SPEECH INTELLIGIBILITY IN NOISE OF NORMAL-HEARING AND HEARING-IMPAIRED INDIVIDUALS WEARING E-A-R PLUGS

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Chapter 1

Hearing conservation efforts in industry and in the military are a response to the well documented relationship between exposure to noise and inner ear damage resulting in a loss of hearing sensitivity. Ideally, in hearing conservation programs every effort should be made to reduce noise at the source. When the real environment is not adaptable to the ideal, hearing protectors are a partial, practical solution.

Research questions have often been drawn from the dissatisfactions of individuals who wear hearing protectors. Common complaints of individuals who wear hearing protectors are that the devices are uncomfortable, that warning signals are less perceptible, and that speech is less understandable in protected conditions (Abel, Alberti, Haythornthwaite, & Riko, 1982; Chung & Gannon, 1979; Schulz, 1983). This study was proposed to examine the complaint that speech is less well understood in noise when hearing protectors are worn.

Previous studies on this subject have produced conflicting results (Abel et al., 1982; Abel, Alberti, & Riko, 1980; Brister, 1979; Chung & Gannon, 1979; Coles & Rice, 1965, 1966; Howell & Martin, 1975; Kryter, 1946; Lindeman, 1976; Lindeman & Van Leeuwen, 1969; Pollack, 1957; Rink, 1979; Schulz, 1983; Williams, Forstall, & Parsons, 1971). Cross-study comparisons are confused by variations in research methods. As the variables of hearing protectors, speech stimuli, noise spectra, and hearing ability of subjects have differed across studies, so have the results. The usefulness of the results of previous or future studies depends on the similarity of the test condition variables to those found in actual work environments.

The purpose of this study was to determine if there is a significant statistical difference when comparing sentence intelligibility in the unprotected and protected conditions for normal-hearing subjects and subjects with bilateral sensorineural hearing impairments in a background of pink noise. This study replicated the work of Schulz (1983) with adjustments made in the matching of sentence lists, the number of subjects and in the signal-to-noise ratio. The research questions were:

1) is there a statistically significant difference between sentence intelligibility scores in pink noise in the unprotected and the protected conditions in the normal-hearing group?
2) is there a statistically significant difference between sentence intelligibility scores in pink noise in the unprotected and the protected conditions in the group of subjects with sensorineural hearing impairments?
3) is the effect of the hearing protector different

for the hearing-impaired group than for the normal-hearing group? In other words, is the magnitude and direction of the change from the unprotected to the protected condition different for the two groups?

Chapter 2

Review of the literature

Introduction

The review of the literature begins with a chronological survey of the investigations of the specific topic of speech perception in noise with hearing protectors. The review of this specific literature exhibits the need to examine other speech perception studies which relate to the selection of appropriate speech materials, subject characteristics, hearing protectors and noise spectra. Each of these variables is considered separately following the chronological survey.

A semantic problem is encountered in the speech perception literature. The words "discrimination", "intelligibility", and "perception" have been used interchangably by some investigators while others have differentiated between the meanings of the words. The ability to discriminate between speech sounds has been described as "discrimination", while the broader ability to process and comprehend speech has been defined as "intelligibility" (Schulz, 1983). "Perception" is commonly used as an overall term which accomodates both "discrimination" and "intelligibility". In this paper, Schulz's definitions of "discrimination" and "intelligibility" are used to clarify the descriptions of the perceptual processes. When no distinction is desired, the term "perception" is used.

Effects of ear protection on speech intelligibility in noise

World War II provided an impetus for much investigation into hearing conservation and protection. Kryter (1946) acknowledged the Army's awareness of the prophylactic potential of hearing protectors for the control of hearing loss, temporary threshold shifts, annoyance and fatigue. Kryter's work initiated the study of the effects of ear protectors on the perception of speech in noise.

