A COMPARISON OF ATTENUATION CHARACTERISTICS OF INDIGENOUS VERSUS IMPORTED EAR PROTECTIVE DEVICES

Reg. No. M.9301

An Independent. Project submitted as part fulfillment of the
First Year M.Sc (Speech and Hearing) to the
University of Mysore.

All India Institute* of Speech *and Hearing
***MYSORE* - S70006**
MAY 1994

DEDICATED TO

MUMMY , PAPA

AND

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CERTIFICATE

This is to certify that the Project entitled :

" A COMPARISON OF ATTENUATION CHARACTERISTICS OF INDIGENOUS VERSUS IMPORTED EAR PROTECTIVE DEVICES "

Is a bonafide work done in part fulifilment for the First Year Degree of Master of Science (Speech and Hearing) of the student with

Reg. No. M.9301

Mysore,
May 1994.

Dr. (Miss) S-Nikam
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CERTIFICATE

This is to certify that the ProjEct entitled :

A COMPARISON OF ATTENUATION CHARACTERISTICS OF INDIGENOUS VERSUS IMPORTED EAR PROTECTIVE DEVICES

has been prepared under my supervision and guidance

Mysore,
May 1994

Dr. (Miss) S.Nikam
GUIDE

DECLARATION

I hereby declare that this Independent Project entitled,

" **A COMPARISON OF ATTENUATION CHARACTERISTICS OF INDIGENOUS VERSUS IMPORTED EAR PROTECTIVE DEVICES** "

is the result of my own work under the guidance of Dr.Miss) S.Nikam, Professor and Head of the Department of Audiology, All India Institute of Speech and Hearing, Mysore, has not been submitted earlier at any University for any other Diploma or Degree.

MYSORE,
MAY 1994

RegNo:M9301

ACKNOWLEDGEMENTS

I am deeply indebted to Dr (Miss) S.Nikam, Prof, and Head of the Department of Audiology, All India Institute of Speech and Hearing Mysore, for the invaluable guidance, encouragement and patient listening.

My heartfelt thanks to Dr (Miss) S.Nikam Director, AIISH, Mysore, for allowing me to undertake this project.

My whole hearted thanks to Mrs. Roopa Nagarajan and Mrs. Rajalakshmi, Lecturer in Audiology, AIISH for their timely help, guidance and encouragement which enlightened my path during the course of this study.

My heartfelt thanks to Ms. Manjula and Ms. Ramadevi for their constant invigilation and unmitigated support.

My sepcial thanks to Mr.Venkatesh and Mr.Jayaram (CIL) for their invaluable help with the statistical analysis.

Ritu, Mona, Jyothi and Deepa, thanks for being such wonderful friends through good times and bad times. I love you all through at times I can easily throttle you all too.

Sashidharan and Rajeev thanks for being there every time I goofed my statistical analysis. Sashi, I wouldn't have found statistics so interesting if not for your company.

Rahul and Chotu words ain't enough for your untiring and selfless help thanks for bearing all the trouble I put you through and for helping me finish this work. I shall cherish your friendship all my life.

Megha, Kanchan, Sara and Pradeep thanks for all the love, affection and encouragement and for making my data collection such a pleasant experience. This extends to all my subjects.

To all my classmate my special thanks for keeping my spirits high and helping me with my work.

My thanks to the library staff for allowing me to use their computer for my data analysis.

I am also grateful to M/s COMPUTER STROKE (A Data Processing Division of RACS) for their timely help.

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INTRODUCTION

Rapid advancement in sience and technology has provided us with a number of luxuries. But at the same time it had introduced into our lives the hazard of excessive noise. That we are annoyed by a noisy device and noisy environment, that noise may interfere with our sleep, our work and our recreation, or that very intense noise may cause hearing loss is frequently the basic fact that leads to noise measurements and attempts at reducing levels. Noise induced hearing loss is a common phenomenon now a days. The fact that this hearing loss sets in, in a subtle manner and before one realises causes considerate damage is what makes it so dangerous since hearing loss ia pernanent damage hearing protection offer the only effective way to fight hearing loss.

LEVELS OF HEARING PROTECTION

There are basically 3 levels at which we can bring about hearing protection. NOISE CONTROL AT SOURCE is the first of the 3 levels. Preventing the generator of the noise is involved in this state. But it is not always possible to reduce levels to within safe limits by treating the source. The next step involve NOISE CONTROL IN THE PATH. In such cases use of noise barrier or acoustic hood to cover the source can be recommended. If this is not possible then we come to the third level, that of NOISE CONTROL AT THE LEVEL OF RECEIVER. This could be in terms of changing the work place or limiting the total exposure time of the person. If all these steps may be impractical then we can take the help of EAR PROTECTIVE DEVICES.

WHAT ABE EAR PROTECTIVE DEVICE ?

Ear protective devices are personal hearing protective devices which when worn appropriately by an individual provide the most effective means of eliminating a potential hazard to hearing.

TYPES OF EAR PROTECTIVE DEVICES

Several ear protectors are available in many brands and types. Depending on their position relative to the ear they can be divided into four categories namely **earplugs, seaiinserts, earmuffs** and **helmets.** Earplugs are devices that are inserted into the ear canal and remain in place without any additional support. Semi inserts are those that close 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 most of the head surface and either through a close fit or through integral earmuff or other types of built in ear pieces supply hearing protection against noise. Depending on the type of ear protectors they are capable of reducing the noise level at the ear by 10 to 45 dB.

ATTENUATION CHARACTERISTICS

Attenuation characteristics of Ear Protective devices refers to their ability in reducing the noise level at the ear to a harmless one if not to a pleasant one. This ability is governed by a number of factors such as comfort, utilization, fit, compactabi1ity, deterioration abuse and percentage of time worn.

Ear protector also has an advantage of improving the speech communication. At the same time it is also belived to impair hearing acuity. But this holds good only in quiet enviornment where there is no necessity of wearing hearing protectors. In noisy situations they not only prevent the impairement of hearing acuity but they may even improve it by cutting down the noise interference level.

