a hard hat, which cavers part of my skull, reduce the bone conduction?

RESPONSE: In order to block the sound and reduce the bone vibration, it would be necessary to wear a completely rigid helmet with a face plate that formal a virtual airtight enclosure about the head. A hard hat, which covers only part of the head and has many gaps through which the acoustical energy can penetrate, is of little value in reducing the ear's response to the bone conducted sound.

QUESTION: Are your ear protectors either ANSI or OSHA approved!

RESPONSE: ANSI does not approve ear protectors. The ANSI standard 53.19-1974, describes how to measure the attenuation of EPDs. Testing a device by the methods of that standard in no way confers any approval or attribules any particular degree of quality to the device. It simply characterizes the laboratory attenuation of the protector, however good or bad that may be. In addition, no federal or state agencies or other U.S standards writing organizations (Table l) approve or disapprove of particular EPDs, although the EPA currently required labelling of EPD packaging.

The only other agency with a hearing protection related regulation is OSHA, whose Hearing conservation Amendment requires the EPDs that are used reduce an employee's 8 hour

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time weighted average noise exposure to 90 dBA or less, and in the case of employees demonstrating significant threshold shifts, to 85dBA or less.

QUESTION:

Can I hurt my eardrum if I insert a plug too deeply or remove it too quickly?

RESPONSE:

The sensitivity of the adult ear canal to pressure or pain increases significantly as the eardrum is approached. The discomfort experienced due to touching these deeper portions of the canal will alert the user to stop pushing on the plug before the device reaches the eardrum. Furthermore, the design of most inserts will prevent inserting them the lenght required (about 22mm) to touch the eardrum. A more likely problem is earware impaction, which can result from the insertion of earplugs, particularly of the pre—molded variety. For this reason, the person fitting earplugs should visually examine the ear canal upto the depth that the plug will be inserted. Persons with chromic earwax impaction problems should consider using semiaural or circumaural EPDs.

For plugs that create an airtight seal, such as pre-molded inserts, rapid removal can be painful and potentially damaging to the eardrum. The plugs should be removed with a slow twisting motion to gradually break the seal as they are extract from the ear with foam and fibrous plugs, which do not create a pneumatic seal (and hence cause less of a blocked-up feeling) there is little possibility of generating a sudden large pressure change upon rapdi removal, and thus virtually no likelihood of damaging or repturing the eardrum.

QUESTION: How can I tell when a noise may be harmful to my ears?

RESPONSE: When a noise is loud enough that we feel the need to shout at a distance of 3 feet in order to communicate with a normal hearing person, the noise levels are probably around 85 dBA or more and may be hazardous to hearing. Additional information on using speech levels to judge noise levels can be gleaned from Fig. 1, which dipicts the ability to conduct fact-to-face communications as a function of the A-weighted sound level. Fig. 1 is a rough guide that is applicable for communication in non-reverberant conditions.

If, after a noise exposure, hearing appears dulled as though having a temporary hearing loss (temporary threshold shift or TTS, or hear a ringing or hissing noise in the ears (tinnitus), this is an indication that the particular exposure over stimulated hearing Repeated exposures over a period of weeks, months, or years, to noises which cause TTS or tinnitus, may in time lead to a noise induced hearing loss which is permanent and irreversible. So we should take the hint before it's too late-if we can't avoid the noise exposure we should wear ear protectors.

COMPLAINT: Sar protectors make my voice sound strange to me and make me more conscious of other body noises such as breathing and walking. They also make it difficult for me to judge how loudly to talk.

RESPONSE: This is generally true. A properly fitted SPD creates an occlusion effect which results in an increase in the ear's sensitivity to bone or tissue conducted sound. This tends to ampligy internal body noises such as those generated by one's own speech and breathing. The effect is most pronounced for devices that cap the canal entrance, such as semi - aural EPDs, although it is usually noticeable for most properly fitted protectors. In fact, listesing for a resonant or bany characteristic to one's own voice while adjusting premolded earplugs, semi-aural devices, or most earmuffs, is a useful technique to aid in attaining a good acoustic seal.

Wearing EPDs will cause most people to talk more quietly in noisy environments since the protector reduces the perceived noise level, while at the same time, due to the occlusion, effect, it amplifies the apparent level of the talker's own speech. Thus, the perceived speech-to-noise ratio is distorted so that the individual believes he is speaking more loudly than actually is the case. This problem can be overcome as wearers become more experienced in the use of their EPDs and if co-workers remind them to speak up.