Kryter (1946) chose V-51R earplugs for his investigation. Eight male, college-aged listeners participated in the study. The hearing sensitivity of the subjects was not reported by Kryter. Submarine engine room noise, with a spectrum similar to pink noise, was selected because of its likeness to the noise generated in many industrial and military settings. Kryter divided his work into three experiments. For Experiments I and II monosyllabic words from the Harvard Psycho-Acoustic Laboratory PB Lists (PAL) were presented concurrently to the entire group of listeners while they sat in a semi-circle at a distance of 12 feet from the loudspeaker. In Experiment III the speech stimuli were delivered directly by the talkers in a person-to-person manner to the listeners who were seated in a semi-circle seven feet from the talker. In each experiment discrimination scores for unprotected and protected conditions were obtained. Experiments I and II were conducted in a reverberant room and Experiment III in an anechoic chamber. In the reverberant settings the discrimination scores were higher in the protected condition than in the unprotected condition. The anechoic chamber testing resulted in equivalent discrimination scores in the unprotected and protected conditions. One hundred decibels of noise was necessary in the direct person-to-person presentations to produce protected discrimination scores which were equal or superior to the unprotected condition. When the monosyllabic word lists were presented through a loudspeaker, it was necessary to reduce the noise to 80 dB in order to achieve equal discrimination scores in the unprotected and the protected conditions.

Kryter (1946) studied the effects that wearing earplugs had on the voice level intensity of speakers. With only residual room noise (65 dB) present, speakers wearing earplugs increased their vocal intensity level by 3 dB. Against more intense background noise (75-105 dB) speakers wearing earplugs decreased their vocal intensity level by 1 to 2 dB.

Pollack (1957) examined the effects of wearing V-51R hearing protectors and wax-impregnated plugs on speech discrimination in noise. The hearing sensitivity of the test population was not noted in the Pollack study. Pollack chose fluctuating white noise with the higher frequencies attenuated to simulate the features of military aircraft noise. Monosyllabic words were used as the speech stimuli. The noise and speech stimuli were presented binaurally through headphones at a 0 dB signal-to-noise ratio with intensities ranging from 70-130 dB SPL. The results indicated no significant differences in single word speech discrimination up to noise levels of 100-110 dB SPL. At greater intensities the listeners achieved better discrimination scores in the protected ear conditions than in the unprotected condition.

Coles and Rice (1965) included two classes of hearing-impaired listeners with a group of normal-hearing listeners to study speech discrimination in noise with Selectone-K hearing protectors. The choice of Selectone-K hearing protectors for this study was made because the low-pass filter characteristics of the earplug were theorized to have the greatest potential of the available hearing protectors to affect negatively the speech discrimination scores of hearing-impaired listeners. The hearing-impaired subjects were assigned to a moderate high-tone loss group or a severe high-tone loss group, depending on individual thresholds. Phonetically balanced monosyllabic words were chosen as the speech stimuli. Neither group of hearing-impaired listeners exhibited significant differences in speech discrimination scores in a noise-masked speech test when the unprotected and protected conditions were compared.

Coles and Rice (1966) reported the results of a study for the British Navy. Field conditions were simulated with 'fire' control orders used as the speech stimuli against a background of machine-gun noise. V-51R and Selectone-K hearing protectors were employed for the protected condition. Comparisons of the unprotected and the protected conditions indicated an advantage for the unprotected condition.

Lindeman and Van Leeuwen (1969) studied a normal-hearing group of adults to determine the effects of various hearing protectors on speech discrimination in noise. Using monosyllables in combination with white noise, Lindeman found large interindividual differences in discrimination scores in both the unprotected and protected conditions.

In a subsequent study Lindeman (1976) used 537 hearing-impaired adults as subjects to investigate discrimination of monosyllabic words against a background of white noise in both unprotected and protected conditions. A signal to noise ratio of 0 dB was employed with trials at 80 and 90 dB SPL. The speech stimuli was delivered through one loudspeaker while the noise came through two loudspeakers. Ear-muffs were chosen for this study to avoid problems associated with acoustical leaks encountered with inserted plugs. General results of the Lindeman study indicated that the greater the "average hearing loss" (the sum of the thresholds at 2500, 3150, and 4000 Hz in both ears divided by 6) the greater was the deterioration in speech discrimination scores in noise with ear-muffs. Discrimination score improvement in noise with ear-muffs was noted only in subjects who had low discrimination scores in the unprotected condition. Age effects were also noted by Lindeman. The "average hearing loss" and percentage of correct responses on discrimination testing was correlated with age. However, Lindeman reported that age was not a significant factor within the categories of hearing loss when unprotected and protected conditions were combined.

