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Evaluation of an Accoustical Ear Muff for Agricultural Tractor Operators

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EVALUATION OF AN ACOUSTICAL EAR MUFF FOR AGRICULTURAL TRACTOR OPERATORS

BY

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AGRICULTURAL TRACTOR OPERATORS

This thesis is approved as a creditable and independent investigation by a candidate for the degree, Master of Science, and is acceptable as meeting the thesis requirements for this degree, but without implying that the conclusions reached by the candidate are necessarily the conclusions of the major department.

Thesis Adviser — Date

Head, Agricultural Engineering Department — Date

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HJT

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INTRODUCTION

The effect of agricultural tractor noise on hearing is a serious problem that is presently attracting much attention. For a number of years all incoming freshmen at South Dakota State University have been given a standardized hearing test. In 1968, 14% of the male students had some type of hearing problem. The nation-wide average for this standardized hearing test was 7%. Upon examination of test results of these students with hearing problems, the majority had been exposed to farm machinery noise.

There have been many developments in farm machinery technology; but in the area of noise control, the progress has not been adequate to cope with the problem. In almost all cases modern agricultural tractors have noise levels sufficient to cause permanent hearing damage.

One of the reasons for the slow progress in the field of noise control is that the major manufacturers of farm machinery have not emphasized noise control. The emphasis up to the present has been on horsepower rather than having a quiet, powerful tractor. Also, in the past horsepower has been associated with loud noise, and public appeal for a quiet tractor has not been sufficient. Good noise control may also be costly in terms of lowering horsepower and in added cost in manufacturing.

The problem of noise in agricultural tractors has increased with the advent of tractor cabs. Research by agricultural engineers at South Dakota State University and other institutions in the United States has shown that noise levels are normally increased when tractor cabs are installed. Many farmers have not purchased cabs because they would rather suffer from inclement weather conditions than be subjected to the increased noise level.

The farmer has two alternatives to reduce tractor noise. These alternatives are to reduce the level of noise produced by the tractor or to use some type of ear protector. If the farmer does not have a cab, he can replace the muffler with a quieter version. An extension on all types of mufflers will usually help reduce the noise level. In most cases these methods of noise control will not eliminate the possibility of hearing damage.

If the farmer has a cab, he has more means to reduce the noise level. He can change the muffler and/or add an extension to reduce the noise level. He can also insulate the cab and put in a sound barrier material under the floor mat. In some cases isolating the cab from the tractor by use of rubber mounts will reduce the overall noise level. Also, if some type of sound barrier material can be placed between the engine and the inside of the cab to act as an insulation barrier (firewall), noise levels can be reduced. Even with an insulated cab there are cases when the noise level is not reduced sufficiently to prevent permanent hearing damage.

Even if farmers implement measures to lower the noise level by the use of a quieter exhaust, noise levels in most cases will be sufficient to cause hearing loss. If a farmer insulates his cab, this may or may not reduce the noise level sufficiently, as it is dependent on how thorough a job of insulating the cab is accomplished.

The other alternative for a farmer is to wear some form of ear protector. This is no substitute for proper design; but until adequate noise control is achieved in tractors, permanent hearing damage will continue.

The two types of ear protectors that are used extensively in industry, but not to a great extent in agriculture, are ear plugs and ear muffs. A small number of tractor operators have used cotton or wax as ear plugs which offer little protection.

Some desirable characteristics of ear plugs are that they have good attenuation at high frequencies and lower attenuation at low frequencies. Most ear plugs must be individually fitted for proper attenuation and for comfort of the operator. In dusty or dirty conditions the ear plugs require cleaning before insertion in the ear but are very inexpensive for the degree of protection they provide.

Ear muffs have slightly better attenuation than ear plugs. The ear muffs do not have to be individually fitted to attain proper attenuation. In dusty or dirty conditions cleanliness is not as great a problem as it is with ear plugs. The ear muffs do have the disadvantage of bulk and of side pressure being exerted on the head.

Ear muffs were selected for this study for the following reasons:

1. Ear muffs have better attenuation than ear plugs.
2. Ear muffs are easier to fit and require less cleaning than ear plugs.
3. Ear muffs do not have to be inserted in the ear.
4. Ear muffs can be stored on the tractor, so that they are convenient for the operator.

PURPOSE AND OBJECTIVE

Agricultural tractor noise is a serious problem of vital concern for tractor operators. Work has been done at South Dakota State University and other institutions to reduce the noise level produced by the agricultural tractor by utilizing various exhaust control methods and insulating cabs. Acoustical ear muffs have not been evaluated as a noise control method. These ear muffs have great potential to offer immediate noise reduction for a very low cost.

The objective of this study was to evaluate a commercial acoustical ear muff for use by farm tractor operators as a noise control method under field conditions.

REVIEW OF LITERATURE

J. K. Jensen (10), in a paper entitled "Are Tractors Noisy," showed that noise levels of representative 1965 models of tractors are nearly identical with 1957 tractors. The noise level in both the 1957 and 1965 models was greater than the level that would cause hearing damage. Jensen did not deal with agricultural tractor cabs in his paper, but in many cases mounting a cab on a farm tractor increases the noise level. It has been confirmed by the National Institute of Acoustical Engineers that, on the average, significantly higher noise levels are present when a cab is fitted to an agricultural tractor.

Effect of Noise on Operator

In 1958, D. M. Lierle and S. N. Reger (11) made a study on the effect of tractor noise on auditory sensitivity of tractor operators. In this study Lierle and Reger took sound pressure levels at the operator's position, 6 inches laterally from first one ear and then the other ear of each of the tractor operators. These measurements were made on 11 different tractors operating under field conditions. The difference in sound pressure levels for the right and left ears was negligible. Results indicated that the mean sound pressure level in the 300-600 cycle band was 95.0 db. (decibels) with a range extending from 88 to 102.5 db; the mean sound pressure level in the

600-1200 cycle band was 90.5 db. with a range of 85 to 98 db. These mean levels were above the noise criteria level of 85 db. that was used in this study.

It was concluded that the noise level is sufficiently high to cause permanent hearing loss when exposed over a long period of time. The second part of the study consisted of testing the hearing sensitivity of 80 tractor operators. All 80 of these operators had no prior history of hearing problems. The results indicated that the sensitivity of the tractor operators was worse above 1000 cycles per second than that of the general population. Tractor operators also have greater dips at 4000 cycles per second, especially at the 30-39 and 40-49 age groups.

The University of Nebraska, Division of Environmental Health and Safety (20), conducted a study of tractor noise. In this study, 67 new tractors were tested. Six different noise measurements were made on the tractor at 100% tractor load, 75% tractor load and at 50% tractor load. The noise measurements were made at the operator's ear in the sitting and standing position. The results showed that every tractor produced noise levels greater than 95 db. in the conversation speech range (300-2400 cycles per second).

B. K. Huang and C. W. Suggs (9) in 1967 conducted a study dealing with the measurement and analysis of tractor noise and how human performance and response is affected by this noise. With the tractor engine at full load and rated speed, the noise level at the operator's ear was in the range of 101-109 db. The noise produced by the tractor was then recorded and reproduced in a test chamber where operator performance was evaluated.

The performance study indicated that for problem solving and steering, noise had little effect. For a tracking task, noise level had a significant effect. Noise exposure time also affected the tracking task. Results of the study showed that new design is needed to minimize the noise that is produced by a tractor.

Measurement of Noise

S. S. Stevens (17) in 1961 proposed a means by which loudness could be calculated from a complex sound. In application of the procedure the spectrum of the sound must be measured in terms of sound pressure levels in third-octave, half-octave, or octave bands. Then each band is converted into a loudness index, and by use of an empirical formula the loudness in sones is computed. The purpose of this procedure is to provide a simple and convenient method by which complex sounds of diverse levels and spectra may be ordered on a scale of subjective magnitude. This procedure is a very useful tool, and in 1963 the American Standards Association proposed this method as an American Standard Procedure.

Tom S. Chisholm (5) in 1967 proposed a method to develop suitable techniques for characterizing the noise produced by an agricultural tractor. In this study it was found that as much as 41 times the acoustic power was radiated in one direction as in another for a particular frequency band. Also, approximately two-thirds of the acoustic power measured was concentrated in the four bands with center frequencies of 40, 50, 100 and 125 cycles per second. It was concluded that by knowing acoustic directivities, an optimum location for the operator could be determined. Also these techniques would be useful for evaluating methods of noise control.

Noise Reduction

Douglas W. Rowley (13) in 1966 presented a paper dealing with the sources of tractor noise, noise levels and noise control. He determined in his study that exhaust is the major source of engine noise, fan noise is second, mechanical noise is third, and intake noise is of least importance. The noise level for the small tractor he used exceeded the 95 db. contour curve in many places. The overall sound pressure level was 112 db., SAE loudness of 510 sones, and 210 Steven's sones. He found in his study that there were three effective methods of noise control. The first means of noise control was distance between the noise source and the operator. The second means of noise control was physical barriers placed between the noise source and the operator. The third means of noise control was directing the noise away from the operator. He also found that better mufflers would help noise control but not in all cases would a muffler remove the noise hazard.

Dennis W. Ryland (14) in 1968 studied ways to reduce noise in tractors. He used a John Deere Model 3010 tractor with a commercial manufactured cab. With and without the cab he tried various noise control methods. These noise control methods were different mufflers, a two-foot extension on the factory muffler, and insulating the cab. He reached the following conclusions: The noise level was increased considerably when the cab was mounted on the tractor. Under certain conditions the noise level was decreased by nearly one-half when the cab was insulated. An extension on the factory muffler was effective with both an insulated cab and a non-insulated cab. A special muffler of larger volume, a snubber in this case, was an effective noise suppressor.

Robert H. Tweedy (18) in 1968 presented a technical paper on the design of a modern steel cab. One of the objectives of this design was to solve the noise problem associated with tractors equipped with cabs. The cab was fully insulated and designed to reduce the noise level to a safe level for the operator. The following noise measurements were recorded using the "C" scale: With engine operating at rated power take off speed, without load, the noise level was reduced from 99 decibels outside the cab to 90 decibels inside the cab. Under full rated power take off load, the noise level difference between inside and outside was 14 decibels using the "C" scale. With the engine operating at rated power take off speed, without load, the noise level was reduced from 75 sones outside the cab to 29 sones inside the cab. This represents a 62% reduction in the noise loudness level inside the cab.

The Bureau of Occupational Health for the State of California (4) in 1966 made an occupational health study of heavy equipment operators. In this study ear plugs and ear muffs were used. Their findings were as follows: ear plugs are not practical for heavy equipment use because the heat, dust and dirt, combined with lack of washing and fitting facilities in the field, make the use of ear plugs uncomfortable. These limitations would limit the effectiveness of the ear plugs. The use of ear muffs would not require the washing and fitting facilities, but they did not stay in place under jolting and bouncing which is ever present when used by heavy equipment operators.

George E. Shambaugh, Jr. (15) in 1966 discussed the use of ear muffs for farmers. He pointed out that when jet airplanes were first introduced personnel working near them were experiencing noise induced hearing loss. At the present time all personnel working near jet planes are required to wear ear muffs. This era may be coming for farm equipment operators if the noise levels of farm equipment are not reduced to safe levels. Research has been conducted by the American Academy of Ophthalmology and Otolanygology and the following results are listed:

> "Individuals vary considerably in their susceptibility to noise damage. Some people experience greater auditory fatigue from brief exposure and greater permanent hearing loss from prolonged or intense exposure. To find those ears that are noise damage susceptible, periodic audiometric testing should be done on everyone exposed to high levels of machinery noise.

Continuous noise levels below 90 decibels probably will not cause deafness even over long periods in susceptible ears. The louder the noise over 90 decibels the greater the reversible fatigue loss and the greater the permanent irreversible noise induced hearing loss.

High pitched sounds are more damaging than low pitched ones.

Sudden sharp explosive peaks or sound are particularly damaging.

A pure tone produces the greatest fatigue loss one-half octave above the fatiguing tone.

The portion of the organ of Corti that responds to 4000 cycles per second is the most vulnerable to temporary fatigue and to permanent noise induced hearing loss. The notching in the audiogram at 4000 cycles is a tell-tale warning of beginning noise induced deafness usually before the person himself is aware of any hearing loss. As exposure and damage increase, the 4000 notch slowly deepens and widens until the critical tone range for speech (500 to 2000 cycles) begins to suffer."

Shambaugh further stated that for agricultural workers, if the noise level cannot be reduced below 90 decibels by noise control methods, ear protectors should be worn by all personnel in the area.

THEORY

Background

Sound denotes a mechanical disturbance in gases, fluids or solids. With airborne sounds, the vibrating movement of gas molecules in the atmosphere sets up small variations in atmospheric pressure, known as sound pressure. Sound pressure may be expressed in microbars. A microbar is equal to a dyne per square centimeter or approximately one-millionth of an atmosphere.