<u>QUESTION</u>: Why can't I modify ay ear protectors to make them more comfortable?

<u>RESPONSE</u>: When designing an EPD, there is often a trade-off to be made between comfort and attenuation. Most atterations that improve comfort, such as low headband tension for ear-muffs, removal of earplug flanges, undersising premolded inserts, removing material from fiber glass, foam, or wax plugs, and cutting holes to permit a device to breathe, will increase an EPDs comfort at the expense of its noise reducing capability.since only the manufacturer or a special test laboratory possesses the capability to determine the exact effects of such modifications, and since manufacturer's reported test data are always for new, unmodified devices, it is likely that user alterations will result in reduced and unverifiable attenuation for the modified ear protector.

If a particular protector is found to be uncomfortable for a given employee or group of employees, then a preferred solution is to offer acceptable alternative brands or models of EPDs until a suitable product is found. Responding to employee's grievances in this way, and also allowing them some influence in the final selection process, will not only increase the likelihood of successfully fitting the employees with an effective protective device, but also result in greater acceptance and increased usage of EPDs.

<u>QUESTION:</u> Are all foam earplugs the same?

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RESPONSE: No, all foam earplugs are not alike. Only two branchs of self-fitting slow recovery foam earplugs are manufactured under the protection of patents granted in the U.S and 14 other industrilized nations.

A number of design parameters affect the performance of foam earplugs. The most important of these are the recovery characteristics of the foam and its stiffness. Not only must these properties be optimized for best performance, but they must be relatively independent of temperature and humidity. If a plug expands too rapidly or is too soft it may be difficult or impossible to insert. Conversely, if it expands too slowly it may dislodge before properly seating, and if it is too stiff it will of course be uncomfortable other proerties to consider are the porosity of the feam, whether or not it has been fully tested for dermal toxicity and allergenic responses, reusability, flammability, and the size, shape, and color of the plug.

QUESTION: Can I use noise reducing ear-plugs for swimming?

RESPONSE: Yes, certain noise reducing earplugs such as those made from vinyl, closed cell foam silicone, and even wax-impregnated cotton can be successfully used in many cases for swimming and showering. In fact they will generally perform better than the plugs that are sold over-the-counter as "Swimmer's plugs" since they fit the ear canal more comfortably and snugly. The plugs should he inserted in a dry condition, before entering the water, and the user should not submerge his head more than a few feet below the surface since this increases the likelihood of water being forced around the plug.

QUESTION: Can I use cotton or my fingers to reduce harmful noise exposures?

RESPONSE: Occasionally one finds persons wearing nonstandard SPDs such as gum, putty, cotton, cigaretee filters, empty bullet casings and other items which will not adequatel seal the ear canal or simply do not possess the needed physical characteristics to effectively attenuate sound. Additionally, such devices are often uncomfortable and unhygenic. For example, ordinary dry cotton is a very poor ear protector as shown in figure 2. Interstingly, a finger tip, although it certainly cannot be utilized for extended periods of time, does provide very good protection (Fig. 2) when forced tightly into the ear canal.

COMMENT: My mother always said "never put anything smaller than your elbow in your ear".

RESPONSE: The platitude is representative of the numerous preconceptions and misconceptions that many people have regarding the use of EPDsm, of course when mother delivered the above pronouncement she had in mind the percils, pins, toothpicks, and clumsily maneuvered Q-tips that could damage the delicate eardrum, or other miscellaneous objects that might become lodged in the ear canal. Unfortunately, she was not aware of the lasting negative mental imprint that this would create with regard to the sage and correct use of properly designed and fitted noise reducing earplugs. In order to overcome such notions it will frequently be necessary for a trainer to correctly insert earplugs for the employee atleast one time during an instructional session, so the employee can expecience the sensation of a correctly inserted earplug placed well into the ear canal often, fitting one of the employee's ears, and then asking him to fit the other so both ears "feel the same", is a helpful technique.

CONCLUSION:

The material reviewed in this section provide a basis for formulating either verbal or written responses (Newsletters, bulletins, pamphlets) to questions and complaints regarding hearing protection and hearnign conservation.

