THE EFFECTS OF HEARING PROTECTION ON SPEECH INTELLIGIBILITY IN NOISE

by

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ABSTRACT

Speech intelligibility was investigated in subjects with and without the use of hearing protection in a high noise environment. Fifteen normal hearing subjects and fifteen subjects with high-frequency hearing losses were given the California Consonant Test (CCT) with and without the use of a circumaural muff-type hearing protector. The CCT was selected as the test stimuli due to its design as a sensitive measure for persons experiencing a high-frequency hearing loss. Testing was conducted in a sound-treated room with the speech and noise stimuli delivered at a high intensity level (85dBA); signal-to-noise ration was zero.

A two-way analysis of variance on the resulting CCT scores indicated a significant difference between the normal hearing subject scores and the hearing impaired subject scores. Statistical significance was also found between the CCT scores obtained with hearing protection and those obtained without hearing protection. Interaction effects between hearing sensitivity and the hearing protection condition were not significant. However, examination of raw score means indicated a trend

toward decreased CCT scores with hearing protection use for the hearing impaired subject group. Individual variability in the CCT scores may have accounted for the lack of significance in the interaction effects. A factor in this variability probably was the broad range of muff attenuation values for the experimental subjects. Future research is recommended to identify factors which cause variability in hearing protection attenuation across individual users.

Future researchers may also focus upon investigating specific variables such as test stimuli, noise levels, signal-to-noise ratios, types of noise, or types of hearing protection. Research in this area is needed to further study the effects of hearing protection on speech intelligibility in high noise environments.

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Chapter 1

Introduction

On March 8, 1983 a ruling was issued on the Occupational Safety and Health Administration (OSHA) Hearing Conservation Amendment (Federal Register, 1983). It is now mandatory for employers to make hearing protection available for those employees exposed to noise of 85dBA over an 8-hour time-weighted-average. Furthermore, for those employees who experience a standard threshold shift and who are exposed to a time-weighted-average of 85dBA the wearing of hearing protection is required. Hearing protectors provide attenuation for unwanted noise, but useful sounds such as speech and warning signals are also reduced. It is important to investigate the effects that hearing protectors may have on speech communication in the presence of excessive noise.

Original studies concerned with speech intelligibility with hearing protectors indicated that normal hearing persons experienced no decrease and sometimes a slight improvement in speech discrimination scores with hearing protection worn in a high noise condition (Kryter, 1946; Howell and Martin, 1975; Lindeman, 1976). It was reasoned that since hearing protectors attenuate all sounds, the basic signal-to-noise ratio should remain the same with or without the hearing protection. Therefore, when speech sounds were of sufficient intensity to provide a favorable signal-to-noise ratio, intelligibility was not seen as a problem. However, these findings contradicted reports from workers in industry who complained of difficulties in communicating while wearing hearing protection devices (Alberti,1982). Two factors may have contributed to the workers' communication difficulties. First, persons exposed to industrial noise may already have high-frequency hearing losses. Secondly, hearing protection devices do not attenuate all sounds equally; characteristically hearing protectors attenuate high frequencies more than low frequencies (Lipscomb,1978).

In response to worker complaints, studies were redesigned to include as subjects persons having noise-induced hearing losses. This was the type of person likely to be found in an industrial, high noise setting. As a result, several studies showed that listeners with a high-frequency hearing loss did have lower speech discrimination scores while wearing hearing protectors than without the protection devices (Lindeman,1976; Chung and Gannon,1979; Abel, Alberti, and Riko,1980).

As a measure of speech discrimination these studies used phonetically balanced, monosyllabic word lists such as the Central Institute for the Deaf (CID) Auditory Test W-22 or the Harvard Psychoacoustics Laboratories (PAL) PB-50 (Chung and Gannon,1979; Abel, Alberti, and Riko, 1980). These standard word tests have been used for both research and clinical assessment of a wide range of hearing configurations from normals to persons with severe hearing losses, However, persons with a high-frequency hearing loss may make very few errors on a word test such as the CID W-22 and still complain of speech discrimination problems (Schwartz and Surr, 1979). The California Consonant Test (CCT) is a more sensitive test of word discrimination for persons experiencing hearing losses in the higher frequencies of the speech spectrum (Konkle and Rintelmann,1983). Therefore, the CCT was selected as a measure of speech intelligibility for persons with a high-frequency hearing loss for this study. Since hearing protection attenuates the higher frequencies to a greater extent than the lower frequencies (Abel, Alberti, and Riko,1980), the CCT may give a more representative measure of intelligibility for both normal and hearing impaired listeners.