In making physical measurements of the sound pressure level, the decibel is used and the base sound pressure level of .0002 microbar is standard. This is zero decibels and is the weakest sound pressure level that is detectable by a keen young human ear under very quiet conditions. A decibel represents a relative quantity base on a logarithmic relationship which is defined by the following equation.

$$Lp = 10 \log \frac{P^2}{P_o{}^2} = 20 \log \frac{P}{P_o}$$

where:

Lp = sound pressure level in decibels

P = sound pressure in microbars

P_o = reference sound pressure (.0002 microbars)

This relationship is such that doubling any sound pressure corresponds to an increase in the sound pressure level of six decibels.

The sound spectrum of tractor noise can be determined by measuring sound pressure levels in a number of frequency bands. A common band width is one octave in which the upper frequency is twice the lower frequency. An octave can be further subdivided into one-half or one-third octave bands.

Measurement in decibels is a nonlinear relationship and makes it difficult to compare two sound spectrums. Converting the sound spectrum to sones results in a linear relationship which facilitates comparison. The loudness of a 1000 cycle per second tone with a sound pressure level of 40 decibels is one sone. Experimenters determined this value by having a large number of observers make a judgment. A tone with a sound twice as loud would be two sones.

To calculate sones by the Steven's procedure, sound must be measured in decibels in one-third, one-half or one octave bands. Each band is converted into a loudness index and the following formula is used.

$$S_T = I_m + F(\Sigma I - I_m)$$

where:

S_T = total loudness in sones

I_m = the greatest of the loudness indexes

ΣI = sum of the loudness indexes

F = factor which is determined by band width

Band Width	F
third-octave	.15
half-octave	.2
octave	.3

Anatomy of the Ear

Public health officials state that the ears of a young person with no history of hearing impairments are sensitive to frequencies ranging from 20 to 20000 cycles per second. The auditory sensitivity curve for a young person is shown in Figure 1.

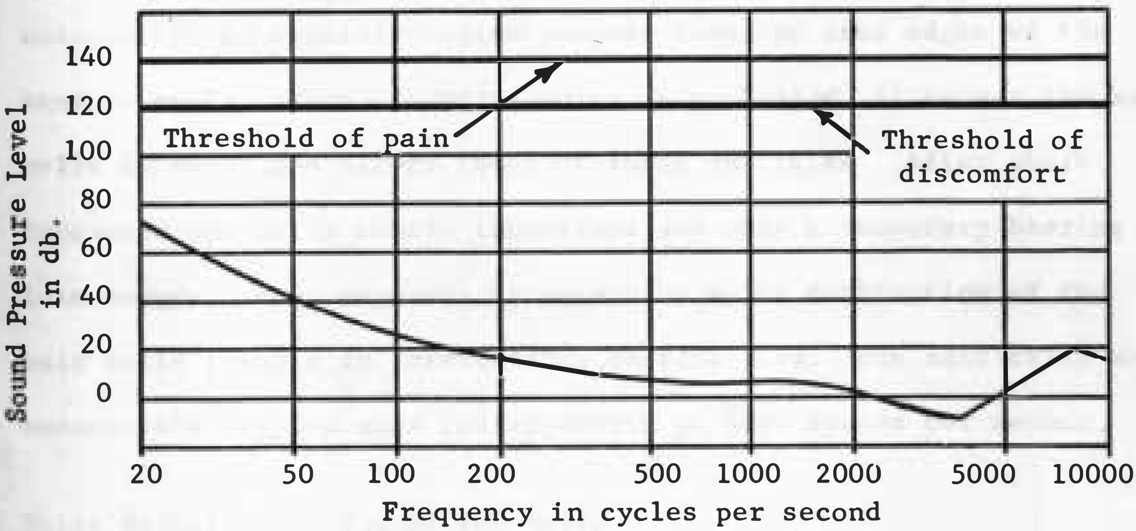


Figure 1. Auditory Sensitivity Curve for a Young Human

The auditory sensitivity curve represents the least sound pressure needed to make a tone audible at various frequencies. The illustration also shows the range of 1000-4000 cycles per second can be heard at lower intensities. There is a great susceptibility to hearing damage in this range, especially 4000 cycles per second, when the ear is exposed to excessive noise over long periods of time.

When the ear is subjected to excessive noise for a prolonged time, varying degrees of inner-ear damage occur. This damage is initially reversible and is commonly referred to as a temporary threshold shift.

With further exposure the damage becomes irreversible and is known as permanent hearing loss.

The organ that is affected by excessive noise is the cochlea. This snail-shaped organ is located in the inner ear and consists of over 20,000 sensory cells. Numerous fine hairs which are very susceptible to excessive noise project from the free edges of the sensory cells. When excessive noise is prolonged, it causes the hair cells to swell and alters their staining qualities. After short exposures the cells repair themselves and only a temporary hearing loss occurs. Long exposure to excessive noise destruction of the hair cells results in irreversible hearing loss. The hair cells most susceptible are the ones corresponding to 4000 cycles per second.

Noise Reduction by Use of Ear Muffs

An ear muff must meet the following requirements to be acceptable for agricultural tractor operator use:

1. The ear muff must attenuate the noise to a comfortable and safe level.
2. The ear muff must be comfortable to wear.

Sound Attenuation

An ear muff attenuates the sound by introducing an insertion loss between the sound source and the eardrum of the listener. This is accomplished primarily by creating a transmission loss between the outside surface and the inside surface of the ear muff.

No ear muff can exclude all the external sound because acoustic vibrations are transferred by bone conduction from the skull, by air leaks around the ear muffs, by propagation through the material in the ear muff and by vibration of the whole device as a rigid body. The attenuation curve for the ear muffs used in this study is shown in Figure 2.

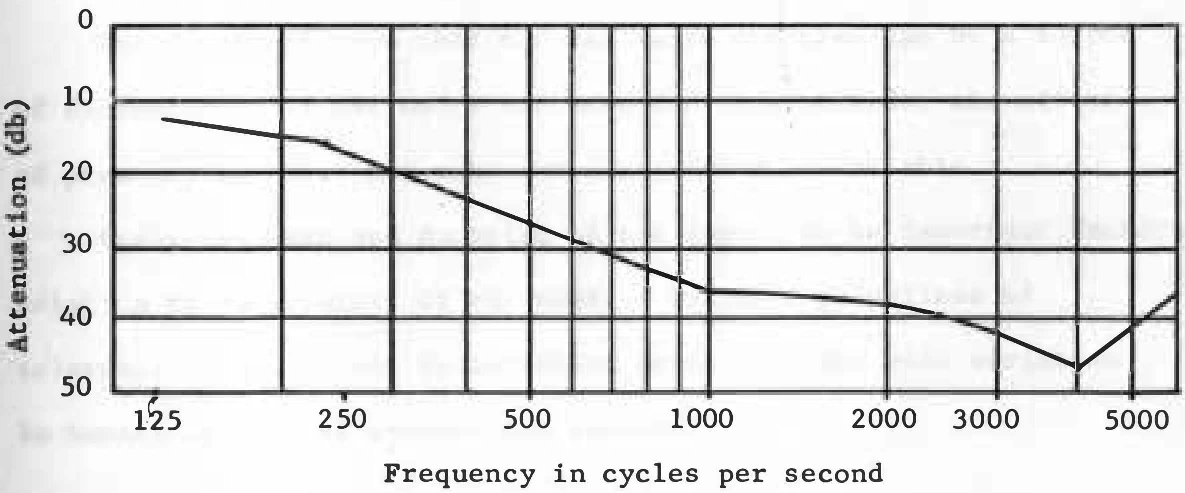


Figure 2. Attenuation Curve for Ear Muffs

The graph shows that the ear muffs attenuate sound less at the lower frequencies than at higher frequencies. This is primarily due to bone conduction and the ear muff vibrating as a rigid body.

Comfort

Ear muffs may provide adequate attenuation for farm tractor operators; however, if they are not comfortable to wear, farmers will probably not use them. Pressure exerted by the ear muff can be a cause of discomfort and is proportional to the force holding the ear muff in place and the contact area. The ear muffs should exert just enough pressure to hold the seal but not enough to cause discomfort.

The temperature of the outside air can be a source of discomfort. The ear muffs tend to insulate the area covered and for high temperatures may become uncomfortable.

The length of time that the ear muffs are used can be a source of discomfort. If ear muffs are worn for long periods, the effect of pressure and heat may make the ear muffs uncomfortable.

Pressure, heat and duration of use appear to be important factors relating to the comfort of ear muffs. Definite guidelines of tolerance are difficult to establish because of the wide variation in humans as to what constitutes comfort.

CRITERIA FOR EVALUATING EAR MUFFS

In this study the amount of ear muff use was defined as the percentage of the total time that the ear muffs were worn during a field operation. The following criteria were developed to evaluate the ear muffs.

1. Field operation versus amount of ear muff use

   Different noise levels are associated with different field operations. In many cases noise is used to judge operation performance. If the ear muffs attenuate the noise to the extent that danger signals are not heard, this may affect their use. Some operations such as raking hay, planting corn, and seeding small grain require less power. In these cases when less power is required, the tractor is normally operated at part throttle. Under these conditions, the noise level is lower and consequently extensive use of the ear muffs may not be required.

2. Frequency of dismounting the tractor (with cab) versus amount of ear muff use

   Frequency of dismounting the tractor (with cab) varies with the type of field operation and the conditions encountered. The categories selected were <u>often</u> (5 or more times per hour), <u>occasionally</u> (2 to 4 times per hour), and <u>infrequent</u> (1 or less times per hour). If a field operation requires many dismountings, this may affect ear muff use.

3. Temperature versus amount of ear muff use

As the temperature in the tractor cab increases (75-80 degrees Fahrenheit), the amount of ear muff use may be affected. The higher the temperature the less the ear muffs will be worn.

4. Comfort index versus amount of ear muff use

The categories selected were uncomfortable, fairly comfortable, and comfortable. These categories represent a means for the cooperator to subjectively evaluate the ear muffs. The ear muffs should be worn less as they become more uncomfortable. It should be kept in mind, however, that what is comfortable for one individual may not be for another.

5. Loudness of tractor in sones versus amount of ear muff use

This comparison was to establish the correlation coefficient between the loudness of the tractor at 75% rated power take-off load and the amount of ear muff use for all field operations.

6. Age of cooperator versus amount of ear muff use

This comparison was to establish the correlation coefficient between the cooperators' ages and the amount of ear muff use for all field operations.

The information from the above comparisons, along with a personal interview, was used to establish categories of ear muff use. The categories were as follows: Extensive use of ear muffs, moderate use of ear muffs, and limited use of ear muffs.

PROCEDURE

Selection of Cooperators

The names of possible cooperators for this project were obtained through correspondence with county agents in Beadle, Brookings, Codington, Kingsbury, Miner, Moody and Minnehaha counties in eastern South Dakota. Each county agent was requested to furnish up to six names of farmers in his county who might cooperate in this project. Upon receipt of the names, each farmer was contacted by letter and was asked if he would cooperate in this project. A general outline of what the project involved was included. Each person was given a self-addressed card and was requested to complete the questions and return the card.

The questions were as follows:

1. Are you interested in being a cooperator? /___/ Yes /___/ No
2. What is the make and model of your tractor?
3. What type of fuel does it burn?
4. What is the make of the cab?
5. What are the directions from the nearest town to your farm?
6. What is your telephone number?

A total of 12 cooperators were then selected from the cards that were returned. The cooperators were selected by the following criteria:

1. Each tractor had to have a cab.
2. The number of each particular make of tractor was to

correspond to their popularity in the state.

3. If possible, the cooperators should be distributed evenly in the counties previously mentioned.
4. There was no discrimination due to age of the cooperator.
5. An attempt was made to have as many different makes of cabs as possible and still comply with the previous criteria.

Table I lists the cooperators and other pertinent information.

Table I. List of Cooperators and Other Pertinent Information

Cooperator Code	Age	Tractor Nomenclature	Cab Make
A	48	Minneapolis Moline 670 Super	Lange*
B	51	International 806	Koehn*
C	21	John Deere 4020	Excel
D	60	Massey Ferguson Super 90	Ansel
E	61	John Deere 4020	Year-A-Round
F	36	John Deere 730	Year-A-Round
G	40	International 806	Larsen
H	42	Allis Chalmers 190	Femco
I	39	Case 930	Egging
J	46	Oliver 1850	Oliver
K	27	John Deere 4010	Cozy
L	40	International 806	International

* Canopy type cabs

Additional information regarding the cooperators is presented in Appendix I.

The sample size was limited to 12 cooperators because of funds, time and distance. With this small sample size, various statistical designs considered were not applicable in this study.