METHODS OF MEASURING ATTENUATION CHARACTERISTICS

There are many standard methods available for measuring attenuation characteristics of ear protective devices they can be subjective or objective. Among the subjective methods we have the Real Ear attenuation at threshold (REAT) which can be performed in sound field or under headphone conditions or with hearing impaired subjects. It involves obtaining the thresholds of the person with and without ear protective devices and finding the difference. In the more complex techniques involving the above threshold procedures we have techniques such as masking, loudness balance, midline lateralization, temporary threshold shift and speech intelligibility.

Among the objective method we have the acoustical test fixture method which involves the use of artificial head-ear and the techniques of microphone in real ear. Both techniques involve probe microphone measurements of insertion response of ear protective devices.

NEED FOR THE STUDY.

Previously the demand for the hearing protectors had to be met by importing them from foreign countries due to the nonavailablity of raw materials for manufacturing them.

Presently we have developed indigenous procedures for the manufacture of ear protective devices. During the review of literature the researcher has not come across any study in our country that had compared the attenuation characteristics of the indigenously available ear protective devices with that of the foreign ones. This present study is a comparative study of the attenuation characteristics provided by the indigenous ear protective devices with that of the imported ones. This study will provide us an estimate about how succesful the indigenously available ear protective devices are in providing good attenuation in comparison to the imported ones.

Also it will tell us whether a particular ear protective device is best suited for providing attenuation at a particular range of frequencies. "It will also tell us whether material variations between the ear protective devices result in significant difference in their attenuation characteristics.

REVIEW OF LITERATURE

One of the most common cause of hearing loss in adults is exposure to noise. What makes so widespread is that it starts as a virtual symptomless disease, initially, losses in picking up sounds of certain pitches. Such losses are difficult to detect except through professional testing. By the time even the most alert sufferer becomes consciously aware of it, hearing loss has grown quite severe.

The fact is hearing once lost cannot be restored. Hence,hearing protection is the only effective way one can fight hearing loss. One of the most efficient ways of hearing protection is by the control of noise brought about by the action of engineering controls and administrative controls. If, however, it is not possible to control noise in this way, the control of noise can be brought about by ear protective devices(EPD).

Ear Protective Devices(EPDS) are personal hearing protective devices which when worn appropriatly by an individual provide the most effective ways 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 50 dB depending on their type and sound frequency.

Hence, by the above definition it is clear that EPD's are the devices placed at the entrance of canal, which cuts off noise from reaching the inner ear. It usually cuts of noise from reaching the inner ear and does nothing about the bone conduction path.

Apart from reducing noise level it has one more function In noisy situation, they not only prevent the impairment of hearing acuity but they may even improve speech communication by cutting down the noise interference level. Speech becomes easier to understand and hence communication is better. But this advantage is not present in situations where intermittent noise is present.

TYPES OF EAR PROTECTIVE DEVICES

There are many brands and types of ear protectors available in the market today. According to their position relative to the ear the personal ear protectors can be classified into four basic types. They are Earplugs, Semi-inserts, Earmuffs and Helmets. As this study is on Earplugs, the researcher have restricted the discussion to only earplugs.

EAR PLUGS

They are devices that are inserted in the ear canal and remain in place without any additional support. They are unobstructive and must be personally fitted for an indivisual and for each ear under medical supervision. They are made of either cotton, paper, wax, glass wool, fiberglass, plastic or expanding single foam etc. Different types of ear plugs have different attenuation charaterstics. The mean attenuation afforded by inserts for pure tones in the frequency range of 100 - 10,000 Hz between 7.3 to 21.9 dB (NAL,1979).

It should be ensured that the wearer insert it correctly and check the seal from time to time for optimum attenuation.

a) **Prefabricated earplugs:** Made up of soft flexible material that will fit into many different ear canal shapes. They are availabale in 3 to 5 dilfferent sizes. Eg:V51 -R is one of the most versatile and effcient type, has asymmetrical shape and single flexible range, can be fitted to a large number of different ear canal. Bullet shaped design is most suitable for round and straight ear canal (A.M. Martin and J.G.Walker).

Premolded universal design is manufacture with two or more ranges on the stem.

b) Disposable and malleable plugs: They are made up of low cost material such as cotton, wax, glasswool , sponge rubber etc. They are capable of providing attenuation values similar to prefabricated types. They can be used whenever necessary by the worker and then thrown off. Atteneuation range is 15-30dB depending on the frequency. It is poor choice in dirty areas as clean hands is to be employed for fitting into ear canal.

c) **Individually molded ear plugs:** They are made by mixing silicon rubber with a fixative agent and inserting into the ear canal and outer ear. The impression is then cured to obtain a permanent custom fit for each ear. They fit perfectly to each ear, but are more expensive.

d) **Super aural (Canal Caps):** Rubber caps suspended by a spring head band are inserted into the ear canals. Sound attenuation is achieved by sealing the opening of the ear canal. Although size is not a problem here, it is difficult for inspector to judge whether they are properly worn.

ADVANTAGES OF EAR PLUGS

1. They are small, easier to store and easily carried.
2. Do not interfere with use of personal items.

3. Less expensive when compared to other ear protectors.

4. More comfortable to wear in hot enviornment, overall plugs are better accepted in all enviornment.

5. Do not interfere with head movements and convenient to use when head of the wearer must be in a close cramped quaters.

6. Hygiene is maintained.

DISADVANTAGES

1. Premoulded plugs require a tight seal of ear canal in order to be effective.

2. Use of those devices is difficult to monitor by safety personnel.

3. Some amount of dexterity is required for insertion.

4. Sizing of each ear is required .

5. If not replaced, they become hard or may shrink.

6. They need to be frequently reseated.

NOISE REDUCTION BY HEARING PROTECTORS.

The prime function of hearing protectors is to reduce the noise level at the wearer's ears to within safe limits. Information on the ability and consistency of hearing protectors to attenuate sound should be examined considering which type is most suitable for a particular noise enviorment.

