OVERVIEW OF BUREAU OF MINES HEARING PROTECTION RESEARCH

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ABSTRACT

Hearing protective devices (HPD's) can be a useful adjunct in an overall program designed to control the noise exposure of miners. Performance data on HPD's obtained using standard laboratory measurements appear to overestimate the amount of protection from noise overexposure a working miner may receive from these devices. In order to more effectively evaluate hearing protector performance, the Bureau of Mines is investigating the basic parameters that influence the noise attenuating properties of HPD's. Initial phases of this research have focused on ear muff-type protectors. Alternative methods for the determination of total attenuation of ear muffs have been compared with the standard laboratory procedure and potential problem areas have been defined. Investigation of human physiological parameters that may affect the intrinsic noise level under a single earcup is being made to measure the absolute or baseline value that might be used as a reference level for the physical measurement of ear muff attenuation.

INTRODUCTION

Exposure to high levels of noise is recognized as a serious potential health hazard. Hearing loss due to noise overexposure in industry is well documented. In addition to hearing loss, the literature contains references of nonauditory effects of noise exposure that indicate general stress reactions, disturbance of sensory functions such as vision, and impairment of task performance and perception of speech. Included are reports of increased cardiovascular disease, general increases in various medical problems and absenteeism, higher accident rates, etc., in noise--exposed workers when compared with groups of workers with less severe noise exposure. Consequently, various criteria have been developed to eliminate or minimize the potential hazards of noise overexposure.

Mining is a noisy industry. Mechanized operations provide the most severe noise exposures. In surface mining, jumbo rock drills typically produce noise levels in the range of 110 to 120 dBA, and bulldozer operators are often exposed to levels that may exceed 100 dBA. In underground mining, hand-held percussion drills and automated mining machines, such as a continuous miner, produce noise levels often greater than 90 dBA. It is not unlikely then that a significant portion of miners are chronically exposed to levels of noise that may be considered harmful to hearing.

The Code of Federal Regulations (CFR 30) provides regulations for the assessment and control of noise exposure to miners in the mineral resource industry. Although minor differences in the regulations exist for various types of mining, the primary goal in each is to prevent permanent hearing loss in miners. An exposure level of 90 dBA of continuous noise is allowed for an 8-h shift, with 5-dBA increases in noise level allowed for a successive reduction of one half the allowable exposure time, up to a maximum of 115 dBA for 15 min. Levels must be monitored to insure compliance. If overexposures are observed, they must be brought into compliance. Engineering and/or administrative control procedures are required to abate the overexposure.

Engineering control involves the reduction of noise by modification of the

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source or by preventing noise generated by the source from reaching the worker. The noise pathway and/or the noise intensity can be reduced to acceptable levels in the worker's environment. This method is preferable since it places no burden on the worker to reduce the hazard. Usually some time is required to install engineering controls on a piece of equipment, and unless the equipment is out of operation, overexposure can continue. Occasionally these controls, while reducing the worker's exposure to noise do not entirely eliminate the problem and some degree of overexposure persists. In some instances, the technology to control a particular source of overexposure is not available.

Administrative control involves restructuring work patterns or product flow to reduce workers' risks of overexposure. For example, workers who are exposed to a high noise level may be shifted to a less noisy job for part of their working time to allow their total exposure to the health to be brought within acceptable limits. This control method is often difficult to implement. It can cause significantly higher production costs, require greater numbers of trained employees for some tasks, and, if the continuous noise level is greater than 115 dBA, it cannot be used.

As a temporary measure until engineering-administrative controls are in place, personal HPD's may be used. CFR 30, part 70, subpart F, paragraph 70.510 and part 71, subpart I, paragraph 71.805 require a "continuing, effective hearing conservation program to assure compliance," which includes the availability of personal ear protective devices to miners.

USE OF HEARING PROTECTIVE DEVICES

Personal hearing protectors represent the least desirable means of controlling a worker's noise exposure. Hearing protectors, like respirators, etc., impose a burden on the worker while the source of the environmental hazard has not been eliminated or altered. However, they can provide a useful adjunct in an overall program designed to protect the worker's hearing when additional protection is needed or other methods of control are not feasible.