Testing the Tractors

The cooperators' tractors with cabs were tested on the farmsteads in September, 1968. The canopy type cabs did not have the canvas bottoms installed. The following procedure was used for each tractor:

1. Locate the tractor in an open area on the farmstead.
2. Attach the M&W portable power take-off dynamometer to the tractor and attach the necessary water lines to the dynamometer.
3. Allow the dynamometer and the tractor to reach operating temperature.
4. Calibrate the sound analyzer. This instrument was manufactured by General Radio Company and consisted of a one-third octave band analyzer (Type 1564-A) and graphic level recorder (Type 1521-B).
5. Locate the microphone (Type 1560-P5), preamplifier (Type 1560-P40), and the tripod on the tractor seat so that the microphone is at the same level as the ear of a seated operator.
6. Test the tractor with all doors and windows shut.

7. The canopy type cabs were tested without the canvas installed.
8. Load the tractor to 75% of rated power take-off horsepower and record two sound spectrums.
9. Load the tractor to 100% of rated power take-off horsepower and record two sound spectrums.
10. Record temperature, humidity, wind velocity and general mechanical condition of each tractor.

Hearing Test of the Cooperators

Each cooperator was requested to travel to Brookings to have his hearing checked. The hearing tests were conducted by the Speech Department at South Dakota State University.

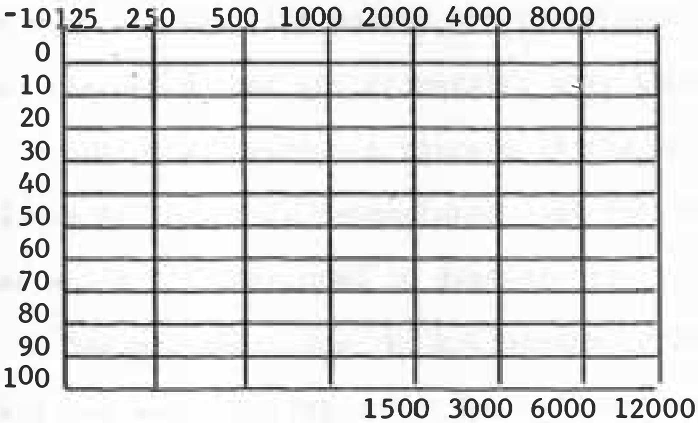
The test consisted of a pure tone, simple air conduction test. The range of the test was from 250 to 12,000 cycles per second and was conducted on both ears. If the audiogram revealed a significant hearing loss, a bone conduction audiogram was conducted. The bone conduction audiogram gives valuable information as to probable causes for the hearing loss. Along with each audiogram, pertinent background information was obtained. A sample audiogram is shown in Figure 3.

Equipment Supplied to the Cooperator

Prior to the Fall 1968 Run each cooperator was contacted at his farmstead. During this visit the ear muffs, instructions for the

SPEECH & HEARING CENTER
South Dakota State University
Brookings, South Dakota

AUDIOGRAM



Key:

	AC	BC	Mask	db
Right (red)	o	>	△	db
Left (blue)	X	<	□	—

ESTIMATED ACCURACY:

	AC	BC
Good	( )	( )
Fair	( )	( )
Poor	( )	( )

LOSS FOR SPEECH:

	Right	Left
500	____	____
1000	____	____
2000	____	____
Ttl	____	____
Av	____	____

- -

Name ______________________ Date __________ Age ____

Address ______________________________ Phone ______

Sex ___ Examiner ______________ Referred by ____________

Are you now or have you been troubled with: Earaches? ________
Running ears? ______ Vertigo (dizziness)? ______ Do other members of your family have a hearing loss? ______ Do you work around loud noises or have you been exposed to loud explosions? ___
Have you ever had a severe blow to the head? ______ Have you taken any medicines or shots regularly? ______ Do you regularly fly in airplanes? ______ Have you ever seen a doctor for ear troubles? ______ Description of tinnitus, if present ________________

COMMENTS, ELABORATION OF HISTORY, OR RECOMMENDATIONS:

Referred to: ______________________________________

Figure 3. Sample Audiogram

data collection, data sheets, and the miscellaneous supplies were distributed.

Each cooperator was shown how to properly adjust and use the ear muffs. It was emphasized that the ear muffs did not have to be worn all the time unless the cooperator desired to do so. It was requested that the cooperator give them a fair try and that he fill out data sheets. A picture of the ear muffs is shown in Figure 4. Complete nomenclature and the attenuation chart for the ear muffs are presented in Appendix II.

The procedure for the collection of data was divided into a fall run and a spring run. The fall run started on September 1, 1968, and terminated when field operations were completed for the year; approximate date was December 1, 1968. The spring run started with the beginning of field work in 1969, approximate date March 15, 1969, and was terminated on June 1, 1969.

There was a distinction between the fall run and spring run because the data sheet required some minor changes. After the results of the fall run were analyzed, the data sheet was altered slightly to gain more information and to be less tedious for the cooperator to complete. The revision of the data sheet necessitated a change in the instructions. Figure 5 shows the fall instruction sheet and Figure 6 shows the fall data sheet.

For the spring run there were some minor changes in the data sheet. Questions number seven and number eight were not included in

Figure 4. Acoustical Ear Muffs

GENERAL INSTRUCTIONS

Complete one of these data sheets at the end of each day whether you used the ear muffs or not.

If more than one operator used this tractor, each one should complete a data sheet unless the tractor was used for a very short period of time. (Less than 1 hour)

If more than one major job is done in a day's time, a data sheet should be filled out for each job.

On October 15, 1968, place the data sheets that you have accumulated up to this date in the folder provided and send them to our department. The remainder of the data should be mailed by Thanksgiving.

SPECIFIC INSTRUCTIONS

Question #1 is self-explanatory.

Question #2 indicate what type of work you were doing for the majority of the time you were in the tractor. Examples are such as discing, plowing, silage cutting, etc. Then indicate how many hours you were doing this job.

Question #3 the category OFTEN refers to 5 or more times an hour that you get on and off. OCCASIONALLY means 2 to 4 times an hour. INFREQUENT is 1 or less times an hour.

Question #4 indicate number of hours that you wear the ear muffs while doing the job that you indicated in question #2. If you wear them the entire period, then your answer in question #4 and question #2 should be the same.

Question #5 is self-explanatory.

Question #6 indicate YES if you could hear a slip clutch or plow hitting a rock, etc. If while not wearing the ear muffs you find for example that a screw in the hood of the tractor is loose and you couldn't hear it while wearing the ear muffs, then indicate NO for this question. If you were on a job that no danger signals were being generated, then leave the question blank.

Question #7 is self-explanatory except that if you had no chance to talk to anyone, leave it blank.

Question #8 is self-explanatory.

Question #9 if you indicate FAIRLY COMFORTABLE or UNCOMFORTABLE, give reasons as to why you rated them as such.

Question #10 indicate the average temperature in the cab today.

Figure 5. Fall 1968 Instruction Sheet

South Dakota State University
Agricultural Engineering
Data Sheet

1. Date ___________ Name of Operator ___________________________
   Age ________
2. What type of field work were you doing? ______________________
   _______________________________ How many hours? __________
3. Did this type of work require getting in and out of the tractor?
   /___/ OFTEN /___/ OCCASIONALLY /___/ INFREQUENT
4. How many hours did you wear the ear muffs? _________
5. Did the ear muffs restrict your performance of necessary tasks?
   /___/ YES /___/ NO If your answer is YES, in what way were you restricted? ____
   ____
6. Did they allow you to hear necessary danger signals?
   /___/ YES /___/ NO
7. Did they allow you to carry on necessary conversation?
   /___/ YES /___/ NO
8. Did they reduce the noise level to a comfortable level?
   /___/ YES /___/ NO
9. How comfortable were the ear muffs to wear? /___/ COMFORTABLE
   /___/ FAIRLY COMFORTABLE /___/ UNCOMFORTABLE If they were not comfortable, what was the reason? ___________________________
   ____
10. What was the approximate average temperature in the cab today?
    /___/ 90 or above /___/ 80 to 90 /___/ 70 to 80 /___/ 60 to 70
    /___/ Under 60

Figure 6. Fall 1968 Data Sheet

the spring data sheet. Question number seven stated: Did they allow you to carry on necessary conversation? This question didn't pertain on many days because the cooperator was alone. The question was important, but the information could be obtained by a personal interview with much less inconvenience to the cooperator. Question number eight stated: Did they reduce the noise level to a comfortable level? This question was answered yes in every case so it was eliminated from the daily data sheet. If there was a change, the personal interview gave this information.

Question number ten on the fall data sheet gave the approximate average temperature in the cab. This was a difficult value to obtain due to extreme variability in temperature throughout the day. The important aspect of this question was at what temperature does heat affect the use of ear muffs. Question number eight on the spring data sheet shows this change. The spring instruction sheet and data sheet are shown in Figures 7 and 8.

To obtain the temperature in the cab when ear muffs became uncomfortable due to heat, a thermometer was installed in the cab. Also, a hook was installed in the cab to provide easy storage of the ear muffs when not in use.

<u>Personal Interview</u>

After both the fall and spring runs a personal interview was conducted. The questions asked in the personal interview were designed to supplement the information obtained by the daily data

GENERAL INSTRUCTIONS

Complete one of these data sheets at the end of each day whether you used the ear muffs or not.

If more than one operator used this tractor, each one should complete a data sheet unless the tractor was used for a very short period of time. (Less than 1 hour)

If more than one major job is done in a day's time, a data sheet should be filled out for each job.

Collect all data sheets and keep them. I will personally come to your farm on June 2, 3, or 4 to collect them. I will contact you by phone about one week in advance to set up the exact date and time.

SPECIFIC INSTRUCTIONS

Question #1 is self-explanatory.

Question #2 indicate what type of work you were doing for the majority of the time you were in the tractor. Examples are such as discing, plowing, silage cutting, etc. Then indicate how many hours you were doing this job.

Question #3 the category OFTEN refers to 5 or more times an hour that you get on and off. OCCASIONALLY means 2 to 4 times an hour. INFREQUENT is 1 or less times an hour.

Question #4 indicate number of hours that you wear the ear muffs while doing the job that you indicated in question #2. If you wear them the entire period, then your answer in question #4 and question #2 should be the same.

Question #5 is self-explanatory.

Question #6 indicate YES if you could hear a slip clutch or plow hitting a rock, etc. If while not wearing the ear muffs you find for example that a screw in the hood of the tractor is loose and you couldn't hear it while wearing the ear muffs, then indicate NO for this question. If you were on a job that no danger signals were being generated, then leave the question blank.

Question #7 if you indicate FAIRLY COMFORTABLE or UNCOMFORTABLE, give reasons as to why you rated them as such.

Question #8 is self-explanatory.

Figure 7. Spring 1969 Instruction Sheet

South Dakota State University
Agricultural Engineering
Data Sheet

1. Date ____________ Name of Operator ______________________________
   Age ________
2. What type of field work were you doing? ____________________
   ______________________________ How many hours? ____________
3. Did this type of work require getting in and out of the tractor?
   /___/ OFTEN (5 or more times per hour) /___/ OCCASIONALLY (2 to 4 times per hour) /___/ INFREQUENT (1 or less times per hour)
4. How many hours did you wear the ear muffs? ____________________
5. Did the ear muffs restrict your performance of necessary tasks?
   /___/ YES /___/ NO If your answer is YES, in what way were you restricted? ____
   ____
6. Did they allow you to hear necessary danger signals?
   /___/ YES /___/ NO
7. How comfortable were the ear muffs to wear? /___/ COMFORTABLE
   /___/ FAIRLY COMFORTABLE /___/ UNCOMFORTABLE If they were not comfortable, what was the reason? ____________________________
   ____
8. What was the temperature in the cab when you took the ear muffs off because of the heat? /___/ 90 or above /___/ 85 to 90
   /___/ 80 to 85 /___/ 75 to 80 /___/ 70 to 75 /___/ Under 70

Figure 8. Spring 1969 Data Sheet

sheet. The spring questionnaire was identical to the fall questionnaire, except that the fall questionnaire had two additional questions. The two additional questions were as follows:

1. How can we improve the data collection?
2. Will you be a cooperator again this spring?

The spring questionnaire is shown in Figure 9.