ACOUSTIC ATTENUATION: The acoustic attenuation of hearing protectors is usualluy expressed in decibels attenuation at various test frequencies. According to a study (R. Vaugh 1973) the dBA attenuation of an ear protector is a function of the C-A valve of the noise spectrum in which it is used and may vary more than 20 dB in noises of different C-A valve. However, in noises of similar C-A value a given EPD provides similar amounts of dBA attenuation. The noise spectra may be sorted into 5 classes on the basis of their C-A values and any value of dBA attenuation one for each noise class and ear protector's five dBA atenuation curve by ameans of a simple calculation procedure to ensure that each calculated dBA attenuation value is obtained or exceeded in a specified proportion of the spectra in the corresponding noise class. Pure tone and 1/3 octaveband measurements of ear protectors attenuation are identical the influence of noise spectrum shape on the octave band atteneuation resulting from a given set of 1/3 octave attenuatioin value is practically negligible in typical broad band industrial noise spectra.In the octaves centered at 500 Hz and above, ear protector attenuatioin should be measured at 1/3 octave intervals to avoid the substancial errors which can occur when measurements are restricted at octave intervals.

Now, considering the factors determining the sound attenuation provided by ear protectors,the most important one is the insertiion loss introduced by the ear protector between the sound source and the ear drum 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 pressure at the inner surface of the ear protector to the sound pressure at its outer surface pil po. (Zwislocki 1957).

In the case of ear muffs leakage between the cushion ring and the skin is generaly the most important factors reducing the acoustic attenuation. Small holes, a few millimeters large drastically reduce attenuation, mainly in the frequency range 100-200 Hz. At low frequencies the noise inside the earmuffs may even be amplified, since the system constitutes a Helmoholtz resonator (Alberti 1982). 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 abillity to fit dilfferent 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 pathways which are often ineffective and the exclusion of sound transmission through the ear canal should afford sufficient protection in most situations.

CHARACTERISTICS AND EFFECTIVENESS OF HEARING PROTECTORS.

PATHS OF THE SOUND AND ATTENUATION LIMITATIONS

The primary area of damage to the hearing mechanism from intense noise is in the cochlea. The purpose of hearing protection devices is to reduce the level of noise entering the outer and middle ears before it reaches the inner ear. Noise can be transmitted through a protected outer ear directly through the protecting device, through a device altered by the wearer, or by the device itself set into vibration by the sound pressure waves impinging on it. The effect then is that transmission of sound to the middle and inner ear is only partially attenuated at the low frequencies, or even at all frequencies.

In addition, vibrations of the skull caused by impinging sound waves are transmitted to the inner ear by way of the outer and middle ear or directly to the inner ear. This limits the amount of attenuation attainable with hearing protectors. Maximum attenuation to be expected is approximately 55 dB other factors governing attenuation are the type of protectors used (muffs or inserts). The compliance of the material used in the device, the design, and the frequency components of the noise in which the devices are worn.

<u>Measuring attenuation</u> : There are many standard methods available for measuring attenuation characteristics of ear protective devices. Most manufacturers publish the attenuation curves of their products but the published test data must be carefully examined to determine if a device will be suitable for a given applicant.

In addition to providing adequate protection to the auditory system from excessive noise several other factors govern the effectiveness of the performance of the ear protective devices.

They are :

1. Comfort: This is ignored in laboratory tests but is cruicial in the real world.

2. Utilization: Due to poor comfort, poor motivation, Poor training or other user problems, ear plugs may be incorrectly inserted and earmuffs may be improrerly adjusted.

3. Fit: Fitting and sizing of ear plugs must be carefully acomplished for each ear, otherwise performance will be degraded.

4. compatibility - since not all HPDs are equally suited for all ear canal and head shapes, the proper device must be matched to each user.

5. Readjustment - Since HPDs can work loose or be jarred out of position employees must be advised of the need for readjustment.

6. Deterioration - No HPDs are permanent or maintenance free. so called permenant HPDs must be inspected at least twice yearly, and replaced or repaired as necessary.

7. Abuse - Employees often modify HPDs to improve comfort at the expense of protection. This must be avoided.

8. Removal - When devices become uncomfortable they are often removed to give the ears a break. This can dramatically reduce the effective protection.

METHODS OF MEASURING HEARING PROTECTOR ATTENUATION

There are basically two main ways of measuring ear protector attenuation

I Subjective methods
II Objective methods

Let us first discuss the subjective methods in brief. They can again be divided into two.

A. Real Ear Attenuation at Threshold (REAT)
B. Above threshold procedures

I . <u>SUBJECTIVE METHODS</u>

A. Real Ear attenuation at Threshold (REAT)

1. Sound field REAT

Probably the oldest, and certainly the most common, method of measuring HPD attenuation is the absolute threshold shift technique, often labeled real- ear attenuation at threshold (READ (Watson and Knudsen, 1944). Virtually all available manufacturer's reported data are derived via this method. Conceptually, the idea is very simple, determine a subjects binaural threshold of hearing without an HPD (open threshold), and then remeasure the subjects hearing threshold level while wearing the HPD (Occluded threshold).

The difference between the two thresholds , the threshold shift, is a measure of the attenuation, more precisely the IL (Insertion loss) afforded by the device. REAT methods have been incorporated in a number of standards, both in India and abroad.

Three ANSI standards have been promulgated for obtaining REAT measures. They include the original 1957 standard (ANSI Z.24.22-1957) that involves the use of pure tone stimuli presented through a speaker in a directional sound field and the 1973 (ANSI S3.19) and 1984 (ANSI S12.6) standards employing 1/3 octave bands of noise in a diffuse sound field.

2. Headphone REAT

Headphone REAT tests are indentical to the sound field REAT tests except that the sound field is established inside a set of circumaural enclosures outfitted with small loudspeakers (Micheal et al, 1976). This makes the testing considerably more portable and also less sensitive to ambient noise, since the headphone provide attenuation during both the open and occluded ear tests. The main disadvantage is that only insert HPDs can be tested. The method is ideally suited to infield measurement of HPD attenuation to determine real world performance.

3. REAT with hearing - imparied subjects.

The technique was first suggested by Thunder and Lankford (1979). Their specific purpose was to investigate HPD attenuation in high sound level environments. They hoped to accopmplish this by comparing HPD attenuation for 5 sensorineural hearing impaired subjects (average hearing threshold levels greater or equal to 40 dB at all frequencies) to that for 5 normal hearing subjects. They founds poorer attenuation at all frequencies (250-8KHz) for the hearing impaired subjects they concluded that HPD efficiency was reduced at high sound levels.