The purpose of this study was to investigate the effects of hearing protection on speech intelligibility as measured by the California Consonant Test. The speech discrimination of normal hearing and hearing impaired subjects was evaluated with and without the use of hearing protection under a high intensity noise condition (85dBA). Specifically, the independent variables were (1) hearing sensitivity and (2) the use of hearing protection.

Chapter 2

Review of the Literature

Several studies have investigated the effeets of hearing protection on speech discrimination. Kryter(1946) tested normal hearing college students under two signal-to-noise conditions (-15,+10). The speech stimuli were monosyllables delivered over a public address system and person-to-person at a distance of seven feet. Kryter's results indicated that hearing protection did not lower speech intelligibility in high noise levels, and in some instances the protection improved discrimination.

Pollack in 1957 studied the effect of V-51R ear defenders on speech intelligibility. Instead of a sound field environment, Pollack utilized earphones placed over the ear defenders. He concluded that there is little difference in discrimination scores with or without protection up to noise levels of 100-110dB SPL. At higher levels up to 130dBSPL, there was an improvement with the ear protection, at least for normal hearing subjects.

Howell and Martin(1975) also determined that with normal hearing subjects ear protection did not degrade speech discrimination. They indicated that hearing protection may reduce distortion products within the ear and even improve speech perception slightly.

In 1967 Coles and Rice found that subjects with high-frequency losses performed more poorly with ear plugs when listening to speech in quiet. They postulated that for the hearing impaired worker the protection puts the level of speech below the already raised thresholds in the high frequency region of speech. Frolich in 1970 found support for this theory when he investigated the effects of circumaural muff-type hearing protectors on the discrimination ability of senior aviators with high-frequency hearing losses (see Figure 1) (Lipscomb,1978).

More recent studies have compared the effects of hearing protection on both normal hearing and hearing impaired subjects (Lindeman, 1976; Chung and Gannon,1979; Abel, Alberti and Riko,1980). Lindeman (1976) noted that a decrease in the speech discrimination score was significantly correlated with an increase in hearing loss. Additionally, he found some improvement in speech perception with circumaural muff-type hearing protection in persons having a slight hearing loss.

Chung and Gannon(1979) studied two groups of normals and three groups of hearing impaired individuals. Their results indicated that at a high signal-to-noise ratio (+10) the normal hearing subjects obtained higher word discrimination scores with ear protectors. On the other hand, at a low signal-to-noise ratio (-5) or when subjects had hearing losses, speech discrimination scores deteriorated with the addition of the protection.