QUESTIONNAIRE

Cooperator: ____________________ Date: ____________________

1. Does heat affect your wearing of ear muffs? ____________
2. If so, what is the temperature when heat becomes a factor? ______
3. Does the amount of times entering and leaving the tractor affect the use of the ear muffs? ____________
4. Do you wear them when you leave the tractor to adjust a machine, etc.? ____________
5. Do you feel that you cannot hear the machines well enough with the ear muffs on? ____________
6. If so, what noises are not heard? ____________
7. Do you have a radio on the tractor? ____________
8. Can you hear the radio better with the ear muffs on? ______
9. Would you like an ear jack in the ear muffs? ____________
10. Does long periods of time affect your use of the ear muffs? ____
11. What do you consider the maximum time for wearing them without discomfort? ____________
12. Did you feel that you had to get used to the ear muffs? ______
13. Were there cases when the ear muffs did not lower the noise level to a comfortable level? ____________
14. Are the ear muffs tolerable? ____________
15. If not tolerable, why weren't they? ____________
16. Do you feel less fatigue or notice any difference on days that you wear the ear muffs? ____________
17. Would you wear the ear muffs if this wasn't an experiment? ____
18. If not, why? ____________
19. What are your complaints about the ear muffs? ____________
____
20. What did you like about the ear muffs? ____________
____

Figure 9. Spring 1969 Questionnaire

PRESENTATION AND ANALYSIS OF DATA

Tractor Noise

The total loudness in sones for each tractor at 75% and 100% rated power take-off load is presented in Table II. Also included in Table II is the total loudness in sones after the attenuation of the ear muffs is introduced for both loads. Sample calculations for both the total loudness with and without ear muffs are presented in Appendix III.

Audiograms

Each cooperator was requested to have his hearing checked. Cooperators C, H, and L were unable to come to Brookings, South Dakota, and have their hearing checked.

The hearing test was a pure tone, simple air conduction test. Each ear was tested and the results were recorded. An example of an audiogram is presented in Figure 3.

A corrected audiogram was obtained by subtracting the aging effect (presbycusis) from the original audiogram. This corrected audiogram indicated the amount of hearing loss incurred at the various frequencies. The hearing loss in decibels for each cooperator that had his hearing checked is presented in Table III. A sample calculation for the hearing loss is presented in Appendix IV.

Table II. Total Loudness (Sones) for Tractors with and without Ear Muffs

Cooperator	Tractor Nomenclature	Cab Make	Without Ear Muffs		With Ear Muffs	
			75% load	100% load	75% load	100% load
A	Minneapolis Moline 670 Super	Lange*	94.88	116.49	33.96	34.31
B	International 806	Koehn*	137.54	162.57	49.02	59.81
C	John Deere 4020	Excel	121.30	128.28	28.19	29.58
D	Massey Ferguson Super 90	Ansel	107.81	109.18	49.36	49.42
E	John Deere 4020	Year-A-Round	113.14	91.17	23.35	22.54
F	John Deere 730	Year-A-Round	108.37	111.44	54.24	55.24
G	International 806	Larsen	124.29	117.32	64.08	58.39
H	Allis Chalmers 190	Femco	66.53	58.89	22.32	20.14
I	Case 930	Egging	73.17	78.28	24.00	22.48
J	Oliver 1850	Oliver	219.37	224.36	95.57	97.40
K	John Deere 4010	Cozy	81.15	94.20	27.71	32.34
L	International 806	International	81.99	91.99	26.17	29.78
		Average	110.80	115.35	41.50	42.62

* Canopy type cabs

Table III. Hearing Loss (Decibels) of the Cooperators

Cooperator Code	Age	1000 Cycles/Sec		2000 Cycles/Sec		4000 Cycles/Sec	
		Right ear	Left ear	Right ear	Left ear	Right ear	Left ear
A	48	2	7	7	22	32	32
B	51	0	0	0	0	30	20
D	60	17	22	0	12	0	0
E	61	7	12	22	12	28	18
F	36	0	5	0	2	0	27
G	40	0	0	0	0	38	38
I	39	10	10	6	9	8	23
J	46	0	0	0	0	0	27
K	27	5	0	10	0	13	0

Fall 1968 Run

The evaluation of the ear muffs was based on a series of comparisons as outlined in the criteria on page 19. In each case the comparisons were illustrated by use of bar graphs. Cooperator L failed to complete data sheets correctly, so his data was not included in the comparisons.

Field operations versus the amount of ear muff use are presented in Figure 10. The miscellaneous category contains the following operations: baling hay, spreading fertilizer, hauling soybeans and raking hay. This category includes operations which total less than three hours.

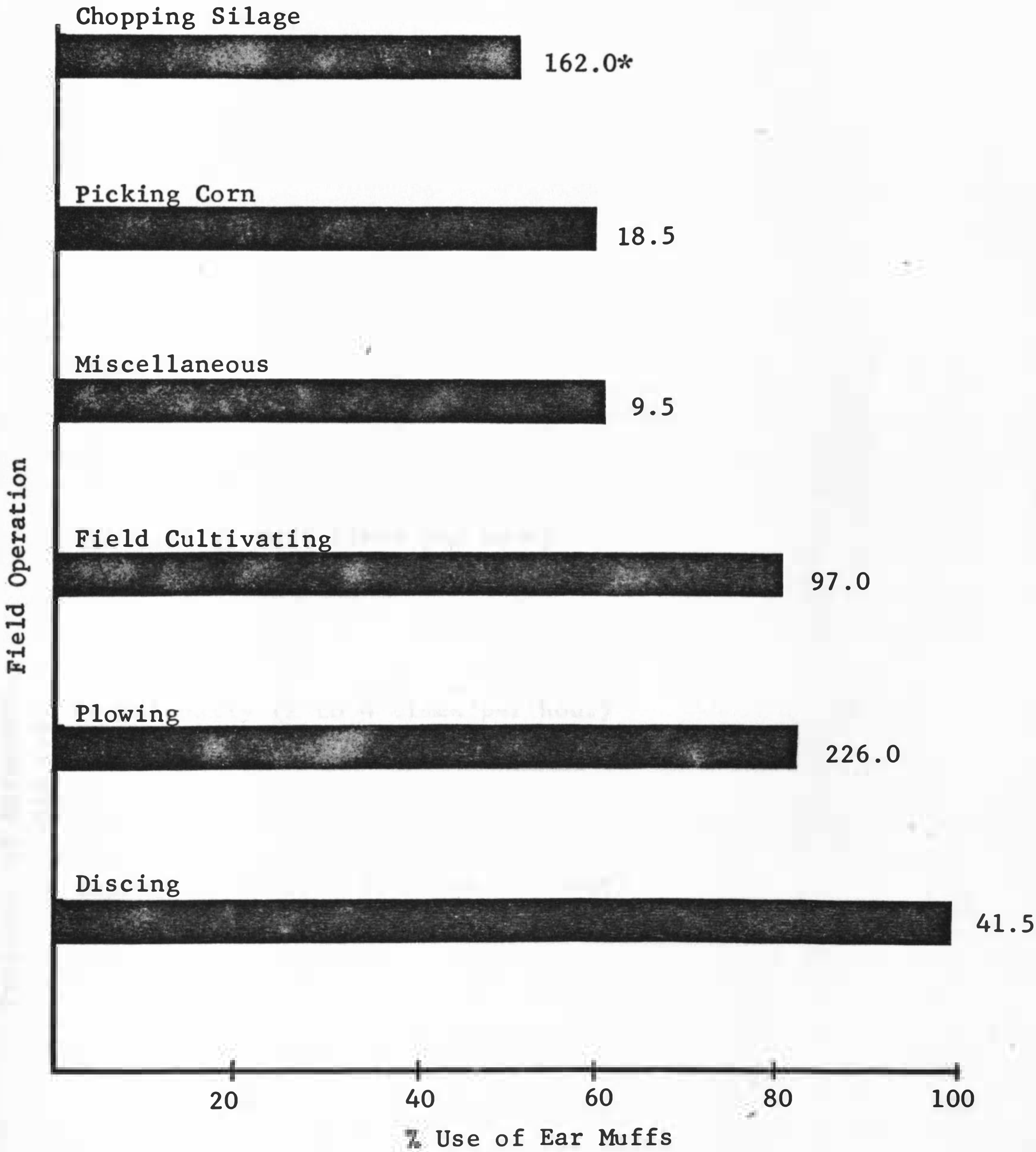
Frequency of dismounting the tractor (with cab) versus the amount of ear muff use is presented in Figure 11. The category, often, refers to 5 or more dismountings per hour. Occasionally means 2 to 4 times per hour. Infrequent means 1 or less times per hour.

Temperature versus the amount of ear muff use is presented in Figure 12. The temperature indicated is the average temperature in the cab over the period of time covered by each data sheet.

Comfort index versus the amount of ear muff use is presented in Figure 13. Each of the categories is a subjective evaluation by the cooperator.

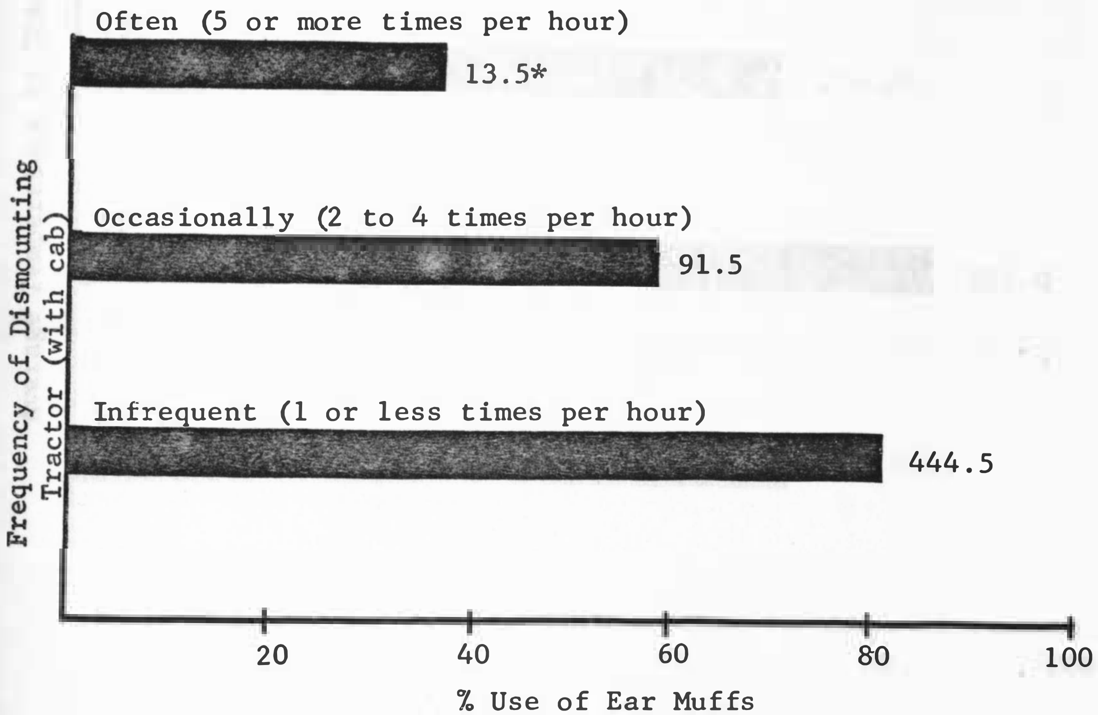
Spring 1969 Run

The evaluation of the ear muffs is based on a series of comparisons as outlined in the criteria on page 19. In each case the



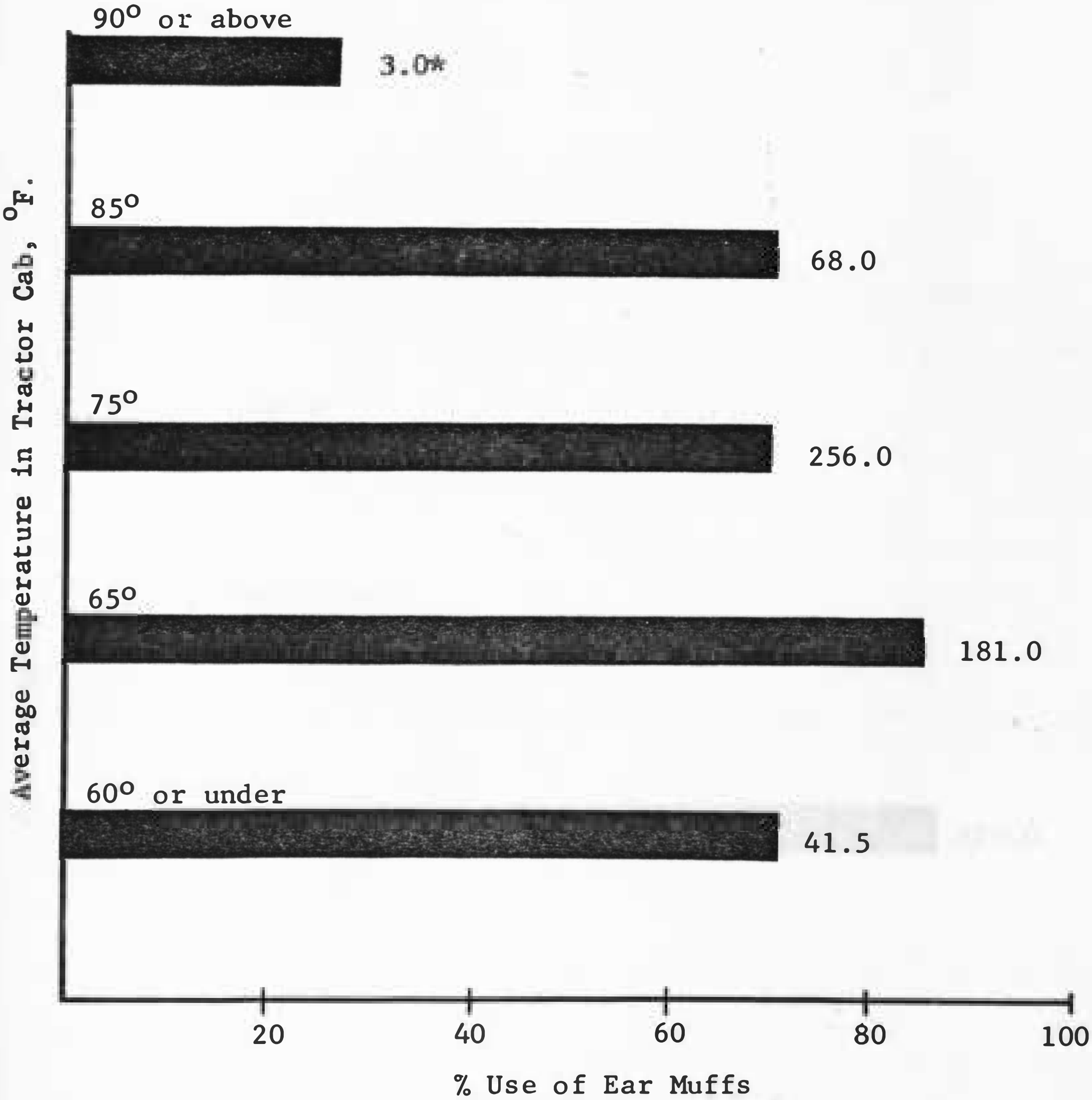
* Hours of Ear Muff Use

Figure 10. Field Operation Versus Amount of Ear Muff Use (Fall 1968 Run)