ABOVE THRESHOLD PROCEDURES

It is always reassuring when a quantity can be measured by alternative technique and similar values result. The above threshold procedures offer this capability. Furthermore, they permit investigation of (a)the posibility of level dependent attenuation effects, (b) REAT errors arising from masking due to amplification of physiological noise and (c) additional methods of measuring the performance of HPDs under field conditions. Above threshold procedure can generally eliminate the need for expensive test chambers necessary to ensure acoustical environments with subthreshold noise levels. The above threshold procedures will account for all acoustic transmission paths to the occulded and unoccluded ear since the final subject responses are based on the excitation of the inner ear.

1. MASKING: One of the earliest descriptions of the use of a masking technique for attenuation measurements may be found in paper by Webster (1955). He described placing an active earphone under an HPD while presenting masking noise via loudspeakers in the test chamber. The subjects noise masked threshold for earphone signal was then found for both the protected and unprotected conditions. He assumed that the change in the masked threshold corresponded to the attenuation provided by the HPD as long as the noise elevated the threshold for the earphone stimuli by atleast 20 dB in the protected condition. This method is only suitable for evaluating circumaural protectors.

2. LOUDNESS BALANCE: In its most simple form, the loundness balance procedure requires a subject to alternately don and doff a set of HPDs and to adjust a suprathreshold test stimulus for equal loudness under both conditions. Another version requires the subject to adjust sounds, presented alternately to the two ears via headphones, for equal loudness. One ear is then occluded by an insert and the loudness balance readjusted. In either case, the difference in signal level that is required to reestablish the balance is a measure of the HPDs attenuation, Loudness balance procedures are deceptively simple in concept, but as Rudmose (1982) and Theile (1985) have discussed, they are subject to many experimental artifacts which can affect the validity of the results.

3. MIDLINE LATERALIZATION : In addition to threshold and loudness balance decisions, human subjects are also adept at making lateralisation judgments. Lateralization occurs with headphone-presented acoustic stumuli. It descreas the sensation that arises when the sound source appears to be inside the head. If sounds of similar intensity and pitch are presented to the two ears via headphones, the lateralized location is the middle of the head that is midline lateralization. When subjects perform midline lateralization at the same position in the head, with and

without an earplug in the test ear (no earplug in the referece ear), the difference between the sound level in the test ear for the two conditions is a measure of the HPDs attenuation.

The midline lateralisation procedure has been described by Fleming and Cudworth (1979) and fleming (1980) The midline lateralization paradigm offers no advantages in speed, accuracy, or implementation relative to REAT testing, except that it can be conducted in higher ambient noise levels (approximately 60 dBA)

4. TEMPORARY THRESHOLD SHIFT: Any auditory phenomenon that is dependent on the intensity of the acoustic stimulation can in theory, be used to infer the attenuation provided by an HPD. The only aural after effect that seems to have actually been used in temporary threshold shift (TTS), is the change in threshold sensitivity at a particular frequency, measured at some designated time after a specfied exposure. The difference between the SPLs necessary to produce a particular TTS in the protected and unprotected conditions, respectively, is the effective protection. For example, suppose that a 5 min exposure to a 100 dB 1000 HZ tone produced a TTS$_2$ (TTS measured 2 min after exposure) at 1500HZ of 20dB in a particular listener's unprotected ear.

If with the HPD in place, it is necessary to raise the SPL from lOOdB to 130 dB in order to produce the same TTS$_2$, then the HPD has provided 130-100 = 30dB of attenuation.

The TTS method has some serious limitations other than the obvious fact that several exposure with the HPD in place will generally be necessary in order to find the SPL that will produce the target TTS. Use of these high levels means that, if the HPD is at all effectiv-e, the protected ear will be given exposures that are increasingly hazardous to the unprotected ear as the SPL is gradually raised successive exposures therefore, great care must be taken to fit the HPD consistently. Also the TTS developed must be limited to 20-30 dB in order to ensure complete recovery and no permanent damage.

Because of the relative inefficiency of the TTS method and the unavoidable hazard associated with its use, a more common implementation has been the measurement of the reduction in TTS generated by given particular exposure.

5. SPEECH INTELLIGIBILITY : Like the TTS- reduction method speech intelligibility test can be used to rate the relative performance of hearing protectors. For example the speach reception threshod, the level necessary for 50% correct

identification of bisylabic word lists, can be evaluated with and without hearing protection. The difference in dB between the speach reception thresholds is then a measure of the HPDs attenuation. The draw back of this approach is that is lacks frequency specificity.

There are some other miscellaneous psychophysical methods developed called cross modality loudness scaling, magnitude estimation and reaction time.

II. OBJECTIVE METHODS

As with the subjective above threshold procedures, the objective methods provide the ability to measure HPD performance at levels above threshold. Furthermore, the first two of the methods to be discussed, the acoustical test fixture and miniature microphone in real-ear methods, can expedite data acquisition, especially with todays computerized signal analysis systems. The remaining objective methods, microphones in cadaver ears and aural-reflex threshold shift (ARTS),do not save time and infact, create significant procedural problems which must be addressed.

The objective methods (with the exception of ARTS) do not directly account for all of the sound paths to the occluded ear, and BC is either incorporated via post- measurment computational adjustments, or ignored altogether. Even the cadaver ear method does not fully account for BC.

A. Acoustical test fixture Cartificial head/ear)

The ATF measurement technique is conceptually the most appealing of the test methods. Ideally, it would eliminate the need for subjects, provide accurate and repeatable. results, reduce test times, accomodate a wide variety of acoustic test signal and be suitable for product design, automated testing, and quality control manitoring. The perfect ATF has not yet been developed, but much literature exists describing efforts in that direction.

The precceding discussions concerning sound field parameters for standardized REAT tests pertain equally to ATF tests. Free or diffuse sound fields and direction of incidence will affect the results in similar ways, whether a real or artificial head is being protected. The only advantage in this regard that the ATF offers is the ability to tolerate higher test room noise levels, providing that the test signals are sufficiently amplified.