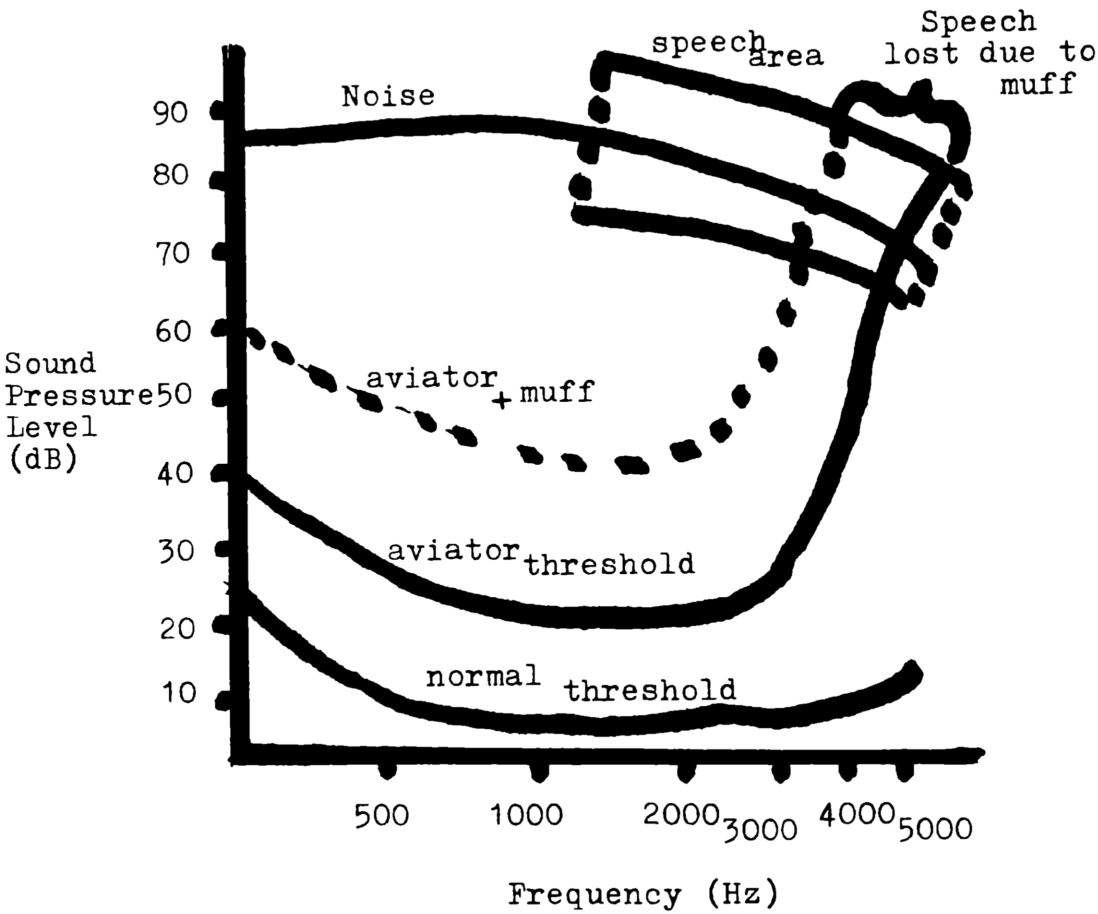

Figure 1. Graph indicating loss of speech information for aviators with high-frequency hearing losses wearing hearing protection. (Frolich from Lipscomb, 1978)

Abel, Alberti and Riko (1980) conducted an extensive study of the effects of hearing protectors. They investigated the following factors: Subject age, type of hearing loss, spectrum and level of noise, attenuation of the hearing protection and fluency of the subject. Their results concurred with previous studies in that the speech discrimination scores of persons with high-frequency hearing losses were substantially affected by the presence of the ear protection. However, for their normal hearing subjects the protection had no significant effect on speech intelligibility as measured by lists of 25 monosyllabic words. The word lists were constructed by using PAL PB-50 word lists. Similar results were obtained with all types of protection tested: MSA comfo 500, EAR plugs, and Wilson Sound Silencer plugs. This study demonstrated that hearing configuration, presence of ear protection, fluency with the English language, level of speech and noise background were all variables which caused changes in word discrimination scores.

In contrast, Berger (1982) stated that at 85dBA or more hearing protection improves speech discrimination for normal listeners and that results on hearing impaired seem to indicate no significant effect.

How to accurately measure speech discrimination is a question which has plagued audiologists for years. Phonetically balanced, monosyllabic word tests have been widely used. The CID W-22 Auditory Test , for example, is a phonetically balanced and standardized test consisting of a simple vocabulary (Konkle and Rintelmann, 1983). A limitation of the CID W-22 test is encountered with persons experiencing a high-frequency hearing loss. They may obtain a high score on the CID W-22, yet still complain of speech discrimination problems (Sher and Owens,1974; Schwartz and Surr, 1979).

Realizing the limitations of the conventional monosyllabic word tests, Owens and Schubert developed the California Consonant Test (CCT) (Owens and Schubert,1977). This test was expressly developed for the evaluation of persons with high-frequency hearing losses. The CCT is a 100-item multiple choice test where either the initial or the final consonants vary within a set of four conconant-vowel-consonant words.

Although the single word stimulus items in the CCT are not representative of ongoing conversational speech, the test is believed to measure those characteristics which may cause hearing impaired persons the most difficulty in understanding everyday speech (Tiffany and Carroll, 1977). These characteristics include (1)phonemes which are difficult for hearing impaired persons to discriminate (for example, voiceless phonemes such as /s/, /θ/),and (2) those phonemes which are easily confused with at least two or three other phonemes (for example,/p/,/t/) (Konkle and Rintelmann,1983).