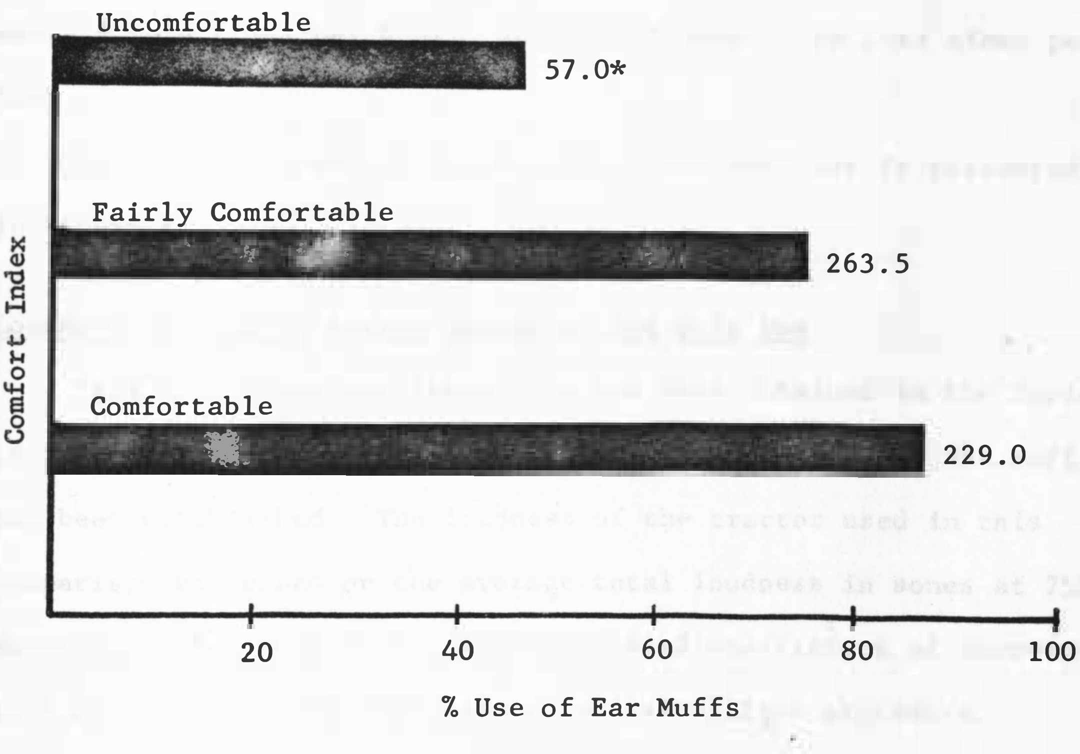
* Hours of Ear Muff Use

Figure 11. Frequency of Dismounting Tractor (with cab) Versus Amount of Ear Muff Use (Fall 1968 Run)



* Hours of Ear Muff Use

Figure 12. Average Temperature in Tractor Cab Versus Amount of Ear Muff Use (Fall 1968 Run)



* Hours of Ear Muff Use

Figure 13. Comfort Index Versus Amount of Ear Muff Use (Fall 1968 Run)

comparisons are illustrated by a bar graph. The number to the right of the bar graph indicates the number of hours the ear muffs were used for that operation. The comparisons include the data from all the cooperators, except Cooperator L who failed to complete data sheets.

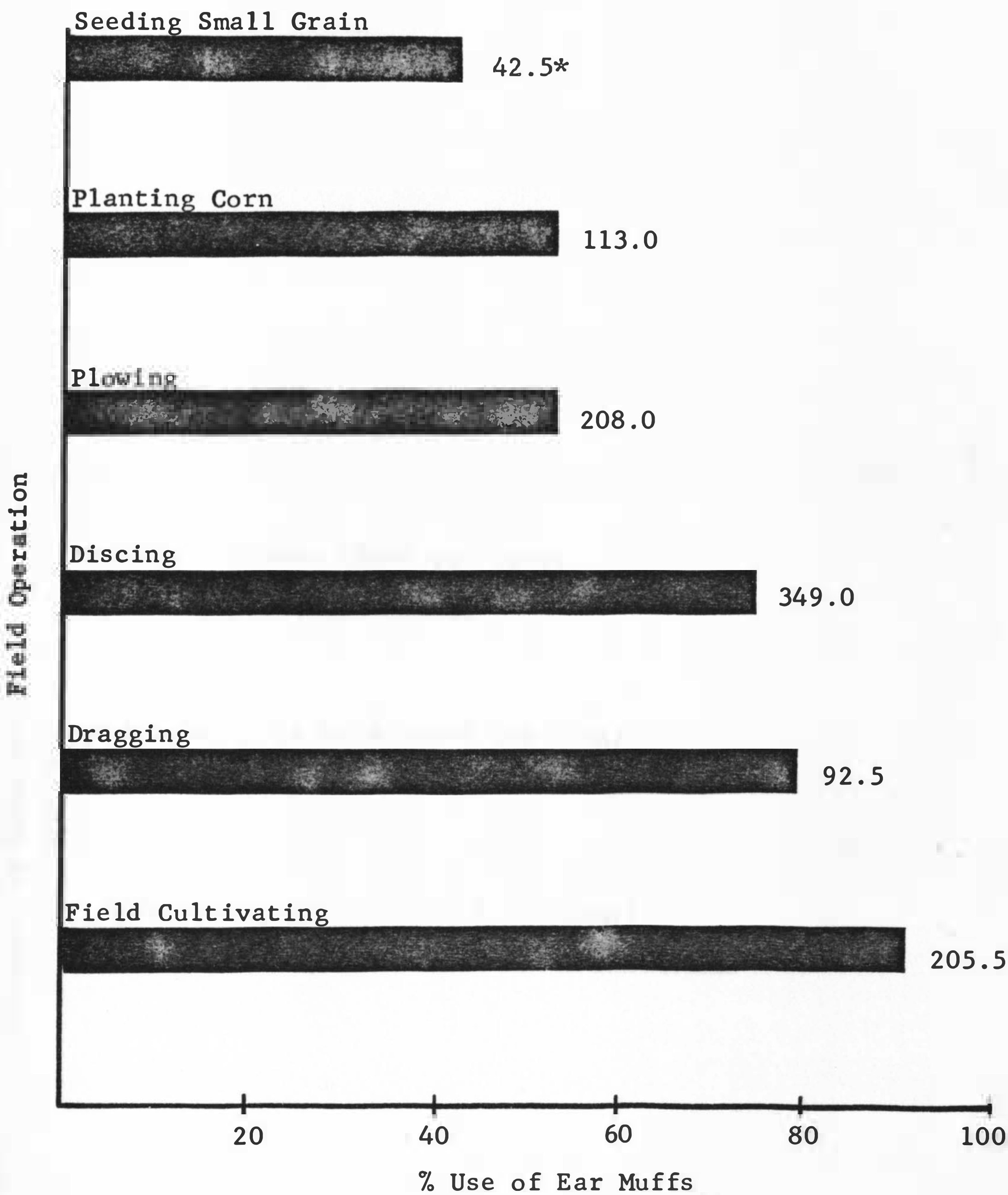
Field operations versus ear muff use are presented in Figure 14. The seeding category refers to planting small grain.

Frequency of dismounting the tractor (with cab) versus the amount of ear muff use is presented in Figure 15. The often category refers to 5 or more dismountings per hour. Occasionally means 2 to 4 times per hour. Infrequent means 1 or less times per hour.

Comfort index versus the amount of ear muff use is presented in Figure 16.

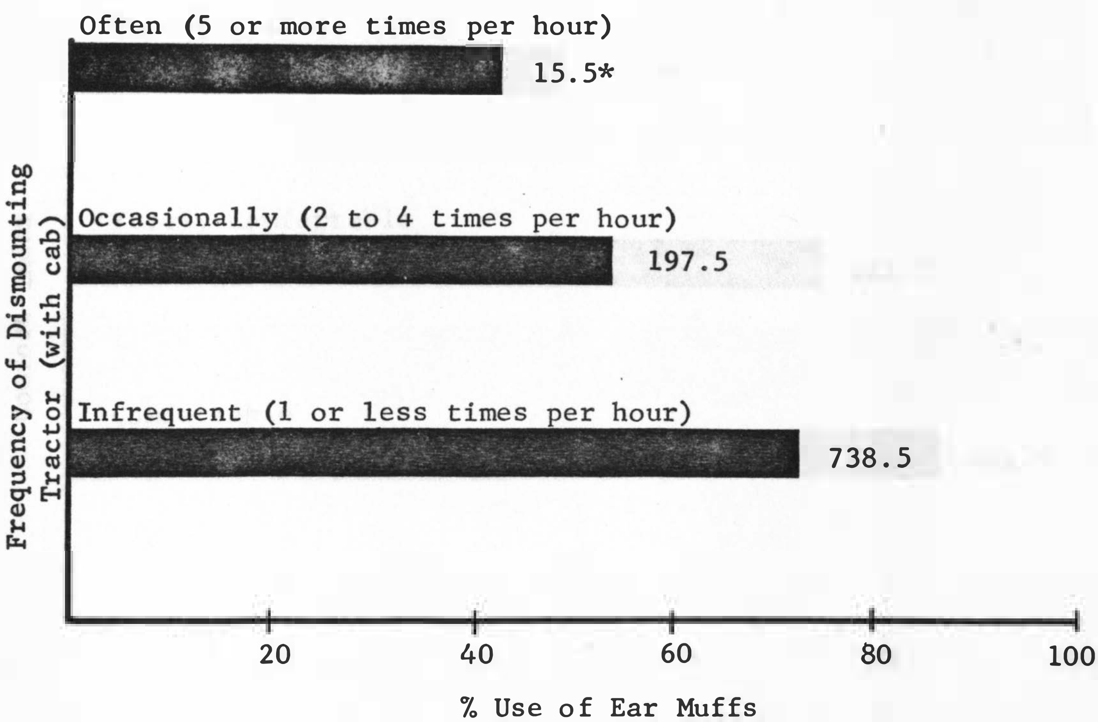
Loudness of Tractor Versus Amount of Ear Muff Use

This comparison was taken from the data obtained in the Spring 1969 Run. The spring data were used because patterns of ear muff use had been established. The loudness of the tractor used in this comparison was based on the average total loudness in sones at 75% rated power take-off load. The calculated coefficient of correlation was $r = .12$. See Appendix V for calculation procedure.