Noise, or unwanted sound, of sufficient intensity can cause hearing damage when it enters the human ear. HPD's prevent the transmission of sound from the environment to the ear by providing a barrier that does not permit the total sound intensity from passing through the protector.

The most common types of personal hearing protectors are earplugs and ear muffs. Earplugs are made of pliant material and are intended to fit snugly into the outer ear canal. Ear muffs are circumaural devices that enclose the entire external ear and prevent the passage of sound. Individual earcups enclose each ear and are held in place with pressure provided by a headband. Soft cushions filled with foam or fluid are intended to seal the space between the head and the ear muff. The ear muff is formed of rigid, dense material for maximum protection. The inside of the earcup is usually filled with open-celled foam material to absorb high frequency sound that may resonate in the cavity of the muff.

Variants of the basic types of protectors include cotton wool, which is inserted into the ear canal; headsets, which generally contain communication equipment or filtering electronics to allow only selected sound to pass; semi-inserts, which rest on and occlude the entrance of the ear canal; and complete head enclosures.

METHODS OF EVALUATING HPD's

ANSI S3.19-1974 outlines standard procedures for evaluating the attenuation (noise reduction) provided by HPD's. The real-ear method is used to measure the hearing threshold of a number of human subjects and then the measurement is repeated on the same subjects while they are wearing the HPD's. The difference in decibels between the unoccluded (no HPD worn) threshold and the subject's threshold while wearing an HPD is the protector's attenuation capability. This is averaged for the various subjects and presented for each audiometric frequency. This laboratory method is the standard method most commonly used to measure the effectiveness of HPD's.

A physical method is also described in ANSI S3.19-1974, which uses a dummy head covered with simulated "human" skin made of a plastic material. A measurement microphone is embedded in one ear. Hearing protectors are placed on the dummy head or into the ear canal of the dummy head, and a sound field is generated around the head. The difference, at the respective frequencies, between the measured intensity at some distance outside of the dummy head (and outside of the HPD) and that measured on the inside of the dummy ear is the attenuation of the HPD.

LIMITATIONS TO THE USE OF HEARING PROTECTORS

No HPD is a perfect attenuator that can eliminate all sound transmission. The effectiveness of an HPD to provide its measured attenuation depends on factors related to the manner in which sound energy is transmitted through or around the HPD. Figure 1 presents the pathways by which sound can reach the ear while a person is wearing hearing protectors. These include (1) small air leaks in the seal between the hearing protector and the head surface, (2) transmission through the material of the HPD, (3) vibration of the HPD in response to the external sound energy impinging upon it, and (4) bone conduction whereby sound is transmitted through the skull.

Theoretical Protection Limits

If the entrance to the ear canal could be occluded with a material impervious to sound, sound would still reach the inner ear through tissue and bone conduction of sound through the skull. This tends to provide a theoretical maximum amount of attenuation one could expect from an HPD. Although this limit has not been precisely determined, figure 2 illustrates the observed range of bone and tissue conduction in individuals. The value varies by individual and frequency, but an average value of 50 dB below the open air conduction level of hearing is often used as the maximum sound attenuation one could expect from a perfect HPD.

Practical Limits of Protection

Certain design considerations tend to further limit the amount of attenuation that can be achieved by hearing protectors. These include size of protector and type of material used. Earplugs must be small enough to fit into the ear canal. Ear muffs must be large enough to