The present study was designed to investigate the following questions:

1) In the presence of 85dBA of speech noise at a zero signal-to-noise ratio, is there a significant difference between intelligibility scores (CCT) obtained from a group of normal hearing versus high-frequency hearing loss subjects when grouped over two listening conditions: with and without hearing protection?
2) Under the above conditions is there a significant difference between the subjects' CCT scores obtained with hearing protection compared to scores obtained without hearing protection?
3) Also within the same conditions are there any significant interaction effects between CCT scores of normal hearing subjects and hearing impaired subjects with and without the presence of hearing protection?

Chapter 3

Method

Subjects: The subject groups consisted of fifteen normal hearing persons and fifteen persons with high-frequency sensorineural hearing losses. For the purposes of this study "normal hearing" was defined as (1) hearing sensitivity for pure tones of 25dB HL or better for the frequencies 500 Hz through 8000 Hz bilaterally, and (2) speech discrimination scores in quiet of 80% to 100% as measured by CID W-22 word lists. "High-frequency hearing loss" was defined as (1) bilateral mild-to-moderate sloping sensorineural hearing loss, (5 to 15dB HL at 500 Hz with hearing thresholds of 40 to 75dB HL within the range of 4000 Hz to 6000 Hz) and (2) speech discrimination scores in quiet of 80% to 100%. The age range for the normal hearing subjects was 22-47 with a mean of 30.53 while the age range for the hearing impaired subjects was 21-48 with a mean of 36.46 (see Table 1).

Subject criteria was determined by pretesting and by interview. Pretesting included pure tone audiometry, air and bone conduction thresholds determined by procedures recommended by the American Speech-Language-Hearing Association (ASHA, 1978), and speech discrimination testing with CID W-22 word lists.

Normal Hearing		Hearing Impaired	
Range	22-47	Range	21-48
Mean	30.53	Mean	36.46

Table 1. Age ranges and means of normal hearing and hearing impaired subjects.

Setting: Subjects were tested individually in an Industrial Acoustics Corporation (IAC) booth, Model 400 Series, where ambient noise levels did not exceed the limitations established by the American National Standards Institute (ANSI S3.1-1977). Experimental testing was performed in sound field. Prior to each test session, noise and speech presentation levels were measured with a sound level meter (Brüel & Kjaer Type 2203, microphone, model 4144) held near the position of the subject's ear. Noise levels were measured by octave filter analysis (see Appendix B).

The testing environment is depicted in Figure 2. The subject was seated midway between two Grason-Stadler speakers (model 162-4). The speech stimuli was delivered through the front speaker (0 degree azimnth) at a distance of 1 meter from the subject's head. Speech noise presented from the rear speaker (180 degree azimuth) was at a distance of 1 meter also. Both speech stimuli and the noise measured 85dBA representing a zero signal -to-noise ratio.

Speech stimuli consisted of the California Consonant Test (first 50 item sets of List one). Three CCT response sheets were used; each sheet differed in its ordering of the correct answer and foils within the item sets.