* Hours of Ear Muff Use

Figure 14. Field Operation Versus Amount of Ear Muff Use (Spring 1969 Run)



* Hours of Ear Muff Use

Figure 15. Frequency of Dismounting Tractor (with cab) Versus Amount of Ear Muff Use (Spring 1969 Run)

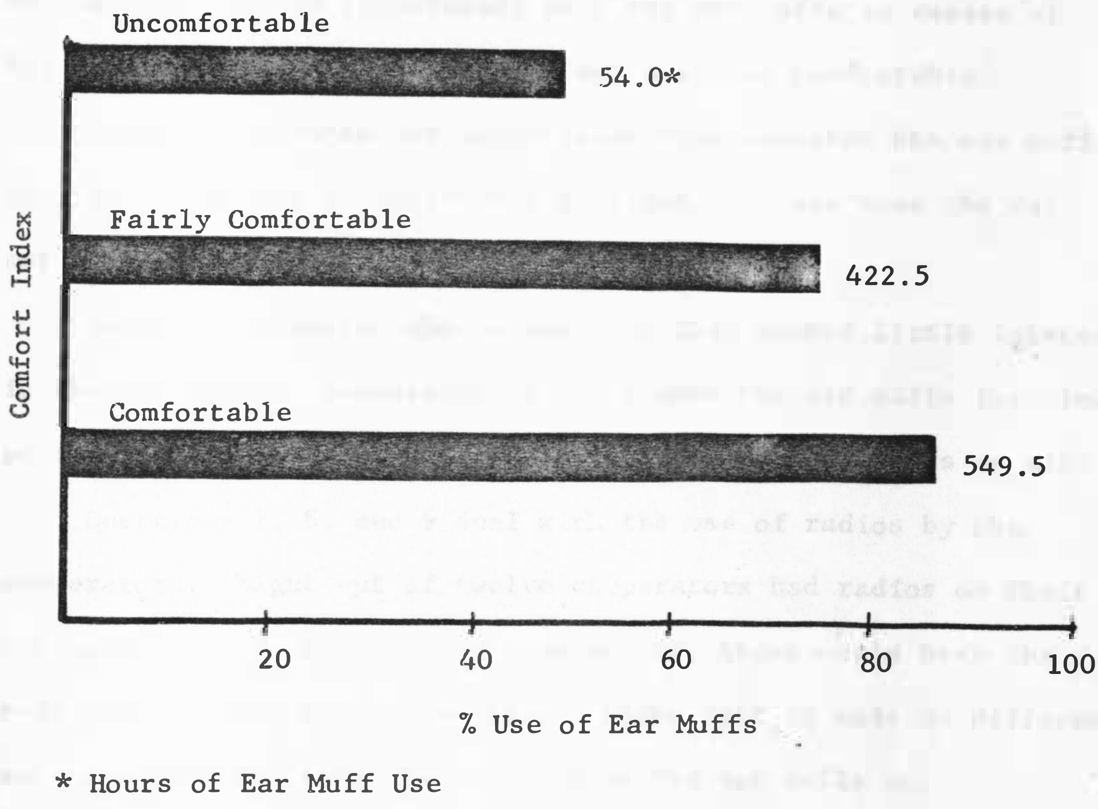


Figure 16. Comfort Index Versus Amount of Ear Muff Use (Spring 1969 Run)

Age of Cooperator Versus Amount of Ear Muff Use

The calculated coefficient of correlation was r = .082. The same procedure was used to calculate r as in the previous comparison.

Personal Interview

Tables IV, V, and VI show the questions, except 7, 8, and 9, that each cooperator was asked to complete. These tables represent a composite of the fall and spring questionnaire.

Table IV represents the cooperators that used the ear muffs extensively. These cooperators wore the ear muffs in excess of 85% of the time and evaluated the ear muffs as comfortable.

Table V indicates the cooperators that accepted the ear muffs; but, for a variety of individual dislikes, did not wear the ear muffs as extensively.

Table VI indicates the cooperators that showed little interest in the ear muffs. Cooperators E and G wore the ear muffs for limited periods of time. Cooperator L did not wear the ear muffs at all.

Questions 7, 8, and 9 deal with the use of radios by the cooperators. Eight out of twelve cooperators had radios on their tractors. Out of these eight cooperators, three could hear the radio better with the ear muffs on, three felt it made no difference, and two heard the radio better without the ear muffs on.

Cooperator F had an AM-FM radio on his tractor. He installed stereo speakers in the ear muffs and was well satisfied with this arrangement.

Table IV. Personal Interview (Extensive Use of Ear Muffs)

Cooperator Code	D	B	K	F	
At what temperature does heat affect ear muff use?	No problem	85 or above	No problem	No problem	
Does frequency of dismounting affect ear muff use?	No	No	No	No	
What operations are affected due to inability to hear the machine?	Corn picker	Silage chopper	Silage chopper	None	
What is the maximum continuous time the ear muffs can be worn without discomfort?	11 to 12 hrs.	9 to 10 hrs.	12 hrs.	12 hrs.	
Did you have to get used to the ear muffs?	No	Yes	No	Yes	
Do you feel less fatigue when you use the ear muffs?	Yes	Yes	Yes	Yes	
Can you tolerate the ear muffs?	Yes	Yes	Yes	Yes	
What are your complaints about the ear muffs?	None	9 to 10 hrs. causes discomfort	Strap causes discomfort	None	
% use of the ear muffs	100%	98.9%	93.8%	85.7%	

Table V. Personal Interview (Moderate Use of Ear Muffs)

Cooperator Code	H	J	A	C	I
At what temperature does heat affect ear muff use?	80 or above	90 or above	85 or above	85 or above	85 or above
Does frequency of dismounting affect ear muff use?	Yes	Yes	No	No	No
What operations are affected due to inability to hear the machine?	Silage chopper	No problem	Corn planter	No problem	No problem
What is the maximum continuous time the ear muffs can be worn without discomfort?	4 to 5 hrs.	12 hrs.	4 hrs.	2 to 3 hrs.	4 to 5 hrs.
Did you have to get used to the ear muffs?	Yes	Yes	Yes	Yes	Yes
Do you feel less fatigue when you use the ear muffs?	No difference	No difference	No difference	No difference	Yes
Can you tolerate the ear muffs?	Yes	Yes	Yes	Yes	Yes
What are your complaints about the ear muffs?	High temperatures cause discomfort	Strange sensation	Hot and tight	Pressure after 2 to 3 hours	4 to 5 hrs. causes discomfort
% use of the ear muffs	66.7%	66.7%	62.3%	42.9%	40%

Table VI. Personal Interview (Limited Use of Ear Muffs)

Cooperator Code	E	G	L		
At what temperature does heat affect ear muff use?	No problem	75 or above	75 or above		
Does frequency of dismounting affect ear muff use?	No	Yes	Yes		
What operations are affected due to inability to hear the machine?	Silage chopper	No problem	Silage chopper		
What is the maximum continuous time the ear muffs can be worn without discomfort?	2 to 2½ hrs.	4 hrs.	½ hour		
Did you have to get used to the ear muffs?	Yes	Yes	--		
Do you feel less fatigue when you use the ear muffs?	Yes	No difference	--		
Can you tolerate the ear muffs?	Yes	Yes	No		
What are your complaints about the ear muffs?	Strange sensation	Hot and tight	A big bother		
% use of the ear muffs	14.7%	13.9%	0%		

DISCUSSION OF RESULTS

Tractor Noise

Table II presents the total loudness with and without ear muffs. The average total loudness without ear muffs was 110.80 sones at 75% rated power take-off load and 115.35 sones at 100% rated power take-off load. The total loudness without ear muffs ranged from 58.89 sones for the Allis Chalmers 190 to 224.36 sones for the Oliver 1850. The Allis Chalmers 190 had a Femco cab that was fully insulated; also, one-inch fiberglass was placed between the engine and the console. These methods of noise control were effective in reducing the noise level. The other tractors did not have insulated cabs and were louder.

With the ear muffs the average total loudness was 41.50 sones at 75% rated power take-off load and 42.62 sones at 100% rated power take-off load. The total loudness with ear muffs ranged from 20.14 sones for the Allis Chalmers 190 to 97.40 sones for the Oliver 1850. In all cases except the Oliver 1850, the noise level was reduced to a safe level to prevent hearing damage. The Oliver 1850 had an extremely loud muffler and an excessively loud hydraulic system.

The sone values with the ear muffs were calculated by subtracting the attenuation from the noise level spectrum. The manufacturer's attenuation curve was obtained by using a pure tone test. A pure tone test did not fully apply for an agricultural tractor because of the continuous noise spectrum, but it was a reasonable approximation.

Audiograms

Table III presents the hearing loss in decibels for the nine cooperators who had their hearing checked. The aging effect has been subtracted so the values indicated are actual hearing loss. At 4000 cycles per second, Cooperator D was the only one without any hearing loss. All the others have some hearing loss with Cooperator G having a 38 decibel hearing loss in both ears. At 2000 cycles per second, which is in the speech range, six cooperators had some hearing loss. Two cooperators had a 22 decibel hearing loss in one ear. At 1000 cycles per second, which is also in the speech range, six cooperators had some hearing loss. Cooperator D had a 22 decibel hearing loss in one ear. All the cooperators have farm backgrounds, and their audiograms indicated that they had some hearing loss. This hearing loss can, in part, be attributed to tractor noise. Other factors may have caused some hearing loss, such as hunting, military service, or disease. In the case of the nine cooperators, their history does not indicate that the audiograms would have been substantially affected by these causes.

Fall 1968 Run

In the Fall 1968 Run 554.5 hours of ear muff use were logged by all cooperators. Figure 10 presents the graph of field operation versus amount of ear muff use. The power take-off operations, such as chopping silage (51.6% use) and picking corn (59.8% use), were categories where ear muffs were not used as extensively as tillage operations. The tillage operations had the following percentages of ear muff use: field cultivation 81.6% use, plowing 83.4% use, and discing 100% use. In most cases when chopping silage and picking corn, the cooperators could not hear the machine well enough to judge its performance; therefore, they did not wear the ear muffs as much. Another factor affecting ear muff use for power take-off operations was the fact that these operations normally required more dismountings from the tractor. This dismounting factor was also apparent in operations such as hauling soybeans and baling hay, which were in the miscellaneous category (61.3% use).

Figure 11 presents the graph of frequency of dismounting the tractor versus amount of ear muff use. The following percentages for the categories were recorded: often (5 or more times per hour) 36.5% use, occasionally (2 to 4 times per hour) 58.7% use, infrequent (1 or less times per hour) 81.7% use. The often category included operations such as chopping silage and picking corn. The occasional category also included some of these two operations.

The infrequent category was comprised of the tillage operations. This shows that as the frequency of dismounting increased, ear muff use usually decreased.

Figure 12 shows the average temperature in the tractor cab versus amount of ear muff use. This indicates that for 90^{o} or above the ear muffs were worn 27.3% of the time. The 85^{o} category was 71%, the 75^{o} category was 70.8%, the 65^{o} category was 86.0%, and the 60^{o} category was 71.6%. This indicates that temperature does affect ear muff use at 90^{o} or above. At 85^{o} the use was higher because one cooperator was not affected by heat, and he wore the ear muffs 100% of the time. This subsequently raised the percent use for that category. Usually the cooperators used the ear muffs less when the temperature was 85^{o} or above. The 60^{o} or under category was mainly due to picking corn. In this case the operation affected ear muff use more than the temperature.

Figure 13 shows comfort index versus amount of ear muff use. The following percentages were recorded: uncomfortable was 46.2% use, fairly comfortable was 75.4% use, and comfortable was 86.8% use. This indicates the use of ear muffs decreased as the ear muffs became more uncomfortable.

Spring 1969 Run

In the Spring 1969 Run 1010.5 hours of ear muff use were logged by all cooperators. Figure 14 presents the graph of field operation versus amount of ear muff use. The seeding small grain (43.8% use) and planting corn (52.3% use) categories were operations where ear muffs were not used extensively. This was due to more dismountings, less power required, and failure to hear the machine. The more frequent dismountings were required to fill corn, fertilizer, insecticide and herbicide boxes. Most of the cooperators operated their tractors at part throttle and in this situation the noise level was lowered considerably; subsequently, the ear muffs were used less. One cooperator, while using the ear muffs, could not hear the click of the planter when checking corn and this affected their use. The plowing category (52.7% use) was lower than the other tillage operations because two cooperators did a large share of the plowing and did not wear the ear muffs over 40% of the time. The other tillage operations had the following percentages of ear muff use: discing 74.4% use, dragging 79.7% use, and field cultivating 90.9% use. The tillage operations for the fall run also had the largest percentages of ear muff use.

Figure 15 presents the graph of frequency of dismounting versus amount of ear muff use. The following percentages for the categories were recorded: often (5 or more times per hour) 43.7% use, occasionally (2 to 4 times per hour) 73.5% use, and infrequent (1 or less times per hour) 73.5% use. The operations of seeding small grain and planting corn composed the often category. One cooperator put these operations in the occasional category. The tillage operations were predominately placed in the infrequent category with a few instances in the occasional category. In the fall run, chopping silage and picking corn comprised the often category, while tillage operations were predominately put in the infrequent category.

Figure 16 presents the graph of comfort index versus amount of ear muff use. The following percentages were recorded: uncomfortable 29.8% use, fairly comfortable 74.8% use, and comfortable 86.3% use. As the ear muffs became more uncomfortable, the use of the ear muffs decreased. The fairly comfortable category was quite high because some cooperators felt that the ear muffs were not comfortable; but because they lowered the noise level and protected their ears, they wore them a large percentage of the time.