Williams et al. (1971) conducted a Naval study to gain information about passenger speech reception on rotary-wing aircraft. Noise levels on rotary-wing aircraft were reported by Williams et al. as being capable of causing temporary threshold shifts, annoyance, and fatigue. Hearing protectors were viewed by these examiners as devices capable of eliminating annoyance and fatigue as well as providing a defense against permanent cochlear damage.

Nine normal-hearing subjects, who tested within normal limits on speech discrimination in noise, served as subjects in the Williams et al. study. The nine subjects were divided into groups of three with each of the subjects serving as talker and a listener. Each subject delivered live voice word lists from the Modified Rhyme Test while the other two listeners in the group served as listeners. Discrimination scores in noise for the protected condition were obtained while the listeners and the talkers wore V-51R earplugs. The results of the protected condition were compared with the results of the same tests in the unprotected condition.

The test environments were a laboratory taped rotary-wing aircraft noise and in-flight tests which took place in the passenger area of a rotary-wing aircraft. The frequency spectra for the laboratory and the in-flight tests were similar. In the laboratory conditions the sound pressure levels from 31.5 to 500 Hz ranged from 95 to 105 dB SPL with an approximate 6 dB per octave attenuation above 500 Hz, approximating pink noise. The in-flight noise spectrum showed a 20 dB drop in sound pressure level from 115 dB SPL at 31.5 Hz to 97 dB SPL at 250 Hz. At 500 Hz the sound pressure level was approximately 105 dB SPL. The sound pressure level at 1000 Hz dropped to 92 dB SPL with attenuation per octave from 1000 to 4000 Hz showing less than the 6 dB per octave shift found in the laboratory spectrum. The in-flight noise spectrum showed a slight increase in sound pressure level at 8000 Hz.

Sound pressure levels for the speech stimuli were not reported by Williams et al. (1971). The talkers were instructed to talk in a very loud voice but were to avoid shouting. Each subject presented the Modified Rhyme Test to their assigned test group of three. The laboratory tests and the in-flight tests were the same with the exception of the noise enviroment. Each participant listened to two word lists read by each of the group members in addition to serving once as the talker. The unprotected and protected conditions were examined for differences in both test environments.

The two test environments yielded different results in the Williams et al. (1971) study. Laboratory environment tests revealed no significant differences between the unprotected and protected conditions. However, in-flight environment test indicated better speech discrimination in the protected condition.

Howell and Martin (1975) examined two aspects, listener effects and talker effects, of speech discrimination in noise with hearing protectors. The listener effects (Experiment 1) were examined in a manner similar to that used by other investigators with the listeners responding to stimuli presented in a noise background in the protected and the unprotected conditions. The talker effects (Experiment 2) considered the effects on the quality and intensity level of speech produced by subjects in noise with and without hearing protectors. Both experiments were carried out in a semi-reverberant room with normal-hearing, male, college students serving as subjects. Boothroyd's (1968) monosyllabic words were used as the stimuli. Howell and Martin chose V-51R earplugs and Anticoustic "Antisonic" earmuffs as the hearing protectors.

Two different broadband noises were used as background in Experiment 1. One noise peaked in intensity in the low frequencies and the other peaked in the high frequencies. Three intensity levels were used for the noise presentation: 65, 80, and 95 dB SPL. Four signal-to-noise ratios, -5, 0, +5, and +10, were employed in the protected and the unprotected conditions. The results of the discrimination testing in Experiment 1 showed that the subjects in noise levels of 80 and 95 dB had better speech discrimination scores in the protected conditions than in the unprotected condition. The protected scores obtained when the subjects wore V-51R earplugs were superior to the scores obtained when the earmuffs were used. Signal-to-noise and noise spectra effects were noted in the results, but were not great enough to alter the overall conclusion that the speech discrimination abilities of normal-hearing individuals are not adversely affected when hearing protectors are worn in noise.