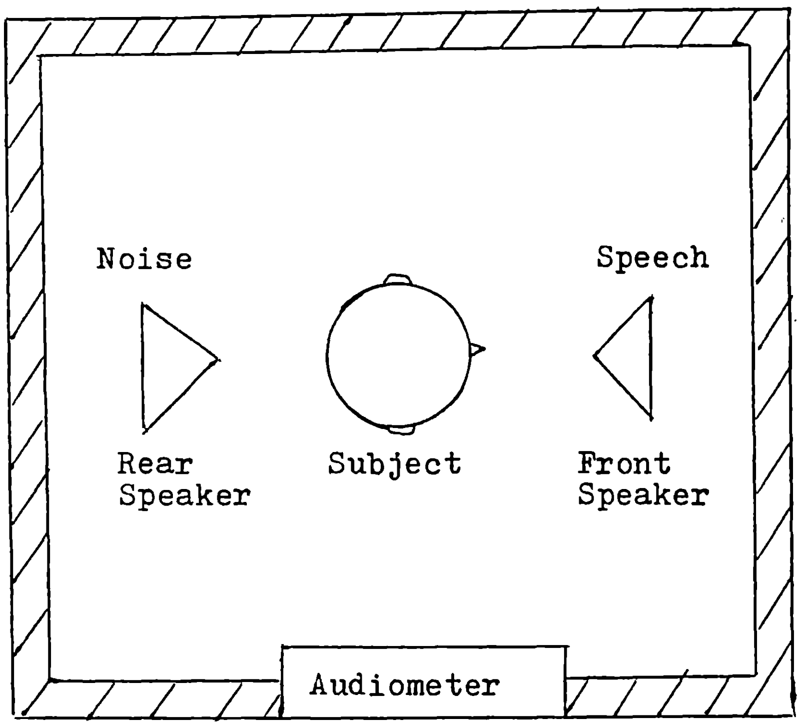

Figure 2. Test environment within IAC booth. Subject seated midway between two speakers. Speech stimuli delivered through the front speaker with noise presented through the rear speaker.

Subjects were required to check the word they heard on these score sheets.

For the hearing protection condition, subjects wore the Bilsom Universal Muff (model 2308-UF-1). According to the manufacturer, this circumaural muff-type hearing protector increases attenuation from 20dB at 250 Hz to 47 dB at 4000 Hz. As with the typical ear protection device, attenuation is greater in the higher frequencies (Lipscomb, 1978; Miller and Silverman,1984).

Procedures: Following the pretesting subjects were seated midway between the speakers. The functional attenuation of the Bilsom muffs was determined by obtaining protected and unprotected thresholds for narrowband noise in sound field at 500 Hz, 1000 Hz, 2000 Hz, and 4000 Hz. This was performed on 27 of the experimental subjects.

Subjects were given the following instructions for the CCT (adapted from CCT instructions, Owens and Schubert,1977):

"This is a multiple-choice word test on a tape recording. Each item set is made of four words. Look at each set of four words before the announcer says the word. When you hear the test word, check the one you think it was. Always check one of the four words even if you must guess. Make only one check per item set."

Following these instructions the first test list was delivered in noise as a practice list. The purpose of this procedure was to avoid possible learning effects.

Each subject was then given the CCT list under two different conditions, including with and without hearing protection. Both conditions were conducted with a signal-to-noise ratio of zero at 85dBA. The presence or absence of ear protection was rotated so that half of the subjects had the ear protection first while the other half had the protection second. Administration of the CCT required approximately ten minutes per condition, and a quiet period of one minute separated each presentation of the word lists. As done by Chung and Gannon (1979) the rest period was introduced to reduce the possible effects of a temporary threshold shift caused by the high intensity noise.

Reliability was determined by the use of a second scorer, a graduate student in audiology. Twenty subject CCT response sheets, 33% of the total, were randomly selected and assessed after the completion of the study.

Chapter 4

Results

The means and standard deviations of the subjects' CCT scores are identified in Table 2. To answer the original questions posed by this study, a two-way analysis of variance (ANOVA) with an interaction procedure was used. The results of this analysis are provided in Table 3.

The first question posed was 1) In the presence of 85dBA of speech noise at a zero signal-to-noise ratio, is there a significant difference between intelligibility scores (CCT) obtained from a group of normal hearing versus high-frequency hearing loss subjects when grouped over two listening conditions: with and without hearing protection? The ANOVA revealed that the overall CCT scores of the two subject groups were significantly different (p=.0002) indicating better CCT scores for the normal hearing subjects than for the hearing impaired subjects.

The second question was 2) Under the same conditions is there a significant difference between the subjects' CCT scores obtained with hearing protection compared to scores obtained without hearing protection? A statistically significant difference (p=.0032) was found when comparing CCT scores obtained under the two hearing

Group	Hearing Protection			
	Without		With	
	$\bar{X}$	S.D.	$\bar{X}$	S.D.
Normal	83.07	12.88	79.6	14.07
Hearing Impaired	76.53	8.72	60.53	10.84

Table 2. Group means and standard deviations of CCT scores for normal hearing and hearing impaired subjects without and with hearing protection.