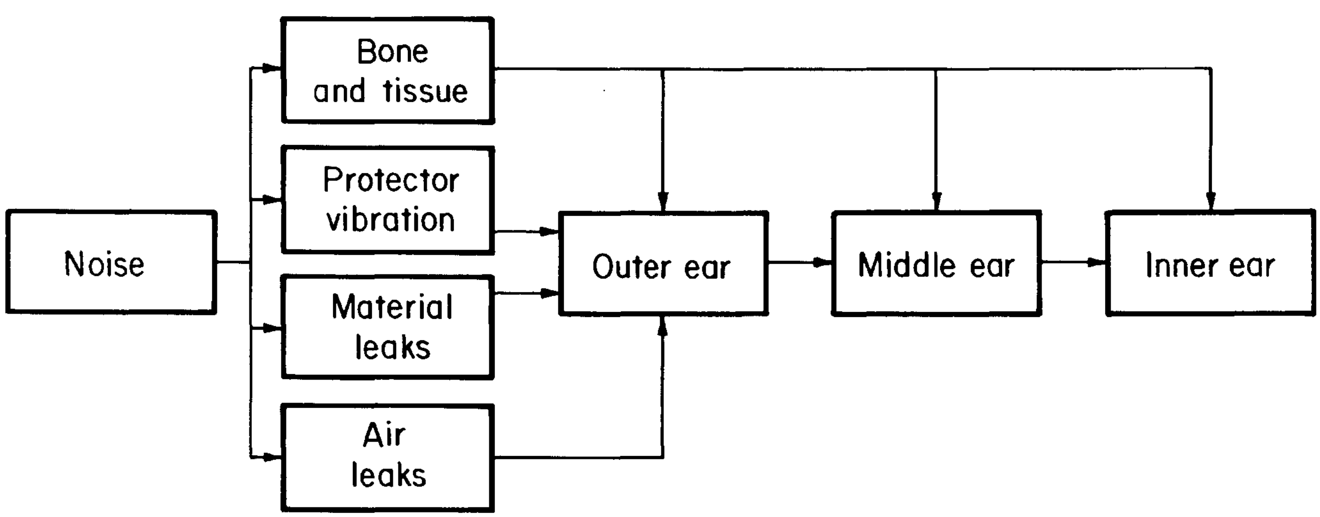

FIGURE 1. - Noise pathways to ear when individuals are wearing hearing protectors.

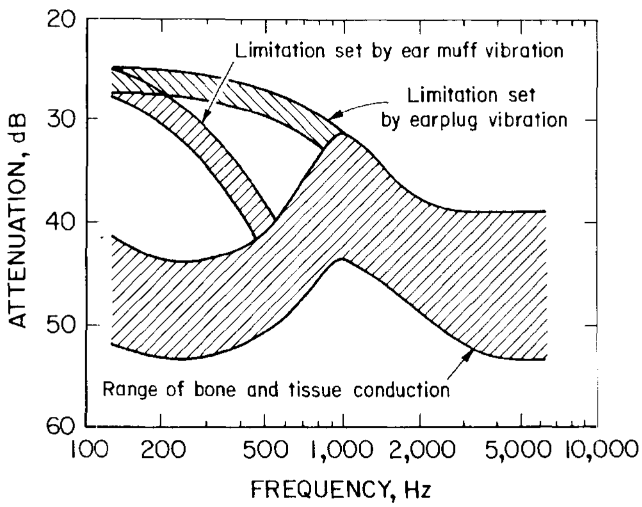

FIGURE 2. - Attenuation limits of hearing protectors imposed by bone conduction and protector vibration.

enclose the space around the ear, but must be made sufficiently small to accommodate the dimensional characteristics of the human head and minimize irregularities over which the acoustic seal takes place.

Materials used to construct earplugs should be pliant enough to fit snugly into the ear canal and prevent leaks. Protector earcups on ear muffs should be made of rigid, dense material and the ear muff cushions should be made of soft, pliant material to provide an adequate seal around the ear. Also, the weight of the material used in making ear muffs is an important factor in comfort and fit.

Figure 2 indicates limitations in attenuation due to earplug and ear muff vibration. The effectiveness of the HPD is significantly less at lower frequencies (below 1 kHz for plugs and below 500 Hz for muffs). In this frequency range the overall performance of the HPD is controlled by the transmission loss characteristics of the materials used in construction of the device. This limit, rather than bone conduction, determines the maximum attenuation one might expect from an HPD.

Sound consisting of frequencies with a wavelength on the order of the size of the earcup of an ear muff can pass into the protector and resonate. The earcup acts as a Helmholtz resonator and the sound intensity can be amplified rather than reduced. Open-celled foam is generally placed on the inside of the earcup to minimize this phenomenon.