An ATF will, of course, be a model of a real head or an average real head. The degree to which it must mimic the mechanical and acoustical behavior of real heads is one of the first problems to be addressed. The most basic approach would be to simply mount a microphone in a box of suitable dimensions with its diaphragm either flush mounted or slightly recessed behind one surface. The insertion loss is then measured by monitoring the SPL with and without the HPD. This model ignores the possible importance of head geometry, skin, bone, eartilage dynamics, pinna and concha effects, eardrum and ear canal inpedance, the development of air leaks at skin HPD interfaces, and the BC paths. Different acoustical test fixtures have been developed by ASA, ISO, ISVR, Lucas, KEMAR and UB.

But none of the authors who have developed and used ATFs has tried to physically model the dynamic structure of the human skull. The model of skull vibration are a function of both frequency and method of excitation and couple via multiple pathways to the cochlea. Thus far, this complex vibratory, system has eluded successful analytical or mechanical modeling.

B. Microphone in real ear

An alternative to using an artifical head as a test fixture in which to place a measurement microphone is to use a real head. This procedure is similar in speed and capability to the artifical head method, while offering the advantage of a more accurate test fixture that exhibits all of the anthropometric features and leakage paths that real world HPD users do. Unfortunately, this method neglects the important BC paths, as does the artificial head approach, although post- measurement corrections can be applied.

When measuring in real ears, either insertion loss (ID (using one microphone) or noise reduction (NR) (using two microphone) measurements are possible the IL measurements are more relevant to actual user protection but in this case, tend to limit the usable test SPLs since, in the unprotected condition, a real ear will be exposed to approximately the same levels as the microphone. Thus the NR measure offers mores flexibility, but does need to be corrected to account for the TFOE.

In the mid-1950s, researchers began investigating the use of microphone in real ear method. (Dickson etal, 1954; Webster, 1955) Until recently (Berger and Kerivan, 1983) this technique has been limited to measuring circumaural and supra-aural HPDs due to difficulty of mounting a microphone or probe tube in the canal in conjunction with the insertion of an earplug.

Weinreb and Touger (1960) found close agreement between microphone in real ear and loudness balance data. Furthermore the microphone -IL and loundess balance values agreed reasonably well with REAT data for the same devices, with the REAT averaging 3 to 5 dB higher except at 2KHz where they were lower. This latter feature can be explained for those devices whose attenuation starts to approach BC thresholds. It is most likely to occur at 2KHz where BC is most sensitive. For that condition the REAT value will be limited by the flanking BC paths, whereas the micriphone in the canal with not sense energy conducted to the ear via that path, and therefore, will measure a lower sound level hence a higher IL.

Another interesting feature of the Weinreb and Touger (1960) study was that the variability they found for the objective data was no smaller than for the subjective data. The data of Berger and Kerivan (1983) also confirm this latter observation to a significant extent as do the reported results of Dickson etal (1954). This suggests that the primary variability in the REAT paradigm is the placement of the HPD or perhaps variations in the test stimuli, and not uncertainty in the determination of the subjects thresholds.

Villchur (1972) measured the IL of earphone drivers mounted in MX-41/AR cushions using a probe tube microphone assembly mounted in the concha. He compared his data to ANSI Z24.22-1957 atenuation values provided by Copeland and Mowry (1971) for the same type of device. The differences were less than or equal to 3dB from 500to 8000 Hz, but increased to 4.3 and 6.9 dB at 250 and 125Hz, respectively. The REAT values exceeded the microphone measured values at all frequencies. The author suggested that the error was in the REAT procedure and that it was due to masking arising from physiological noise. He provided confirmation of his hypothesis by comparing earphone and free field thresholds for five subjects. The earphone thresholds were masked by the same amount that the REAT exceeded the IL measured values.

The most comprehensive comparison of REAT and microphone in real ear data, and the only one to include semiaural and insert HPDs was conducted by Berger and Kerivan (1983). They limited their investigation to frequencies upto and including 2KHz, since only up to that frequency was the SPL measured in the ear canal substantially independent of the microphone position. This assured that IL would be unaffected even if the microphone moved slightly during application or removal of the HPD their data confirm the occlusion effect/physiological noise hypothesis, as well as the general accuracy of the REAT methodology.

Dillon and Murray (1987) have demonstrated quite convincingly, the equivalence of functional and insertion gain . Hawkins and Dirks and Kincaid (1987) have shown that real ear measure of insertion gain are highly reliable if care is exercised in positioning the probetube at a constant location within the ear canal.

Due to the success of the probe tube microphone system in real ear amplification measurement, Gerling, Metz, Boemer-Bonko and Rowsey used it in meaurement of attenuation of hearing protectors, specifically they used, it in comparing foam insert hearing protectors using probe, tube microphone method and threshold method. The results reveals that the functional attenuation and real ear occlusion loss were within ldB to 7dB of each other through 3000HZ. Above 3000HZ the probe results show a progressively marked decrease in the amount of occlusion loss when compared to the behavioral attenuation obtained in this study. These resutls can again be supported by the explanation that comes from Berger and Kerivan (1983) study.

In another study by Traynor, Ackley and Wierbowsky the mean attenuation in dBSPL (functional measurement) was compared with those obtained from two probe tube microphone conditions

(a) Insertion held condition where the subject was made to hold the HPD in place with thier finger to increase the hermetic seal afforded by the HPD.

(b) Insertion condition where the HPD was not held in postion but simply inserted as far as possible. A difference in mean attenuation in dBSPL of about 17.94 dB between the real ear at threshold condition and the simple insertion condition was obtained while a difference of only 6.25 dBSPL from real ear at threshold and insertion held condition was obtained. Although this difference was smaller than the insertion condition the variability was much higher.

The difference in average dB SPL attenuation noted between the real ear at threshold and the probe tube technique were thought to be created by the loss of the HPDs hermetic seal due to the introduction of the probe tube between the HPD and ear canal.

ADVANTAGES

Nixon (1982) in a review of several methods avaiblable for assessment of attenuation characteristics of hearing protectors, cited 5 criteria that a procedure must satisfy in order to make it suitable for standardization. The five criteria were that it

1) was relatively simple,

2) had universal application,

3) yielded results that could be generalised to the total population,

4) was not too costly,

5) was not time consuming.