The subjects were divided into groups of four for Experiment 2 with three members of the group serving as listeners and one member acting as the talker. Each member of the group served as the talker twice and as listener six times. The intensity of the talker's voice was monitered as he read the discrimination lists. The listeners recorded their responses to the words which were presented in background noises of 54 dB SPL (the "quiet" condition) and of 93 dB SPL (the "noise" condition). The importance of evaluating the talker effect on intelligibility of speech in noise with hearing protectors becomes apparent when considering real-life situations in which individuals wearing hearing protectors are talkers as well as listeners.

The results of Experiment 2 indicated that hearing protector type influenced the intensity level produced by the talker. Comparisons of the protected and unprotected conditions in noise showed talkers speaking with less intensity when wearing hearing protectors. Earplugs produced a more pronounced effect than earmuffs with vocal intensities lessening by an average of 4.2 dB in the earplug protected condition. Earmuff usage caused an average intensity drop of 2.7 dB from the unprotected to the protected condition.

In Experiment 2, a large drop in listener scores from 56% to 31% could not be wholly accounted for by the decrease in the signal-to-noise ratio as the talkers lowered their voices in the protected conditions. Howell and Martin (1975) speculated that the quality, as well as the intensity of the talker's speech, was affected when hearing protectors were worn. Howell and Martin proposed that with the occlusion effect enhancing the low frequencies, the talker's perception of his own bone-conducted speech was changed. Thus, it was speculated that the speech became less clear due to the talker's inability to correctly monitor his own speech.

Howell and Martin (1975) concluded that there was "an improvement in intelligibility when the listener wears protectors in noise and a degradation of intelligibility if the talker wears them in noise". In the type of situation likely to occur in the military or in industry with both the listener and talker wearing hearing protection, the combined listener and talker effects showed an overall reduction in discrimination.

Brister (1979) compared the results of intelligibility scores on the Revised Central Institute for the Deaf (RCID) Everyday Sentence Lists obtained in unprotected and protected conditions in quiet and with a background of taped aircraft noise reduced to pink noise. Thirty-six normal hearing subjects, ranging in age from 20 to 39 years, responded to the speech stimuli in three signal-to-noise ratio conditions: 0 dB (86 dB SPL speech in 86 dB SPL noise), -3 dB (89 dB SPL speech in 92 dB SPL noise), and -9 dB (95 dB SPL speech in 104 dB SPL noise). E-A-R and V-51R earplugs were the hearing protectors used in this study. Listeners were assigned to two groups according to listening experience in noise. Eighteen subjects, who were grouped together, lacked significant listening experience in noise. The remaining 18 subjects had a minimum of 1 year of exposure to industrial noise exceeding 91 dBA. The purpose of this grouping was to eliminate the possibility of listener experience biasing the results. Brister found no significant statistical difference between the two groups, a finding which conflicted with the results of other research (Acton, 1970; Miller, 1971).

Comparisons by Brister (1979) of signal-to-noise ratio conditions indicated that at -3 and -9 dB S/N ratio, speech intelligibility improved significantly in the protected conditions. No significant difference was noted at 0 dB S/N ratio. V-51R earplug intelligibility scores were better than those obtained with E-A-R plugs only at the -3 dB S/N ratio. No significant differences were found between the V-51R and E-A-R earplugs at 0 or -9 dB S/N ratio.