Source	Degrees of Freedom	Sum of Squares	F Value	P
Hearing Sensitivity	1	2457.600	16.46	*.0002
Hearing Protection	1	1421.067	9.52	*.0032
Hearing Sensitivity X Hearing Protection	1	589.067	3.95	.0519
Error	56	8360.000		
Corrected Total	59	12827.773		

Table 3. Two-way ANOVA with interaction procedure. "*" is an indication of statistical significance with α=.05.

protection conditions (with/ without). This finding indicated overall decreased word discrimination scores in the presence of hearing protection.

The third question addressed was 3) Also within the same conditions are there any significant interaction effects between CCT scores of the normal hearing subjects and the hearing impaired subjects with and without the presence of hearing protection? Analysis of the interaction effects of hearing sensitivity and hearing protection did not result in statistical significance ($p=.0519$). Due to the absence of significant interaction effects between CCT scores of normal hearing and hearing impaired subjects with and without hearing protection, post hoc comparisons would not be valid. Therefore, further statistical analysis of the data was not conducted.

Reliability was determined by a second scorer who was given a random sample ,33%, of the total CCT response sheets. The subjects' answers were assessed, and point-to-point reliability was computed. Reliability between scorers was found to be 99.5%.

Chapter 5

Discussion

The two-way ANOVA indicated that both independent variables, hearing sensitivity and the presence of hearing protection, had an effect on the resulting CCT scores. It was expected that word discrimination scores in noise for the normal hearing subjects would be better than the scores of the hearing impaired subjects. It has been documented that persons with high-frequency hearing losses have poorer word discrimination in noise than normal hearing persons (Tillman, Carhart, and Olsen,1970; Lipscomb, 1978; Giolas, 1982).

As with previous studies (Lindeman,1976; Chung and Gannon, 1979; and Abel, Alberti,and Riko,1980) hearing protection did have an effect on speech discrimination scores, However, unlike these earlier studies, the interaction effects between hearing protection and hearing sensitivity in the present study was not significant; though a trend was evident with a p=.0519.

Since post hoc comparisons were not possible, one can only speculate as to what factors contributed to the significance found with the two independent variables. In Figure 3 the means of CCT scores for the two subject groups are plotted with respect to the hearing protection condition, with and without muffs. Although not statis-

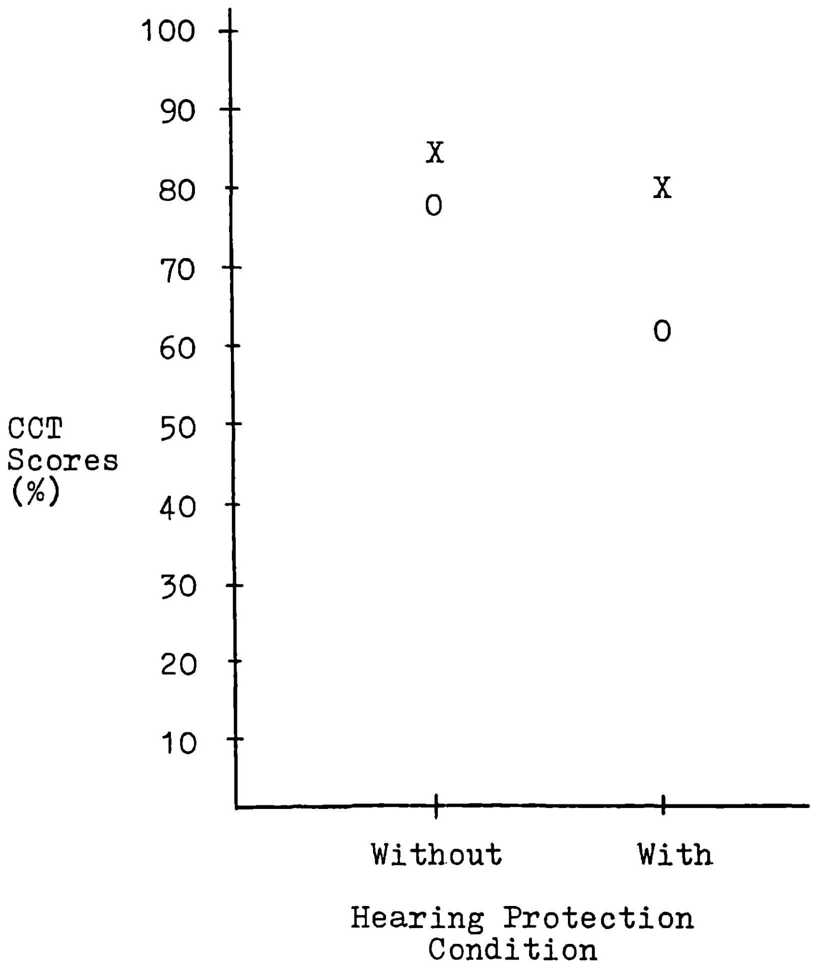

Figure 3. Mean CCT scores of normal hearing subjects (X) and hearing impaired subjects (O) with respect to the hearing protection condition, without and with.