It appears that the probe technique of assessing hearing protection device attenuation does hold promise in satisfying these five criteria.

a) In addition it also provides information over a large array of frequencies and changes in attenuation in ldB step can also be determined.

b) There is also elimination of subjects threshold response variabi1ity

c) No contamination of aided thresholds by room noise. Room noise could be a problem with REAT measurements especially if the subjects have normal thresholds.

DISADVANTAGES

i. This method negelects the important BC path.

METHODOLOGY

A: This study is aimed at comparing the attenuation characteristics of the indigenously manufactured ear protective device with that of the imported ones.

B: Included is also a case study comparing the attenuation characteristics of two custom made ear protective devices, one made of indigenously available raw material[Rhodorsil - 3B] and the other made of imported raw material[otosil].

SUBJECTS

A: Thirty ears with normal hearing were chosen for the study Of these, 16 ears belonged to females and 14 ears to males. All these ears were free from any otologic complaint prior to and at the time of testing.

B: Eight ears with normal hearing were chosen. For each ear custom made ear protective devices from both types of raw materials were made.

SELECTION OF EAR PROTECTIVE DEVICES

A: Four types of ear plugs were chosen of which two were imported and two were indigenously manufactured.

(1) IMPORTED PLUGS;

(a).E.A.R PLUGS: They are patented energy absorbing soft polymer foan ear plugs. Available in one size,the expandable foan plugs are self fitting. They are reusable,washable and have a NRR of 35dB.

(b) WAXED PUTTY TYPE OF PLUGS: They are reusable and moldable plugs made of a waxed putty-like substance.

(2).INDIGENOUS PLUGS;

(a).FLANGED EAR PLUGS: They are made of soft, sturdy rubber having tapered concentric flanges to snug ear properly. They are reusable after cleaning.

(b).EXPANDABLE FOAM PLUGS: They are reusable foam plugs which take the shape of the ear canal once inserted.

B: INDIGENOUSLY AVAILABLE RAW MATERIAL:

RHODORSIL - 3B: It is a silicone based Material.

IMPORTED RAW MATERIAL: OTOSIL: This is again a silicon based material.

INSERTION RESPONSE MEASUREMENT

Insertion response measurement was done in a sound treated room using Fonix 6500. The noise levels were within permissible limits. Room and Probe Calibration was done as instructed in manual prior to data collection.

PROCEDURE: For measuring the insertion loss, the subjects were seated 12 inches away from the loudspeaker at 45 degree azimuth. The speaker height was adjusted to the same height as that of the individuals' ear. The patients were instructed to sit still. The sweep frequency warble tone from the loud speaker was maintained at a constant level of 70 dB SPL. The soft probe tube microphone was placed at the ear canal and a red line was drawn on the probe tube by a marker to keep the insertion length constant. The test was carried out first without the EPD.

After this, without removing the probe tube, the EPD was anchored to the ear. The occluded measurement was done with the EPD in the ear. The insertion loss for the warble tone was measured from 500 Hz to 8 KHz at every 500 Hz step in dBSPL. The insertion loss values were then compared across frequencies as well as across the different types of EPD's.

DATA SHEETS

TABLE 1: Attenuation characteristics obtained from EPD 1: Flanged ear plug [indigenously available] from 30 subjects.

FREQUENCY [in Hz]	MEAN ATTENUATION [in dB]	STANDARD DEVIATION
500	5.27	5.59
1000	9.14	6.39
1500	10.18	5.97
2000	13.91	6.21
2500	16.83	6.81
3000	14.48	7.22
3500	11.24	6.55
4000	9.67	5.96
4500	8.96	6.47
5000	8.45	8.08
5500	6.74	6.46
6000	5.53	5.34
6500	3.45	6.01
7000	4.46	7.51
7500	4.28	5.32
8000	4.81	6.87

TABLE 2: Attenuation characteristics obtained from EPD 2: Expandab1e Foam[indigenously available] from 30 subjects.

FREQUENCY [in Hz]	MEAN ATTENUATION [in dB]	STANDARD DEVIATION
500	7.16	3.98
1000	11.42	4.55
1500	12.10	5.42
2000	14.25	5.25
2500	17.90	5.92
3000	15.12	7.34
3500	14.24	7.27
4000	14.06	6.68
4500	12.57	7.29
5000	11.04	7.79
5500	8.81	6.40
6000	7.03	7.05
6500	5.10	6.55
7000	3.68	6.32
7500	3.96	6.50
8000	4.42	7.53

TABLE 3: Attenuation characteristics obtained from EPD 3 (imported expandable foam ear plugs) from 30 subjects.

FREQUENCY [in Hz]	MEAN ATTENUATION [in dB]	STANDARD DEVIATION
500	8.54	4.39
1000	11.72	4.64
1500	14.57	5.10
2000	15.55	5.54
2500	19.74	7.15
3000	16.28	9.28
3500	14.34	8.22
4000	14.18	6.89
4500	12.70	7.55
5000	11.20	7.72
5500	9.79	8.01
6000	7.61	7.45
6500	5.20	7.20
7000	3.75	8.11
7500	5.01	7.62
8000	6.52	8.30

TABLE 4: Attenuation characteristics obtained from EPD 4 (imported waxed putty type) from 30 subjects.

FREQUENCY [in Hz]	MEAN ATTENUATION [in dB]	STANDARD DEVIATION
500	6.17	5.24
1000	10.40	5.39
1500	12.00	5.71
2000	14.13	6.17
2500	18.93	6.35
3000	14.92	7.13
3500	13.45	6.86
4000	13.25	5.85
4500	12.13	7.18
5000	10.09	7.58
5500	8.02	8.07
6000	6.37	6.37
6500	5.27	6.13
7000	4.54	7.94
7500	4.75	7.84
8000	5.77	8.46

RESULTS AND DISCUSSION

The present study was designed to compare the attenuation characteristics of two indigenously available and two imported ear protective devices (EDPs).