Rink (1979) compared the protected and unprotected speech discrimination scores in a reverberant condition among three groups of sensorineural hearing-impaired listeners and one group of normal-hearing listeners. Thirty sensorineural hearing-impaired listeners were placed in one of three groups according to probable etiology. The etiologies were noise-induced hearing loss, presbycusis, and sensorineural hearing loss of unknown origin. Ten subjects were assigned to the normal-hearing group and to each of the hearing-impaired groups. The variables of visual cues, discrimination in quiet and noise, and absence and presence of hearing protectors were manipulated under eight test conditions. The Modified Rhyme Test was administered live voice as the test stimuli in a background of broadband noise. The speech stimuli were presented at 65 dBA in quiet and at 85 dBA in noise. The noise was filtered to include only the spectral energy between 350 Hz and 2800 Hz. Presentation level for the noise was 90 dBA. The Wilson 153 Sound Barrier, an earmuff, was the hearing protector chosen by Rink. When the test conditions required visual input, the subjects watched the speaker through a window which separated the test room from the control room.

The normal-hearing group in the Rink (1979) study showed no change in speech discrimination abilities from the unprotected to protected condition in quiet. In noise, speech discrimination scores improved with the hearing protectors for the normal-hearing group.

The hearing-impaired group in the Rink (1979) study showed results differing from the normal-hearing group. Hearing protectors reduced the speech discrimination scores of the hearing-impaired group in quiet while having no effect on the scores in noise.

Rink (1979) also reported on the effect of visual cues. Visual cues enhanced the speech discrimination scores in all Rink's test conditions with the exception of normal-hearing listeners in quiet.

Chung and Gannon (1979) presented findings which conflict somewhat with the findings of other researchers. Forty normal-hearing and 60 hearing-impaired subjects, seated in a sound-treated chamber, listened to tape recordings of CID Auditory Test W-22 in a background of pink noise. The stimuli were presented at two signal-to-noise ratios, 10 and -5 dB. The Welsh model 4530 earmuff was used for hearing protection.

Only the normal-hearing group, at the high signal-to-noise ratio of 10 dB, demonstrated improved speech discrimination scores in the protected condition. The opposite effect was shown in all other conditions of the Chung and Gannon study. The normal-hearing group showed better speech discrimination scores in the unprotected condition at the low, -5 dB, signal-to-noise ratio. The hearing-impaired group performed better without the earmuffs at both signal-to-noise ratios.

The findings of Abel et al. (1980) also disputed evidence offered in other research that speech perception in noise is improved with hearing protectors. Subjects with "pre-existing, noise-induced hearing losses" were compared to normal-hearing individuals. Other variables considered were age, noise spectra, signal-to-noise ratio, and the familiarity of the listener with the language in which the speech stimuli were presented. Eight groups of 12 subjects (96 total subjects) were classified according to hearing sensitivity, shape of hearing loss, age, and fluency in the English language. Each of the subjects was presented 12 taped lists of 25 monosyllabic words from the PAL-PB 50 word list at levels of 80 and 90 dBA. Subjects wore MSA Comfo-500 muffs while responding to the word lists presented sound field in quiet and in 85 dBA background noises of white and crowd noise.

Only the normal-hearing group exhibited discrimination scores in noise which did not worsen in the protected condition. Other subject characteristics did cause significant changes in discrimination scores in the protected condition. Non-fluency could not be linked to a consistent pattern of change; hearing loss, low speech-to-noise ratios, and the presence of background noise negatively affected discrimination scores in a consistent manner.

Abel et al. (1982) expanded the 1980 study to include subjects with flat hearing losses and to examine a greater variety of hearing protectors. The methods for presentations of the stimuli were the same as in the 1980 study by Abel et al. The MSA Comfo-500 muff, the E-A-R plug, the Wilson Sound Silencer plug, the Wilson Sound Ban occluded, and Proppo-plast Swedish wool were used for the hearing protectors. The attenuation values of the hearing protectors were measured with the results indicating that significant attenuation differences existed among some of the protectors. Subjects with normal-hearing, flat and high frequency losses were tested.