tically significant, the relative positions of the mean scores indicate that the greatest difference was between the normal hearing subjects with hearing protection compared to the hearing impaired subjects with hearing protection. Another major difference shown graphically was between the hearing impaired subjects' CCT scores obtained with hearing protection versus those obtained without hearing protection. Thus, the effects of hearing protection on CCT scores appear to be greater with the subjects having high-frequency hearing losses than with the normal hearing subjects.

The absence of statistically significant interaction effects may have been due to the variability in individual CCT scores. A contributing factor in this variability may have been the broad range of muff attenuation values obtained for the experimental subjects (see Figure 4). As expected greater attenuation existed in the higher frequency range. However, the variability in attenuation between subjects is evident by the large standard deviations. Differences in individual hearing protection attenuation may be a function of the acoustic seal between the hearing protection device and a person's head. Size and shape of an individual's head certainly are factors in the fit of a circumaural muff. Sound pressure leaks would alter the effective attenuation of the hearing protection.

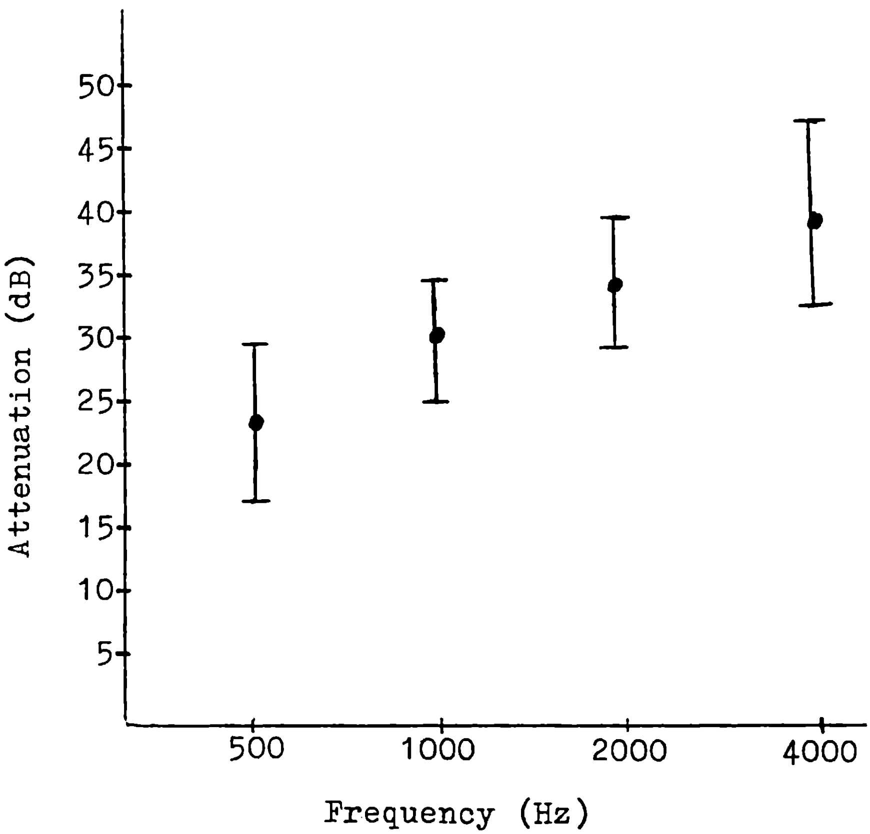

Figure 4. Circumaural muff attenuation means and standard deviations.

Since industrial employers are depending upon the constancy of hearing protection attenuation across individual users, research is needed to identify those factors which cause variability in hearing protection attenuation. Only with the use of reliable hearing protection will noise-induced hearing losses be prevented.