The study was performed on 30 normal ears and attenuation characteristics were obtained for each ear protective device from 500 Hz to 8000 Hz, in 500 Hz steps using probe microphone measurements.

The data collected was statistically analysed. The mean and standard deviation of the attenuation characteristics obtained at the various frequencies for the four EPDs are presented in tables 1, 2, 3 & 4 respectively.

The tables indicate that the best attenuation for all the four EDPs was obtained between 1 KHz and 5 KHz. On either side of this range the attenuation characteristic was relatively less.

Analysis of variance (ANOVA) was done to see whether there was any difference in the overall attenuation provided by the four different EPDs. The 'F' ratio obtained was 1.88 and the probability was 0.1363. This suggests that the difference in the attenuation characteristics between the four EPDs was insignificant.

Since no difference in the overall attenuation was seen,further analysis was done-by applying the 't' test to see if there was any difference at individual frequencies between the four EPDs. To see whether a particular EPD was best suited to provide attenuation at a particular set of frequencies.

TABLE:5 showing the level of significance obtained from 'T' test between 1the two indigenously available EPD's. EPD 1 (flanged) EPD 2 (expandable **foam)**

Frequency(Hz)	t	P	Level Of Significance
500	-1.51	0.13	NS
1000	-1.59	0.11	NS
1500	-1.30	0.19	NS
2000	-0.22	0.82	NS
2500	-0.64	0.51	NS
3000	-0.34	0.73	NS
3500	-1.67	0.09	NS
4000	-2.68	0.00	**S****
4500	-2.03	0.04	S*
5000	-1..26	0.21	NS
5500	-1.24	0.21	NS
6000	- .92	0.35	NS
6500	-1 .01	0.31	NS
7000	+0 .43	0.66	NS
7500	+0 .20	0.83	NS
8000	+0 .20	0.83	NS

Table 5 shows that there is significant difference between EPD 1 and EPD 2 only at 4 KHz and 4.5 KHz. This suggests that there is no statistically significant difference between the two indeginously andd available EPD's.

Note: ** significant at .01 level * significant at .05 level

TABLE:6 Showing the level of significance obtained from 't' test between EPD1 (Indigenous flanged plugs) and EPD3 (imported E.A.R plugs)

Frequency(Hz)	t	P	• Level Of Significance
500	-2.51	0.01	S**
1000	-1.78	0.07	NS
1500	-3.06	0.00	**S****
2000	-1.07	0.28	NS
2500	-1 .61	0.11	NS
3000	-0.83	0.40	NS
3500	-1.61	0. 11	NS
4000	-2.70	0.00	**S****
4500	-2.06	0.04	**S***
5000	-1.35	0.18	NS
5500	-1.62	0. 10	NS
6000	-1.24	0.21	NS
6500	-1.01	0.31	NS
7000	+0.34	0.72	NS
7500	-0.43	0.66	NS
8000	-0.86	0.38	NS

TABLE:6 Shows that there is significant difference between EPD-1 and EPD-3 at 500 Hz ,1000 Hz,4000 Hz at .01 level and 4500 Hz at 0.05 level.

TABLE:7 Showing the level of significance obtained from *'T'* test between EPD-1 (Indian flanged plugs) and EPD-4 (Imported waxed putty plugs).

Frequency(Hz)	t	P	Level Of Significance
500	-0.64	0.52	NS
1000	-0.82	0.41	NS
1500	-1.20	0.23	NS
2000	-0.13	0.89	NS
2500	-1.23	0.22	NS
3000	-0.23	0.81	NS
3500	-1.27	0.20	NS
4000	-2.34	0.02	**S***
4500	-1.79	0.07	NS
5000	-0.81	0.42	NS
5500	-0.68	0.49	NS
6000	-0.55	0.58	NS
6500	-1.15	0.25	NS
7000	-4.34	0.96	NS
7500	-0.27	0.78	NS
8000	-0.48	0.63	NS

TABLE:7 Shows that there is significant difference between EPD-1 and EPD-4 only at 4000 Hz at 0.05 level. This shows that there is no statistically significant difference in the overall attenuation provided by the two EPD's.

TABLE:8 Showing the level of significance obtained from 't' test between EPD-2 (Indian expandable foam) and EPD-3 (Imported E.A.R plugs)

Frequency(Hz)	t	P	Level Of Significance
500	-1.27	0.20	NS
1000	-0.24	0.80	NS
1500	-1.82	0.07	NS
2000	-0.92	0.35	NS
2500	-1.08	0.28	NS
3000	-0.53	0.59	NS
3500	-0.05	0.95	NS
4000	-6.46	0.94	NS
4500	-6.93	0.94	NS
5000	-8.23	0.93	NS
5500	-0.52	0.60	NS
6000	-0.31	0.75	NS
6500	-5.43	0.95	NS
7000	-3.90	0.96	NS
7500	-0.57	0.56	NS
8000	-1.02	0.30	NS

TABLE:8 Shows that there is no significant difference in the attenuation characteristic any frequency between EPD-2 and EPD-3.

TABLE:9 Showing the level of significance obtained from 't' test between EPD-2 (Indian expandable foam) and EPD-4 (Imported waxed putty plugs)

Frequency(Hz)	t	p	Level Of Significance
500	+0.82	0.41	NS
1000	+0.79	0.43	NS
1500	+6.95	0.94	NS
2000	+8.32	0.93	NS
2500	-0.64	0.52	NS
3000	+0.10	0.91	NS
3500	+0.43	0.66	NS
4000	+0.50	0.61	NS
4500	+0.23	0.81	NS
5000	+0.47	0.63	NS
5500	+0.41	0.67	NS
6000	+0.37	0.70	. NS
6500	-0.10	0.91	NS
7000	-0.46	0.64	NS
7500	-0.42	0.66	NS
8000	-0.65	0.51	NS

TABLE 9 Shows that there is no significant difference between EPD-2 and EPD-4 at any frequency.