Temperature was not a factor for the spring run. The fall run plus the personal interview showed when temperature affects ear muff use.

Loudness of Tractor Versus Amount of Ear Muff Use

The coefficient of correlation for the loudness of the tractor at 75% rated power take-off load versus the amount of ear muff use was r = .12. This indicated for this load condition that there was no correlation between the loudness of the tractor and ear muff use.

Age of Cooperator Versus Amount of Ear Muff Use

The coefficient of correlation for age of cooperator versus amount of ear muff use was r = .082. This indicated that there was no correlation between the age of the cooperator and ear muff use.

Personal Interview

Tables IV, V, and VI present the information obtained by personal interview. Table IV presents the cooperators that used the ear muffs extensively and rated them as comfortable. The range of ear muff use was from 100.0% to 85.7%. Table V represents the cooperators that used the ear muffs; but for a variety of personal dislikes, did not wear them as extensively. The range of ear muff use was from 66.7% to 40.0%. Table VI represents the cooperators that showed very little interest in the ear muffs. The range of ear muff use was from 14.7% to 0.0%.

Temperature had the following effect on ear muff use. Four cooperators had no problem with heat. Two cooperators experienced discomfort at 75^{o} or above. The other six cooperators experienced discomfort from 80^{o} to 90^{o} or above.

Eight cooperators indicated that frequency of dismounting did not affect ear muff use. Four cooperators indicated that it did affect ear muff use.

Five cooperators indicated that they could not hear the forage chopper with the ear muffs on and this affected their use. Cooperator

D could not hear his corn picker, and Cooperator A could not hear the corn planter. The other five cooperators had no problem hearing a machine.

The maximum continuous time the ear muffs could be worn without discomfort ranged from one-half hour to twelve hours. The maximum continuous time may have included some lunch breaks or rest periods. Five cooperators could wear the ear muffs ten or more hours without discomfort. Six cooperators could wear the ear muffs two to five hours without discomfort. One cooperator could wear the ear muffs for a maximum of one-half hour.

Nine cooperators indicated that they had to get used to the ear muffs. Two cooperators did not have to get used to the ear muffs to accept them. One cooperator did not wear the ear muffs, so this question didn't apply.

Six cooperators felt less fatigue when using the ear muffs. Five cooperators felt no difference in fatigue after wearing the ear muffs. These five cooperators wore the ear muffs less than 66.7% of the time. One cooperator did not wear the ear muffs, so this question didn't apply.

Eleven of the twelve cooperators could tolerate the ear muffs. Two cooperators had no complaints about the ear muffs. Three cooperators indicated that the ear muffs were hot and exerted excessive pressure on their head under high temperatures. Three cooperators indicated that they experienced discomfort after four to ten hours of continuous use. Two cooperators indicated that the ear muffs gave them a strange sensation, similar to having your head under water. One cooperator experienced some discomfort from the strap of the ear muff, which caused pressure to be exerted on the top of his head. One cooperator considered the ear muffs a big bother and didn't wear them.

Cooperator E, who wore the ear muffs 40% of the time, rated the ear muffs as comfortable. Much of his operation consisted of seeding grain and planting corn and under these conditions he used the ear muffs very little. He operated the tractor at part throttle and this reduced the noise level. For hard pulling, such as plowing and field cultivating, he wore the ear muffs 100% of the time.

Cooperator G wore the ear muffs 13.9% of the time, but for chopping silage he wore them 80% of the time. He had a rotary cut and throw silage chopper, which was extremely loud. In this operation he preferred to experience some discomfort rather than be subjected to the excessive noise level.

All the cooperators felt that the ear muffs lowered the noise level to a comfortable level. All the cooperators, except Cooperator L, will continue to wear the ear muffs in approximately the same proportion as they did during the study. In general, the cooperators would rather experience some discomfort from wearing the ear muffs than be subjected to the excessive noise produced by agricultural tractors and machines.

CONCLUSIONS

The tractor noise was significantly reduced when the ear muffs were worn by the operators. The average total loudness of the tractors at 75% rated power take-off load was 110.80 sones without ear muffs and 41.50 sones with ear muffs. In one case the noise level was not reduced sufficiently by the ear muffs to prevent some hearing damage.

The twelve cooperators in the study were requested to have their hearing checked, and nine cooperated in that respect. The audiograms indicated that nine out of nine cooperators had some hearing loss over and above their nonfarmer counterpart. The hearing loss ranged from 13 decibels to 32 decibels. The history of the cooperators indicated that the hearing loss was due mainly to excessive tractor noise.

The type of field operation affected ear muff use. Power take-off operations, such as chopping silage (51.6% use) and picking corn (59.8% use), resulted in less use of ear muffs than tillage operations (over 75% use). This was due to frequent dismountings and inability to hear the machine well enough to judge its performance. Operations such as seeding small grain (43.8% use) and planting corn (52.3% use) also resulted in less use of ear muffs. This was primarily due to more frequent dismounting of the tractor and less power required, which lowered the noise level.

Temperature had the following effect on ear muff use. Four cooperators had no problem with heat, while eight cooperators experienced discomfort from 75^{o} to 90^{o} or above.

There was no correlation ($r = .12$) between loudness of the tractor (at 75% load) and the amount of ear muff use.

There was no correlation ($r = .082$) between the age of the cooperator and the amount of ear muff use.

The maximum continuous time the ear muffs could be worn without discomfort ranged from one-half hour to twelve hours. The maximum continuous time may have included some rest breaks. The average was from four to five hours, but five cooperators could wear the ear muffs more than ten hours continuously.

Nine out of twelve cooperators indicated they had to become accustomed to wearing the ear muffs.

Six of the cooperators felt less fatigue after wearing the ear muffs at the end of the day.

Eleven out of the twelve cooperators used the ear muffs to varying degrees and indicated they will continue to use them about the same amount as during the study. The range of ear muff use was from 100% to 0%. Four cooperators wore the ear muffs more than 85.7% of the time. Five cooperators wore the ear muffs from 66.7% to 40.0% of the time. Two cooperators wore the ear muffs 14.7% and 13.9% of the time. Only one cooperator did not wear the ear muffs.

The ear muffs reduced the noise level to a comfortable level in all cases and that was what the cooperators liked about them. Seven cooperators experienced some discomfort of varying degrees from the ear muffs, but eleven out of twelve would rather wear the ear muffs than be subjected to the excessive noise level.

SUMMARY

Twelve cooperators from seven counties in eastern South Dakota were selected to evaluate an acoustical ear muff for farm tractor use. Data were collected between September 1, 1968, and June 1, 1969. This was accomplished by giving each selected cooperator a pair of ear muffs. Each cooperator completed data sheets after operating the tractor under actual field conditions. A personal interview was also conducted to obtain additional information beyond that obtained on the data sheets.

The noise level for each cooperator's tractor with cab was measured. Steven's Mark IV procedure was used to calculate the noise level in sones. The noise level was excessive in all cases to the point where hearing loss could be incurred.

Nine of the twelve cooperators were given hearing tests and all showed some hearing loss. Background of the cooperators indicated that the hearing loss was due mainly to excessive tractor noise.

The following items affected ear muff use:

1. The type of field operation
2. Frequency of dismounting the tractor
3. Temperature
4. Length of time the ear muffs were worn

Eleven of the twelve cooperators used the ear muffs to varying degrees and plan to continue using them in approximately the same

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GLOSSARY

Acoustics--Acoustics is the science of sound, including its production, transmission, and effects.

Acoustical--Acoustical means containing, producing, arising from, actuated by, related to, or associated with sound.

Attenuation--Attenuation is defined as the decrease in sound power between two points in a system.

Audiogram--An audiogram is a graph showing hearing loss as a function of frequency.

"C" Scale--A weighting network used principally to make sound-level measurements providing a flat response to about 8000 cps.

Correlation Coefficient--A statistic used in linear correlation that provides a measure of the proportion of variation in one variable that is associated with variation in another variable.

Decibel--The decibel is one-tenth of a bel. Thus, the decibel is a unit of level when the base of the logarithm is the tenth root of ten, and the quantities concerned are proportional to power.

Frequency--Frequency is the time rate of repetition of a periodic phenomenon. The frequency is the reciprocal of the period.

Hearing Loss--The hearing loss of an ear at a specified frequency is the amount, in decibels, by which the threshold of audibility for that ear exceeds a standard audiometric threshold.

Loudness--Loudness is the intensive attribute of an auditory sensation, in terms of which sounds may be ordered on a scale extending from soft to loud.

Microbar--A microbar is a unit of pressure commonly used in acoustics. One microbar is equal to 1 dyne per square centimeter.

Noise--Noise is any undesired sound. By extension, noise is any unwanted disturbance within a useful frequency band, such as undesired electric waves in any transmission channel or device.

Noise Level--Noise level is the level of noise, the type of which must be indicated by further modifier or context.

Octave--An octave is the interval between two sounds having a basic frequency ratio of two.

Presbycusis--Presbycusis is the condition of hearing loss specifically ascribed to aging effects.

Sone--The sone is a unit of loudness. By definition, a simple tone of frequency 1000 Hz, 40 decibels above a listener's threshold, produces a loudness of 1 sone. The loudness of any sound that is judged by the listener to be n times that of the 1-sone tone is n sones.

Sound--Sound is an oscillation of pressure, stress, particle displacement, particle velocity, etc., in a medium with internal forces (e.g. elastic, viscous), or the superposition of such propagated alterations.

Sound Pressure Level--The sound pressure level in decibels, of a sound is 20 times the logarithm to the base 10 of the ratio of the pressure of this sound to the reference pressure. The reference pressure shall be explicitly stated.

APPENDICES

APPENDIX I

Table VII. Cooperator Information

Cooperator Code	Name	Address	Age
A	Virgil Biddle	Garretson, South Dakota	48
B	Alfred Fox	Watertown, South Dakota	51
C	Kenneth Gilbert	Hitchcock, South Dakota	21
D	Arnold Hauge	Howard, South Dakota	60
E	Iver Isaacson	De Smet, South Dakota	61
F	August Mundhenke	De Smet, South Dakota	36
G	Curtis Nelson	Brookings, South Dakota	40
H	Henry Rentschler	Howard, South Dakota	42
I	Harold Schrier	Flandreau, South Dakota	39
J	Delmar Tobey	Willow Lake, South Dakota	46
K	Mike Tofte	Brookings, South Dakota	27
L	Reuben Vostad	Brookings, South Dakota	40

APPENDIX II

EAR MUFF NOMENCLATURE

The ear muffs were manufactured by:

Mine Safety Appliances Company
201 North Braddock Avenue
Pittsburgh, Pennsylvania 15208

The catalog number and description are as follows:

09-95635 Noisefoe Mark IV assembly, complete with foam-filled ear seals

Noisefoe Mark IV specifications are as follows:

Weight: 9.7 ounces
Head Pressure at 6.2 inches: 38 ounces
Ear Opening at flange: 2.75 x 1.6 inches
Volume ear cup: 9.5 cubic inches
Worn: over the head, behind the head, under the chin
Cost: $5.75

The attenuation curve for the ear muffs is as follows:

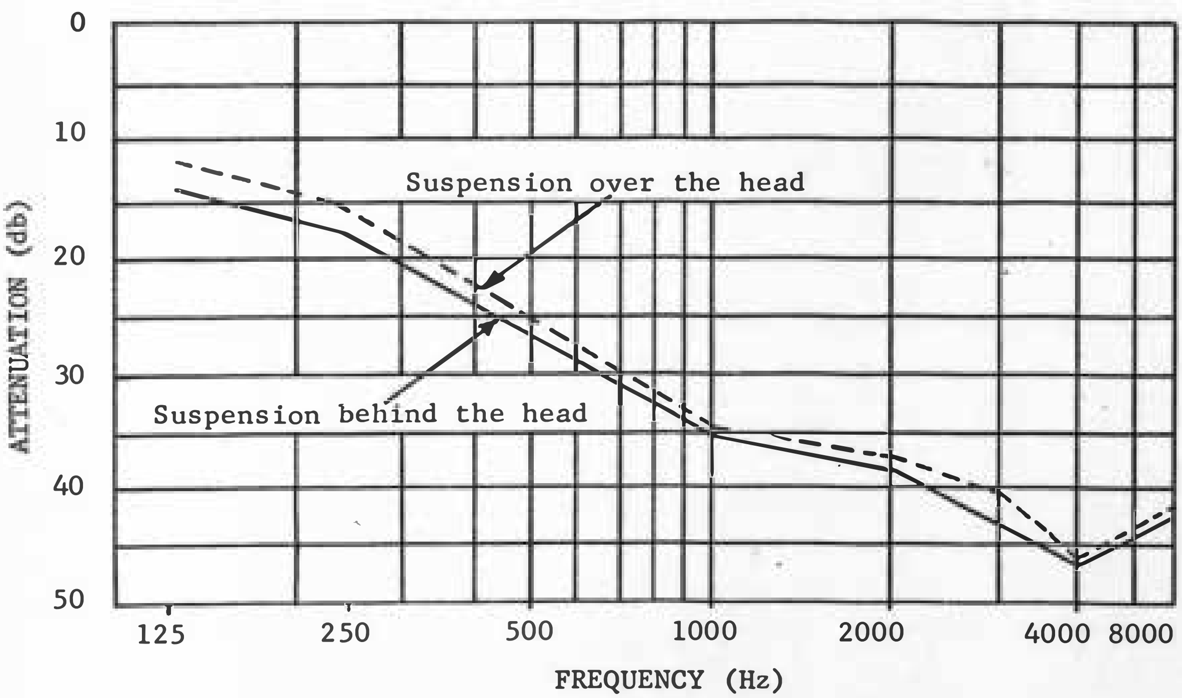

Figure 17. Attenuation Curves for Acoustical Ear Muffs

APPENDIX III

SAMPLE CALCULATIONS

Total Loudness

Tables VIII and IX present the sound pressure level as read from the chart paper of the graphic level recorder for cooperator A's tractor at 75% load. Table IX includes the attenuation of the ear muffs at each band center frequency. These attenuation values were obtained from Figure 17. An example of Stevens' procedure for calculating the total loudness in sones for observation 1, 75% load with no ear muffs, is presented below.