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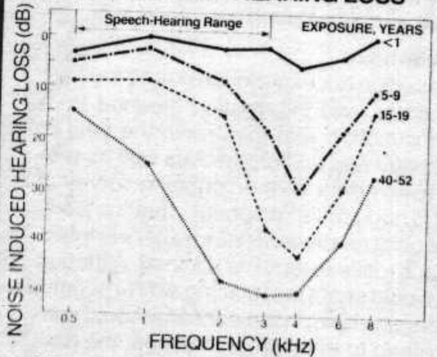
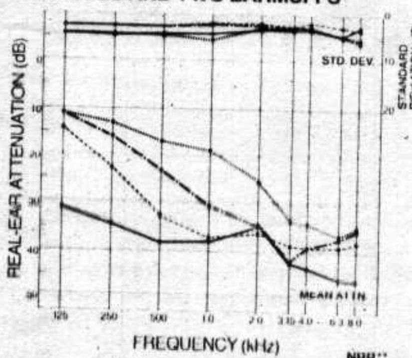
ILLUSTRATION OF THE DEVELOPMENT OF NOISE INDUCED HEARING LOSS*



*All exposure levels were approximately 100 dB SPL (After Taylor, et al.[2])

Figure 1

REAL-EAR ATTENUATION OF TWO EARPLUGS AND TWO EARMUFFS*

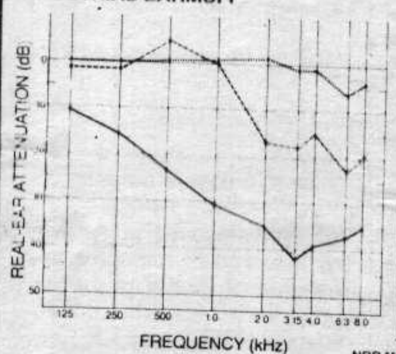


	NRR**
EARPLUG A (Foam plug)	28
EARPLUG B (Fiberglass down)	9
EARMUFF A (High performance muff)	25
EARMUFF B (Popular muff)	19

*All data from E-A-R Division Acoustical Laboratory
**Noise Reduction Rating per U.S. EPA

Figure 2

ATTENUATION OF RECREATIONAL EARPHONES VS. A POPULAR INDUSTRIAL EARMUFF*

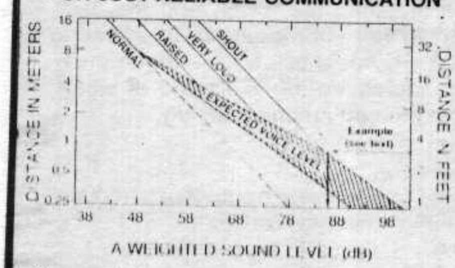


	NRR**
POPULAR INDUSTRIAL EARMUFF	20
LIGHTWEIGHT FOAM EARPHONES	0
CIRCUMAURAL RADIO HEADSET	0

*All data from E-A-R Division Acoustical Laboratory
**Noise Reduction Rating per U.S. EPA

Figure 1

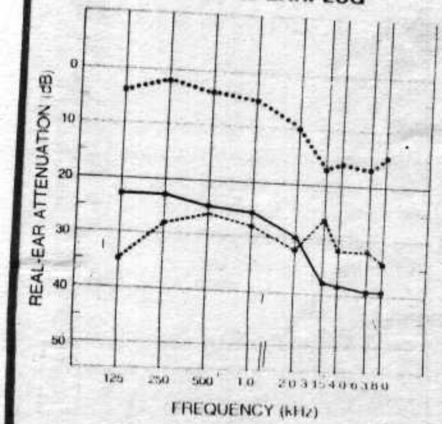
TALKER-TO-LISTENER DISTANCES FOR JUST RELIABLE COMMUNICATION



The region below each curve shows the talker-to-listener and noise-level combination for which just reliable face-to-face communication is possible. The parameter on each curve indicates the relative voice level. The shaded triangular region shows the range of expected voice levels due to the normal raising of one's voice in noisy surroundings. The A-weighted sound levels shown on the abscissa are approximate. Data from ANSI S3.14-1977[2].

Figure 1

ATTENUATION OF TWO NONSTANDARD HEARING PROTECTORS COMPARED TO A TYPICAL EARPLUG



- TYPICAL EARPLUG*
- DRY COTTON[9]
- FINGER TIP[10]

*Average data from 16 earplugs measured according to ANSI S3.19 in the E-A-R Division Acoustical Laboratory

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