TABLE 10: Showing the level of significance obtained from 't' test between EDP 3 (imported EAR plugs) and EDP 4 (imported waxed putty plug)

Frequency(Hz)	t	P	Level Of Significance
500	1.89	0.06	NS
1000	1.01	0.31	NS
1500	1.84	0.07	NS
2000	0.93	0.35	NS
2500	0.46	0.64	NS
3000	0.63	0.52	NS
3500	0.45	0.64	NS
4000	0.56	0.57	NS
4500	0.30	0.76	NS
5000	0.56	0.57	NS
5500	0.85	0.39	NS
6000	0.69	0.49	NS
6500	-0.04	0.96	NS
7000	-0.38	0.70	NS
7500	0.12	0.80	NS
8000	0.34	0.73	NS

Table 10 shows that there is no significant deference between EPD 3 and EPD 4 at any frequency. The results suggest that all the ear protective devices were equally were efficient in providing the same amount of attenuation at the same set of frequencies.

RESULTS OF THE CASE STUDY

The case study was done to compare the attenuation characteristics of two custom made ear protective devices, one made of indigenously available raw material (Rhodorsil - 3B) and other made up of imported raw material (otosil).

The study was performed in a similar manner as for the previous four EPD's, but only on a small group of eight ears.

Table 11 and 12 represent the mean attenuation and the standard deviation obtained for the two EPD's respectively.

On doing the analysis of variance the 'F^5 ratio was found to be 0.90 and the probability was 0.3576 . This shows that the difference in the attenuation characteristics between the two custom made EPD's was insignificant.

TABLE 11: Attenuation characteristics obtained from custom made EPD from the material rhodorsil - 3B (indigeneously available)

FREQUENCY I in Hz]	MEAN ATTENUATION [in dB]	STANDARD DEVIATION
500	12.48	7.95
1000	13.18	7.84
1500	17.07	6.86
2000	17.88	6.08
2500	20.23	6.79
3000	21.81	7.34
3500	20.25	5.75
4000	19.21	5.34
4500	16.83	6.20
5000	13.58	7.37
5500	13.55	9.26
6000	10.68	9.33
6500	7.54	7.99
7000	6.43	5.53
7500	7.28	5.18
8000	7.65	6.25

TABLE 12: Attenuation characteristics obtained from custom made EPD from the material otosil [imported raw material).

FREQUENCY [in Hz]	MEAN ATTENUATION [in dB]	STANDARD DEVIATION [in dB]
500	10.56	9.17
1000	9.82	6.67
1500	15.68	6.45
2000	16.40	5.33
2500	19.10	6.13
3000	20.67	7.98
3500	19.01	6.07
4000	17.03	5.48
4500	15.86	7.23
5000	13.23	7.68
5500	13.58	10.40
6000	11.12	9.84
6500	6.16	8.56
7000	5.21	5.04
7500	6.40	5.20
8000	7.36	6.75

TABLE 13: Level of significance obtained from "t" test between the custom made rhodorsil - 3B EPD and custom made otosil EPD.

FREQUENCY (Hz)	t	P	LEVEL OF SIGNIFICANCE
500	0.96	0.35	NS
1000	1.84	0.08	NS
1500	0.79	0.43	NS
2000	0.97	0.34	NS
2500	0.65	0.52	NS
3000	0.60	0.55	NS
3500	0.85	0.40	NS
4000	1.73	0.10	NS
4500	0.61	0.55	NS
5000	0.18	0.85	NS
5500	0.01	0.98	NS
6000	0.18	0.85	NS
6500	0.67	0.50	NS
7000	0.87	0.39	NS
7500	0.67	0.51	NS
8000	0.18	0.85	NS

TABLE 13 shows the results obtained on doing further analysis through "t" test. It was found that the difference in attenuation characteristic between the two EPDS frequencies was insignificant at all levels of significance.

SUMMARY AND CONCLUSION

The present study was aimed at answering the following questions:-

(1) Are indigenously available ear protective devices comparable to the imported ones in providing attenuation?

(2) Do the different ear protective devices provide varying attenuation at different frequency range?

(3) Do material variations result in significant differences in the attenuation characteristics of the different ear protective devices?

A sample of 30 ears with normal hearing were tested. The attenuation characteristics of the four ear protective devices was measured from 500 Hz to 8000 Hz in steps of 500 Hz using probe microphone measurements with Fonix 6500.

For the case study a sample of 8 ears with normal hearing were tested. The attenuation characteristics of the two custom made ear protective devices from different materials was measured in a similar manner as for the above four standard ear protective devices.

The study revealed that all the four ear protective devices provided attenuation of similar magnitude in the same frequency range with no statistically significant difference at any frequency.

The average attenuation provided by EPD - 1 [Indigenous flanged variety] was 8.58 dB across all the frequencies with maximum attenuation of 16.83 dB at 2.5 KHz. Maximum attenuation was provided in the mid frequency range while attenuation was low for the lower and higher frequencies.

The average attenuation provided by EPD - 2 [Indigenous expandable foam variety] was 10.18 dB with maximum attenuation of 17.90 dB at 2.5 KHz and a minimum of 3.68 dB at 7KHz. The spread of attenuation across the frequencies was similar to maximum attenuation at the mid frequency range and lower attenuation at low and high frequencies as seen above.

The average attenuation provided by EPD - 3 {Imported EAR plugs] was 11.24 dB with a maximum attenuation of 19.74 dB at 2.5 KHz and a minimum of 3.75 dB at 7 KHz.

The average attenuation provided by EPD - 4 [Imported waxed putty variety] was 10.01 dB with a maximum attenuation of 18.93 dB at 2.5 KHz and a minimum of 4.54 dB at 7 KHz. For both the above imported EPDs the spread of attenuation across the frequencies was similar to that seen in the indigenously available EPDs with maximum attenuation in the mid frequencies and lower attenuation at the low and high frequencies.

Based on the above result it can be inferred that an individual can choose any of the four ear protective devices to provide him with attenuation based on his comfort and best fit.

Preliminary testing with custom made ear protective devices seem to indicate that they provide more attenuation than do the standard ear protective devices. Further studies comparing the attenuation provided by standard ear protective devices with that provided by custom made ear protective devices is recommended to understand whether custom made ear protective devices provide better attenuation than do the standard ear protective devices.

Also from the case study it may be inferred that material differences do not result in any significant differences in attenuation characteristics between the ear protective devices.

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