The total loudness, S_t, is calculated by the following formula:

$$S_t = I_m + F(\Sigma I - I_m)$$

where:

I_m = greatest of loudness indexes

$= 36.65$

ΣI = sum of loudness indexes

$= 421.05$

$F = .15$ (for one-third octave bands)

$$S_t = 36.65 + .15(421.05 - 36.65)$$

$$S_t = 94.31 \text{ sones}$$

Table VIII. Total Loudness for Cooperator A's Tractor at 75% Load

Band Center Frequency (cps)	Observation 1		Observation 2	
	SPL	I	SPL	I
40	90.0	10.10	90.0	10.10
50	98.0	22.10	99.0	24.00
63	83.0	8.20	83.0	8.20
80	94.0	20.00	94.0	20.00
100	101.0	35.30	101.5	34.10
125	89.0	16.40	89.5	16.95
160	91.0	20.00	93.0	23.00
200	96.0	30.50	97.0	32.90
250	89.0	20.00	89.0	20.00
315	81.5	13.05	82.0	13.50
400	86.0	18.70	87.0	20.00
500	90.0	26.50	90.0	26.50
630	93.5	36.65	93.5	36.65
800	83.0	18.70	83.0	18.70
1000	80.5	16.95	80.0	16.40
1250	81.0	18.70	81.0	18.70
1600	80.5	19.35	80.0	18.70
2000	78.0	17.50	78.0	17.50
2500	75.0	15.30	74.5	14.85
3150	71.5	13.05	72.0	13.50
4000	69.0	11.80	69.0	11.80
5000	68.5	12.20	69.0	12.60
Sum of Loudness Indexes, ΣI		421.05		428.65
Total Loudness S_t, Sones		94.31		95.45
Average Total Loudness S_t, Sones			94.88	

Table IX. Total Loudness for Cooperator A's Tractor at 75% Load with Ear Muffs

Band Center Frequency (cps)	Observation 1				Observation 2			
	SPL_1	Atten.	SPL_2	I	SPL_1	Atten.	SPL_2	I
40	90.0	5	85.0	7.20	90.0	5	85.0	7.20
50	98.0	6	92.0	13.60	99.0	6	93.0	14.80
63	83.0	7	76.0	5.00	83.0	7	76.0	5.00
80	94.0	8	86.0	11.70	94.0	8	86.0	11.70
100	101.0	10	91.0	17.50	101.5	10	91.5	18.10
125	89.0	12	77.0	7.80	89.5	12	77.5	8.00
160	91.0	13	78.0	8.80	93.0	13	80.0	9.90
200	96.0	15	81.0	11.10	97.0	15	82.0	11.80
250	89.0	16	73.0	7.40	89.0	16	73.0	7.40
315	81.5	20	61.5	3.95	82.0	20	62.0	4.10
400	86.0	23	63.0	4.60	87.0	23	64.0	4.90
500	90.0	27	63.0	4.90	90.0	27	63.0	4.90
630	93.5	29	64.5	5.65	93.5	29	64.5	5.65
800	83.0	33	50.0	2.53	83.0	33	50.0	2.53
1000	80.5	35	45.5	2.05	80.0	35	45.0	1.99
1250	81.0	36	45.0	2.11	81.0	36	45.0	2.11
1600	80.5	37	43.5	2.05	80.0	37	43.0	1.99
2000	78.0	38	40.0	1.75	78.0	38	40.0	1.75
2500	75.0	39	36.0	1.54	74.5	39	35.5	1.49
3150	71.5	42	29.5	.98	72.0	42	30.0	1.02
4000	69.0	47	22.0	.53	69.0	47	22.0	.53
5000	68.5	44	22.5	.64	69.0	44	25.0	.80
Sum of Loudness Indexes, ΣI				123.32				127.66
Total Loudness S_t, Sones				33.38				34.53
Average Total Loudness S_t, Sones						33.96		

APPENDIX IV

SAMPLE CALCULATIONS

Hearing Loss

Figure 18 shows the audiogram for cooperator A. Figure 19 shows the presbycusis curves for a large sample of men chosen at random. These curves represent only the average hearing loss due to age.

The hearing loss in Table III was calculated by subtracting the presbycusis effect from the audiogram. This calculation for cooperator A is presented in Table X. The age of cooperator A is 48.

Table X. Hearing Loss for Cooperator A

Frequency	Audiogram (db)		Presbycusis Effect		Hearing Loss	
	R	L	R	L	R	L
1000 Cycles/Sec.	5	10	3	3	2	7
2000 Cycles/Sec.	15	30	8	8	7	22
4000 Cycles/Sec.	50	50	18	18	32	32

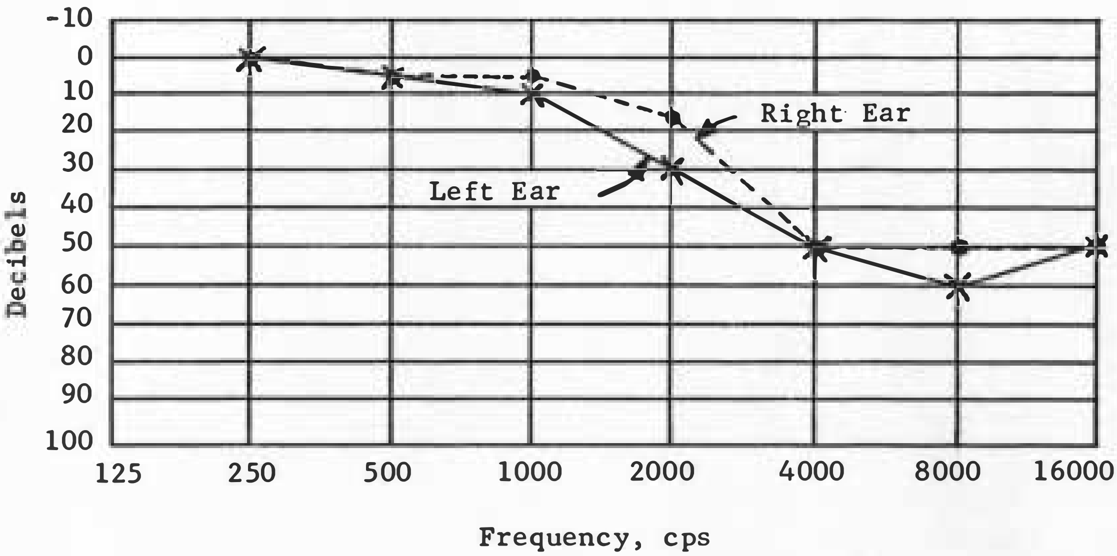

Figure 18. Audiogram for Cooperator A

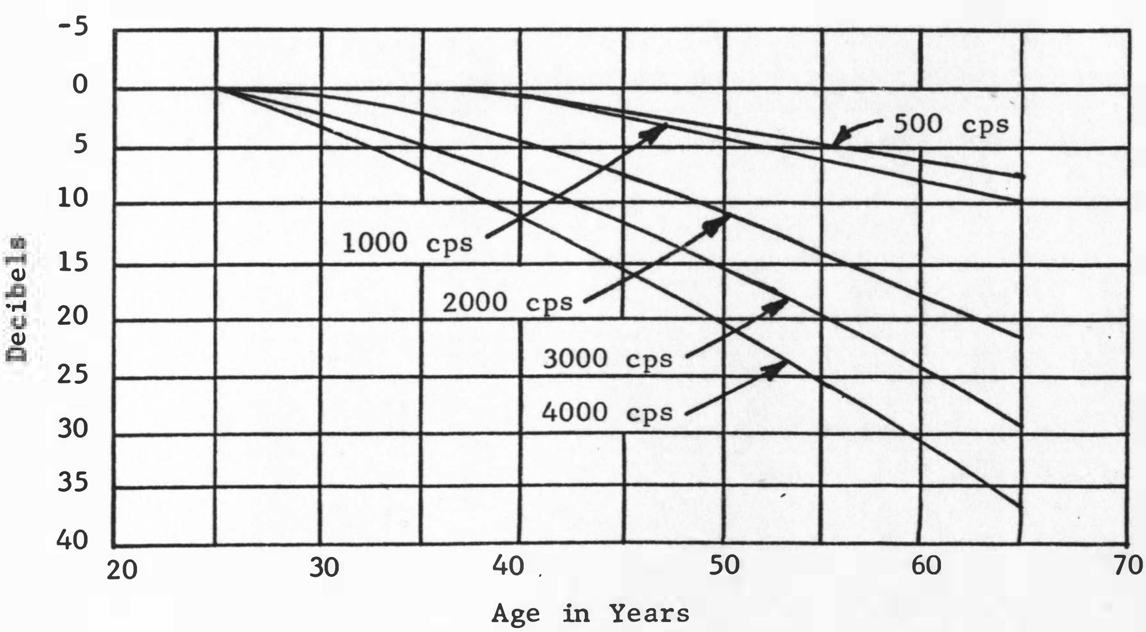

Figure 19. Presbycusis Curves for Men

APPENDIX V

SAMPLE CALCULATIONS

Coefficient of Correlation

The coefficient of correlation was calculated by use of the following formula:

$$r = \frac{\Sigma XY}{N\sigma_x \sigma_y}$$

where:

r = coefficient of correlation

X = average total loudness in sones for each tractor at 75% load, data obtained from Table II

Y = % use of ear muffs for each cooperator for the spring run, data obtained from Tables IV, V, and VI

N = number of cooperators

$$x = \sqrt{\frac{\Sigma x^2}{N}}$$

$$y = \sqrt{\frac{\Sigma y^2}{N}}$$

Table XI indicates the procedure necessary to obtain numerical values for x^2, y^2, and xy. With these values, the coefficient of correlation can be calculated as follows:

$$r = \frac{\Sigma xy}{N\sigma_x \sigma_y}$$

$$r = \frac{1823.73}{12(36.95)(33.40)}$$

$$\underline{\underline{r = .12}}$$

$$\sigma_x = \sqrt{\frac{\Sigma x^2}{N}} = \sqrt{\frac{16389.62}{12}} = 36.95$$

$$\sigma_y = \sqrt{\frac{\Sigma y^2}{N}} = \sqrt{\frac{13382.32}{12}} = 33.40$$

Table XI. Calculation of Correlation Coefficient

Cooperator Code	X	Y	x	y	x^2	y^2	xy
A	94.88	62.3	-15.92	5.17	253.45	26.73	-82.31
B	137.54	98.9	26.74	41.77	715.03	1,744.73	1,116.93
C	121.30	42.9	10.50	-14.23	110.25	202.49	-149.42
D	107.81	100.0	-2.99	42.87	8.94	1,837.84	-128.19
E	113.14	14.7	2.34	-42.43	5.48	1,800.00	-99.29
F	108.37	85.7	-2.43	28.57	5.91	816.25	-69.43
G	124.29	13.9	13.49	-43.23	181.98	1,868.83	-583.17
H	66.53	66.7	-44.27	9.57	195.98	91.59	-423.66
I	73.17	40.0	-37.63	-17.13	1,416.02	293.44	644.60
J	219.37	66.7	108.57	9.57	11,787.44	91.59	1,039.02
K	81.15	93.8	-29.65	36.67	879.12	1,344.69	-1,087.27
L	81.99	0.0	-28.81	-57.13	830.02	3,263.84	1,645.92
$\bar{X}$ = 110.80		$\bar{Y}$ = 57.13			16,389.62	13,382.32	1,823.73