The effects of age, fluency, signal-to-noise ratio, and the spectrum of the noise on speech intelligibility in noise with hearing protection were examined. Age was not found to be a significant factor across groups when the unprotected and protected conditions were compared. Non-fluent subjects showed a decrease of 10% to 20% across groups from the unprotected to the protected condition. Signal-to-noise ratio had a more deleterious effect on the protected discrimination scores of the hearing-impaired groups than on the normal hearing groups in comparisons of the unprotected and protected conditions. Background noise was also found to interact with hearing loss. Across groups, crowd noise background resulted in poorer discrimination scores than did the white noise background with the most pronounced effects occurring in the hearing impaired group.

The attenuation value of the hearing protectors did not cause a difference in discrimination scores across groups in comparisons of the unprotected and protected conditions. The overall conclusion of the work of Abel et al. (1980, 1982) was that hearing-impaired individuals are additionally communicatively handicapped in a noise environment which requires the use of hearing protection.

Schulz (1983) followed procedures similar to the methods used by Brister (1979) to test speech intelligibility in noise with E-A-R plugs. A hearing-impaired group and a normal-hearing group comprised the test population. The groups' unprotected and protected scores on the RCID Everyday Sentence Lists were compared. At the test signal-to-noise ratio of 0 dB with noise and speech presentation levels of 94 dB, no significant differences were found for the unprotected and protected intelligibility scores for either test group.

Nonequivalency of the RCID Everyday Sentence Lists was cited by Schulz (1983) as a problem in comparative testing. The nonequivalency of the lists was mentioned as a factor which confounded the test results.

Speech stimuli

The development of appropriate speech perception testing material has been pursued for years with Egan's (1948) publication of the PAL PB Word Lists marking the formal beginning of speech perception testing. The development of a variety of speech perception test material since Egan's pioneering work in 1948 has allowed investigators to choose the type of speech material best suited for a particular test condition. Choices include nonsense syllables, monosyllabic words, rhyme tests, sentences and continuous discourse. Speech perception results obtained in equivalent test conditions vary with the speech stimuli (Kryter, 1962).

Investigators of speech perception in noise have employed various speech materials. The most commonly used speech stimuli have been monosyllabic word lists (Abel et al., 1980; Abel et al., 1982; Acton, 1970; Coles & Rice, 1965; Howell & Martin, 1975; Kryter, 1946; Lindeman, 1976; Lindeman & Van Leeuwen, 1969; Pollack, 1957). Standardized monosyllabic word lists utilized have been the Harvard Psycho-Acoustic Laboratory Phonetically Balanced Word Lists (PAL), the Central Institute for the Deaf (CID) Auditory Test W-22, and Boothroyd's C-V-C word lists (Boothroyd, 1968). Other speech stimuli have included military 'fire' control orders (Coles & Rice, 1966), the Modified Rhyme Test (Williams et al. 1971) and the RCID Everyday Sentence Lists (Brister, 1979; Schulz, 1983).

Phonetically balanced monosyllabic word lists or nonsense syllable lists are the standard materials for the testing of speech discrimination skills with the results indicating the ability of the subject to discriminate between speech sounds. Speech processing ability, i.e., intelligibility, can not be consistently predicted from performance on speech tests which are designed to test discrimination abilities (Giolas, 1966).

Williams and Hecker (1967) suggested requirements to be considered when choosing appropriate speech perception material. For the test condition requirement of the evaluation of the intelligibility of everyday speech, Williams and Hecker stated a preference for sentences as test material. This view was supported by many others (Brister, 1979; Elkins, 1974; Erber, 1975; Hagerman, 1982; Niemeyer, 1976; Speaks, Parker, Harris & Kuhl, 1972; Suter, 1978).

Brister (1979) stressed the importance of choosing speech material which would be representative of field conditions and which could be sufficiently controlled in the laboratory. The requirement of laboratory control of speech materials necessitates the use of recorded rather than live voice presentation of speech perception material (Kreul, Bell & Nixon, 1969). Brister and Schulz (1983), in studying speech intelligibility in noise with E-A-R plugs, chose recordings of RCID Everyday Sentence Lists as the test stimuli. The choice of the recorded RCID Everyday Sentence Lists as stimuli was made with the intent to provide subjects with listening material which related closely to connected discourse. Highly variable inter-list differences led Schulz (1983) to conclude, however, that the sentence lists could not be used as equivalents.