At best then, a good HPD can be expected to provide a maximum average attenuation of 25 to 35 dB. As a rule, ear muffs offer greater attenuation at higher frequencies than earplugs (fig. 3). A combination of the two generally provides greater protection than each one individually (fig. 4). Although the total protection at any given frequency is not

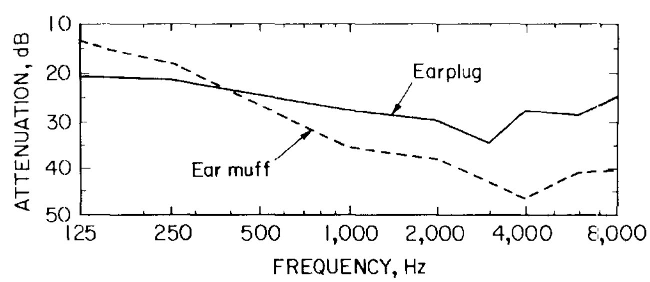

FIGURE 3. - Comparison of the attenuation of an ear muff and an earplug.

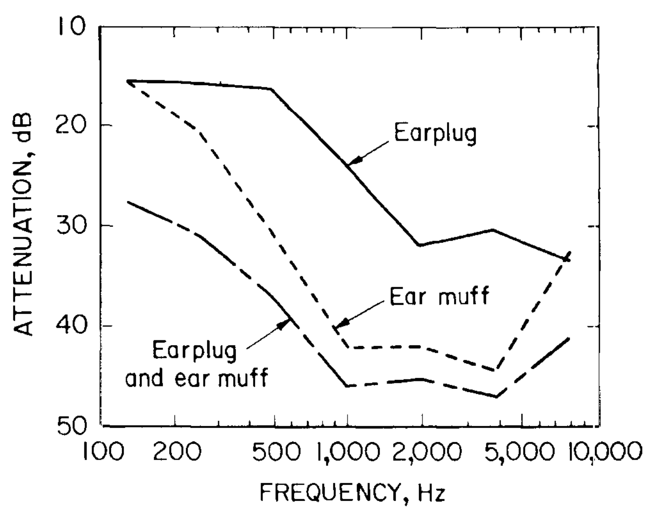

FIGURE 4. - Mean attenuation of an earplug, an ear muff, and combination.

merely the simple sum of the individual attenuations, a rule of thumb estimates the average resultant attenuation of about 6 dB greater than the higher attenuation of the individual HPD at most test frequencies.

FIELD PERFORMANCE OF HPD's

Laboratory measurements of real-ear attenuations provided by HPD's tend to approach those practical reductions in sound intensity that might be achieved. There is evidence to suggest that the effectiveness of HPD's when worn under working conditions is not as great as measured in the laboratory. Thunder (1),[3] in a comparison of a specific ear protector on "normal" and hearing impaired subjects, indicated that the real-ear method as described in ANSI S3.19-1974 may overestimate the attenuation of HPD's used in a noisy environment.

In a NIOSH-sponsored study, Edwards (2-3) indicated that for noise reduction by earplugs, noise attenuation levels measured in the field were only 35 to 50 pct of the potential attenuation levels measured in the laboratory.

[3]Underlined numbers in parentheses refer to items in the list of references at the end of this paper.

A study done by Holland (4) compared the use of V51-R earplugs with attenuation of noise achieved by applying finger pressure on the tragi (the tragus is the fleshy protrusion at the front of the external opening of the ear) to close off the ear canal; placing the fingers in the ear canal; and firmly pressing the palms of the hands over the external ear. The results indicated that the use of tragus pressure provided the most effective attenuation, palm pressure and fingers slightly less attenuation, and the earplug the least attenuation.

Berger (5) compiled data shown in table 1, which compares laboratory or manufacturers data on the noise reduction rating with observed field measurement's of noise reduction for various HPD's. In all cases, the laboratory measurements indicate greater average attenuations than field measurements. These data were compiled from several sources and may reflect some variation because of measurement technique, differences in sample size, and other factors, but the trend is consistent.