There are many other possibilities for further research in this area. A replication of the present study with larger subject groups may yield significant interaction effects which would allow more detailed analysis of the specific variables. Opportunities exist for studies designed to investigate variables such as noise levels, signal-to-noise ratios, types of noise or types of hearing protectors. Important information could also be obtained by varying test stimuli to include non-speech stimuli, connected speech, or warning signals.

The greatest challenge facing the industrial audiologist is in public education concerning the hazards of noise exposure, and the absolute necessity of wearing hearing protection in high noise (greater than 85dBA) areas. However, the audiologist should also be responsive to workers who have legitimate complaints about hearing protection, as verified by the decrease in speech understanding found in this study. A method of managing such complaints is to explain the effects of hearing protection on speech intelligibility and to offer alternatives such as use of nonspeech signals or written communication. Research based on problems existing in the workplace is a step toward solving or at least diminishing the problems relating to the use of hearing protection.

Chapter 6

Summary

Fifteen normal hearing and fifteen hearing impaired subjects were given the California Consonant Test (CCT) within a high noise environment with and without the use of hearing protection, a circumaural muff. Specifically, this study investigated the following questions:

1) In the presence of 85dBA of speech noise at a zero signal-to-noise ratio, is there a significant difference between intelligibility scores (CCT) obtained from a group of normal hearing versus high-frequency hearing loss subjects when grouped over two listening conditions: with and without hearing protection?
2) Under the above conditions is there a significant difference between the subjects' CCT scores obtained with hearing protection compared to scores obtained without hearing protection?
3) Also within the same conditions are there any significant interaction effects between CCT scores of normal hearing subjects and hearing impaired subjects with and without the presence of hearing protection?

Resulting CCT scores were analyzed by a two-way ANOVA to determine statistical significance. The ANOVA revealed that both variables, hearing sensitivity and the hearing protection condition, had significant effects. Analysis of the interaction effects between hearing sensitivity and hearing protection indicated no significance. Examination of raw score means indicated a trend toward decreased CCT scores with hearing protection use for the hearing impaired subject group. Individual variability in CCT scores may have accounted for the lack of significance in the interaction effects. A factor in this variability probably was the broad range of muff attenuation values for the experimental subjects. Future research is needed to identify factors which cause variability in hearing protection attenuation across individual users.

In conclusion, hearing protection may be detrimental to the understanding of speech for workers, but this finding should not contraindicate the use of hearing protectors in high noise areas. Further research and public education are recommended to diminish problems relating to the use of hearing protection.

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Appendix A: Hearing threshold levels (dB HL) for subjects with high-frequency hearing losses. (R=right L=left)
*6000Hz not tested on every subject.

Subject Number	Ear	Frequency (Hz) 500	1000	2000	4000	6000	8000
1	R	5	5	20	40	*	15
	L	5	15	30	55		40
2	R	15	20	35	60		50
	L	10	15	25	55		40
3	R	10	5	10	40		30
	L	15	10	20	40		40
4	R	15	10	10	45		70
	L	15	15	20	60		85
5	R	10	5	5	65		70
	L	10	10	5	75		70
6	R	5	5	15	65	65	65
	L	5	5	25	70	75	65
7	R	5	5	0	40	30	35
	L	5	5	5	50	50	65
8	R	15	10	15	55		80
	L	15	10	25	70		90
9	R	0	5	10	45	70	60
	L	0	0	5	35	75	65
10	R	15	20	30	65	75	65
	L	10	25	20	45	55	45
11	R	10	20	45	50	30	35
	L	15	25	35	50	30	40
12	R	15	20	60	75	70	50
	L	15	20	55	65	50	30
13	R	5	5	15	60	30	20
	L	5	5	15	55	50	45
14	R	10	10	20	50	65	45
	L	10	10	25	70	75	55
15	R	10	5	5	50	45	25
	L	5	10	5	45	35	25

Appendix B Octave filter analysis of noise stimulus at five different points in relation to the subject's head position (see diagram). Calibration prior to each test session was conducted at position #5.

Position	dBA	Octave Filter Analysis 250	500	1000	2000	4000
1	83	70	77	75	79	76.5
2	85	69	76	77	80	79
3	86	70	77	77	82	80
4	85	69.5	76	77	80	78
5	85	69	76	76.5	81	81