Air Leaks

It is apparent that noise reductions achieved in the field are much lower than those demonstrated in the laboratory.

TABLE 1. - Comparison of laboratory- and field-measured noise reduction rating (5), decibels

	Laboratory	Field	No. of measurements
Earplugs:			
Earplugs	29	13	152
Custom	17	6	291
Wilson EP 100	15	3	95
V51-R	23	2	296
MSA Acufit	14	2	13
Bilsom Down	16	3	56
Norton Comfit	26	7	18
Ear muffs:			
David Clark 805	23	15	17
Safety Supply 258	22	12	15
Hellberg MK IV	23	11	58
MSA MK IV	23	11	47
Welsh 4530	25	20	5
Miscellaneous	20	14	101

The primary cause for this is due to improper seal of the HPD, which allows air to leak between the HPD and skin. An 0.5-mm air leak can reduce the attenuation of a hearing protector by about 5 to 10 dB. Small leaks significantly reduce the low frequency attenuation of sound and as the leak becomes larger, attentuation is reduced at all frequencies (6).

Seal leaks are primarily caused by poor or improper fitting HPD's. Ear muffs worn over long hair, eyeglasses, or other objects provide less attenuation because of leakage caused by an incomplete seal. Nixon (7) reported that ear muffs worn over eyeglasses lose from 1 to 10 dB of attenuation at the individual frequencies. Ear muff cushions can become stiff and crack because of age, which also causes air leaks. Unless earplugs are seated properly in the ear canal, a tight seal does not occur between the earplug and the surface of the ear canal, thus causing air leakage and a reduction in attenuation. The headband on an ear muff or ear-canal-cap-type protector loses compliance after some usage. This reduces the force placed upon the HPD, which in turn reduces the effectiveness of the seal and allows air leakage. When HPD's are worn in the field, body movement, jaw movement, etc., can create small air leaks in the seal.

Thus, leakage of air around the protector is the primary factor limiting the amount of noise reduction afforded by a HPD. Under laboratory conditions, those factors that allow air leakage can be adequately controlled. However, in the field the same control is not possible, and expected attenuations are rarely achieved.

Comfort

Comfort of fit is another factor to consider in evaluating an HPD. Tight-fitting earplugs or ear muffs can effectively reduce noise, but can become uncomfortable upon extended wear. Soft materials can be used for the plug construction or the ear seals of muffs, but in general these materials are not as effective in preventing the transmission of sound (material leaks). A compromise must usually be reached, which tends to reduce the potential effectiveness of the HPD.

Speech Communication and Acoustic Cues

In many noisy environments, workers must be able to communicate and hear warning signals as well as other acoustic cues. HPD's can interfere with the ability of workers to receive acoustic information necessary to perform their jobs safely. The effect on communication is varied. In a quiet environment, the use of HPD's can reduce the intelligibility of speech unless the speech sound is of sufficient intensity. At about 85 to 90 dBA, various sources indicate that HPD's may improve intelligibility of speech and other signals. This is due to a mutual reduction in the signal and noise, which prevents overloading of the hearing mechanism and allows the ear to handle the signal more efficiently. Kerivan (8) reports that pitch discrimination in noise by workers in a submarine engine room was reduced by the use of earplugs. Spectral cues necessary for excellent performance was impaired to a greater degree (25 pct) by the use of ear muffs.

Durkin (9) found that "for speakers talking at normal levels of 65 dBA or less, . . . hearing protectors significantly reduced speech intelligibility."

In an in-flight evaluation of four aural protectors, Parker (10) reported that two problems associated with the use of earplugs were comfort and interference with cabin communication.

Russell (11) reported impairment of localization (that ability to identify direction of sound) with the use of HPD's.

Howell (12) investigated the effect of HPD's on speech communication. It was concluded that "when hearing protectors are worn by both talker and listener, the composite effect is an overall reduction in speech intelligibility."

Saperstein (13) suggested that roof talk (audible signals emanating from the roof in mining operations) could be discriminated equally well when wearing hearing protection as when not if the ambient noise level was sufficiently high to warrant the use of HPD's.

The above results are quoted for normal hearing. The effect observed for hearing impaired is uncertain. Additionally, the worker may perceive problems with HPD's, which will often affect acceptance of their use.

PREVIOUS WORK

Early efforts in the study of noise and hearing protection in underground coal mines was done under a Bureau of Mines contract (14). Part of the research involved investigation of the ability of miners to understand speech of coworkers and hear roof talk signals with and without standard ear protectors. The findings indicated that below 90 dBA, discrimination of speech and roof talk signals were worse when hearing protection was provided for both a group of normal hearing subjects and a group of subjects with a simulated hearing loss. At 90 dBA and higher, discrimination of roof talk in the two groups was comparable or slightly better when hearing protection was provided. In general, the conclusions drawn confirmed that the use of ear protectors in a noise environment of 90 dBA and above does not additionally impair discrimination of speech and roof talk signals. The results further indicated that hearing protection should only be used by miners if the sound level exceeded 90 dBA.

A discriminating ear muff was developed by the Bureau (9) to allow protection when noise exceeded 90 dBA, while improving discrimination of speech and warning signals. An electrical system was incorporated into the muff so that inputs having a sound pressure level of 83 dBA or less were passed unaffected to the ears of the wearer. Inputs greater than 83 dBA were progressively attenuated as the level increased to an upper limit of 90 dBA when the input level was 120 dBA. In tests performed at the Pennsylvania State University, discrimination scores of subjects were significantly improved below and above 90 dBA as compared with results of tests with normal protective devices. Field tests noted good protection while providing adequate communication in low-noise environments.

Research conducted by Stewart (15-16) studied the noise attenuating properties of ear muffs worn by miners. The research effort was directed towards the study of the attenuating properties of ear muffs and development of a simple method to determine noise reductions provided by HPD's in the field.

Volume 1 of the report compared the measured attenuation of the standard psychophysical real-ear method to attenuation measured by a physical method that might be suitably adapted for field measurements. In the laboratory, this type of study permitted the control of several variables that may influence attenuation measurements in the field. The experiment was conducted using normal hearing human volunteers. Real-ear attenuations were measured for five different ear muffs using 12 subjects. With the same subjects, a physical measurement of attenuation was performed using calibrated microphones placed on the outside and inside of the earcup and measuring the incident sound field and the sound transmitted through and around the muff. The difference represented the attenuation of the muff. Test results indicated that average ear muff attenuation measured in the frequency range of 125 Hz to 2 kHz was comparable for both methods. Above 2 kHz, the difference in attenuation varied from 3 dB at the audiometric testing frequency of 3.15 kHz to about 7 dB at 6 and 8 kHz. For all subjects and all muffs, the differences were consistent with the physical measurement method, providing lower values at frequencies above 2 kHz.

A reason postulated for this observation was that at higher frequencies, the shorter wavelength allowed amplification associated with resonance of the open external ear, which is eliminated by wearing of an ear muff.

Volume 2 of the report discusses the application of the information obtained in the first phase of the study to the development of a laboratory procedure to measure physical attenuation as a predictor of real-ear measurements of ear muffs.

Dosimeters were modified to account for the observed differences between the physical and psychophysical measures presented in earlier work. A system with linear response was used to measure the sound level outside an ear muff worn by a human subject, while a system incorporating a "correction" filter to compensate for the average differences in the physical and real-ear methods was used to measure the inside muff noise levels.

This method was moderately successful, but some apparently severe limitations were discovered in the adaptation of the method in the field. With reasonable control over the stimulus parameters and other experimental parameters, it was possible to use the physical measurement procedure to predict the psychophysical method of evaluation in the laboratory. However, positioning of the instrument on the subject was found to be important. Contact with the subject's body and microphone cable movement resulted in recording of a high noise level under the muff. To provide an adequate signal-to-noise ratio, the stimulus sound pressure levels needed to be at least 100 dB in each one-third octave band of noise. Average attenuation brought the level of sound in the higher frequencies (2 to 8 kHz) inside the muff close to 65 dB. The measured noise floor under the muff was 57 dB. This difference in signal detection is marginal. In the field, it is not common that sound pressure levels in the third octaves in the region above 2 kHz would exceed 100 dB. This would tend to invalidate the results.

At lower frequencies where ear muff attenuation is much less, the needed signal level for adequate high frequency response resulted in instrument overload.

The conclusion was that these considerations would severely limit the application of the method to field use.

CURRENT AND FUTURE BUREAU OF MINES INVESTIGATIONS OF HPD's

With emphasis placed upon the use of HPD's as an adjunct to an adequate hearing conservation program in industry, it has become increasingly important to develop a simplified method of evaluating the performance of HPD's worn by miners in the field.

The immediate objective of the Bureau study of personal HPD's is to investigate their attenuation characterisitics. Performance data obtained using a standard psychophysical method in the laboratory appears to overestimate the amount of protection against noise overexposure provided by HPD's when used by the worker in the field. In order to more accurately measure the actual reduction of noise afforded the working miner by HPD's, basic parameters effecting the acoustic performance of HPD's are being investigated. Laboratory methods providing significant control of these parameters are being developed, which predict the attenuation of hearing protectors using standard methods of measurement. The ultimate goal of the study will be to develop a laboratory procedure that can be adapted to measure the degree of protection provided by HPD's in the field.

The current study of hearing protector performance characteristics will initially evaluate work performed under Bureau contract J0188018, "Noise Attenuating Properties of Ear Muffs Worn by Miners." Limitations to the development of the method proposed under that study will be looked at more intensively. Alternative measurement techniques and state-of-the-art signal and correlation analysis will be used to investigate the various parameters of limitations such as the measured noise floor under the muff. The causes of those limitations will be identified and assessment made of the degree to which those parameters affect the measurements and to what degree they can be controlled.

Alternative methods for determining attenuations in the field need to be postulated and investigated. The procedure outlined by Stewart (16) is specific for ear muffs. It is desirable to devise a testing procedure that is generally applicable to all types of HPD's. Earplugs would be difficult to evaluate using Stewart's method. Therefore, serious thought must be given to the application of this method and others to earplugs.

The research can be expanded to provide a laboratory method of evaluation for HPD's that can accurately predict attenuations observed by the standard real-ear method. This has already been demonstrated for ear muffs.

Upon development of a field method of evaluation of the attenuation characteristics of HPD's, it will be necessary to demonstrate the procedure in the field. Acquisition of field data is therefore anticipated as a future effort.

The information gained in the program may additionally be used to provide design criteria for hearing protectors used by miners that will provide adequate protection under noisy conditions while not reducing miner safety.

Status of Current Work

The ultimate objective of the program is to develop a method for evaluating hearing protector performance that might be adapted for use in the field. The initial phases of such a task is much more fundamental. Considerations currently being addressed include the following:

1. Identification of the parameters affecting the noise attenuation characterisitics of HPD's.

2. Development of measurement methods to evaluate the parameters involved in hearing protector performance.

3. Evaluation of equipment needs.

4. Assessment of the effect of the measurement method in altering the attenuation characteristics of the hearing protector.

5. Quantification of the degree of protection from hearing loss afforded by the protective device.

The research plan includes the following tasks:

1. Evaluate the limitations expressed in reference 16--

    a. Quantify the noise floor generated under an ear muff when worn.

    b. Evaluate if possible the physical and physiological components of the noise floor.

    c. Determine what degree of control can reasonably be anticipated over those parameters in attempting to lower that noise floor.

    d. Assess and attempt to minimize instrument effects in the measurement of attenuation.

    e. Evaluate level and spectral attributes necessary for making valid measurements that can be related to the standard psychophysical method of attenuation measurement.

2. Propose and investigate a method that is generally applicable to all types of HPD's.

3. Postulate and evaluate alternative methods of measurement of attenuation.

4. Develop a laboratory measurement procedure based on prior investigations of the parameters of measurement.

5. Demonstrate the measurement technique under simulated conditions typical of work situations.

6. Field evaluate the method.

To date, a literature review has been performed and pertinent articles selected. This task is continuing and will be updated as cogent information develops in the literature.

Investigations have focused on the study of ear muff attenuation to maintain continuity with previous contract work and because methods developed under that contract are more applicable to ear muffs. The most severe restriction imposed by the research plan was the lack of a sufficient signal-to-noise ratio to make a suitable measurement of the attenuation of an ear muff at high frequencies. This was attributed to a relatively high noise floor under the earcup of the muff when placed on the human head and sealed as tightly as possible.

The first series of experiments was designed to confirm and quantify the presence of a noise floor under an ear muff worn by a human subject. The experiments were conducted in a large anechoic chamber where the performance of hearing protectors on human subjects could be accurately measured. Although the subject remained passive in the experiment (no human response was measured or necessary except for cooperation in remaining as quiet as possible during measurement periods of the various levels at the frequencies of interest), it was felt that certain characteristics of the human ear such as impedance, etc., could not easily or accurately be accounted for by use of things such as a dummy head. By using human ears these considerations could be neglected.

A Knowles BT[4] series 1759 microphone was selected for measurement of the noise floor under the muff. This subminiature electret condenser microphone was selected because it had a reasonably flat frequency response in the frequency region of interest for measurement (31.5 Hz to 8 kHz). Its dimensions were small so that it would not appreciably affect the volume under the earcup and its weight (0.28 g) would not appreciably add to the mass of the earcup. It could easily be attached to the entrance of the ear canal of the subject to measure the noise floor at that point. The microphone was calibrated at 1 kHz and several other frequencies using an insert voltage technique. A standard Bruel and Kjaer (B&K) type 4160 condenser microphone was used as reference.

Initially, one subject was tested using one ear muff, the MSA Mark V. In order to evaluate the effect of some physiognomic and physical parameters that might influence the measurements, nine other volunteer subjects were recruited. These included three females, three bearded males, and three clean-shaven males. The Knowles microphone was taped to the subject's neck just under the earlobe with the microphone placed just outside the entrance of the ear canal and the leads firmly attached to the recessed area between the jaw and the back of the neck. This arrangement allowed a firm seal of the ear muff over the lower portion of the ear. The right ear was used for all subjects. Coaxial wires were then attached to a 1617 B&K band pass filter and a 2606 B&K measuring amplifier outside of the anechoic chamber. The output of the measuring amplifier was then fed into a B&K model 2305 strip-chart recorder.

The environmental levels of the noise in the chamber with the subject present were first determined. The muffs were then fitted tightly onto the subjects, and the noise floor determined at the frequencies of 31.5 Hz, 63 Hz, 125 Hz,

[4]Use of manufacturer or brand names is for identification purposes only and does not imply endorsement by the Bureau of Mines.

250 Hz, 500 Hz, 1 kHz, 2 KHz, 4 kHz, and 8 kHz, as before. The average measured noise floor ranged from 57.7 dB at 31.5 Hz dropping to 16.0 dB at 500 Hz and rising slightly to 21.7 dB again at 8 kHz. The respective average environmental levels at these frequencies were 29.7, 16.1, and 21.7 dB.

The same measurements were made with the subjects wearing glasses or by simulating a small air leak near the temple. Average values for the noise floor at 31.5 Hz, 500 Hz, and 8 kHz were 46.2, 16.0, and 21.7 dB.

The data are currently being analyzed and the human physiological parameters that influence the measurements are being identified. Preliminary analyses tend to attribute the presence of the noise floor to human respiration and pulse, but the magnitude and frequency characterization of these two parameters have not yet been determined. These factors appear to have a significant influence on the noise floor under the muff only at frequencies less than 500 Hz. The problems anticipated in the investigation implied difficulties with inadequate signal-to-noise ratios at the higher frequencies for ample measurement. The procedure developed for the physical measurement of attenuation showed close agreement with the standard psychophysical measurement at frequencies below 500 Hz.

Information from these initial studies require further analysis. Other experiments are being designed and conducted to further clarify the relationships and significance of the various parameters influencing the measurement of the attenuation of HPD's. These measurements are prudent and necessary for establishing baseline data for future investigations into the performance of hearing protectors.

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