An examination of the history of the development of the RCID Everyday Sentence Lists is necessary to assess the appropriateness of using the sentences for speech intelligibility testing. The Committee on Hearing and Bio-Acoustics (CHABA) of the National Research Council outlined the criteria to be used in the development of sentence material for speech perception testing. The criteria stressed the importance of developing sentences that paralleled "everyday" speech with special attention given to sentence length, grammatical structure, vocabulary, and redundancy (Silverman & Hirsh, 1955). Researchers at the Central Institute for the Deaf produced the original CID Everyday Sentence Lists.

Differences in the sentence length of the items on the original CID lists prompted Harris, Haines, Kelsey, and Clack (1961) to devise the Revised CID (RCID) Everyday Sentences. Rippy, Dancer and Pittenger (1983) studied the list equivalency of the RCID Everyday Sentence Lists and determined that the lists were not equivalent and were therefore inappropriate for intraindividual comparisons. Suter (1978) found that the lists were not equivalent but used the lists as stimuli by pairing the lists to bring the mean scores to within 1 1/2% of each other. Schulz (1983) attributed a wide discrepancy in the results of her study of speech intelligibility in noise with E-A-R plugs to list non-equivalency.

Noise stimuli

The review of the literature on speech perception in noise with hearing protectors makes apparent the options available for noise stimuli. White noise was the choice of Abel et al. (1980, 1982), Lindeman (1976), Lindeman and Van Leeuwen (1969), and Pollack (1957). Howell and Martin (1965) used two broadband noises, one with the energy concentrated in the low frequencies and the other with the energy peaking in the high frequencies. Crowd or babble noise was used by Abel et al. (1980, 1982).

Williams et al. (1971) used rotary-wing aircraft noise in two conditions: taped aircraft noise in a laboratory test condition and actual aircraft noise heard by listeners sitting in aircraft. Coles and Rice (1966) also employed noise, machine-gun noise, which would simulate conditions found in military settings.

Rink (1979) filtered broadband noise to create a noise with a frequency range from 350 to 2800 Hz. Brister (1979) and Schulz (1983) cited studies (Acton, 1970; Karplus & Bonvallet, 1953) which indicated that pink noise was similar to the noise often found in industry. Suter (1978) stressed the importance of stimuli which closely paralleled "everyday" conditions. Acton (1970), Chung and Gannon (1979), and Kryter (1946) also chose pink noise, with its low frequency emphasis, for their investigations.

Intensity levels for speech and noise

Intensity levels for the presentation of speech and noise stimuli have been as varied as the types of speech and noise stimuli. Pollack (1957) covered the broadest range of intensities by presenting the combined stimuli at intensities ranging from 70 to 130 dB SPL. Other investigators have avoided the extremes of the intensity level range used by Pollack and have opted for simulating more common lifelike conditions. Intensities in the range from 80 to 110 dB SPL have been used in the large majority of the studies (Abel et al., 1980; Abel et al., 1982; Brister, 1979; Kryter, 1946; Lindeman, 1976; Schulz, 1983; Williams et al., 1971).

Signal-to-noise ratios which are most applicable to actual field conditions are those that reflect the effects of noise on vocal effort. The well known Lombard effect occurs when a speaker increases vocal effort as the background noise is increased. Kryter (1946) and Pickett (1957) found that noise intensities in excess of 105 dB SPL made speakers' efforts to shout over the noise ineffective.

Hearing protectors

Individual anatomical differences, situational differences, and individual preferences have led to the development and use of a variety of hearing protective devices in hearing conservation programs. V-51R earplugs have been the most common choice of investigators of speech perception in noise (Brister, 1979; Coles & Rice, 1965; Howell & Martin, 1975; Kryter, 1946; Michael, 1965; Pollack, 1957; Williams et al., 1971). Other earplugs used for this type of study have included E-A-R plugs (Abel et al., 1982; Brister, 1979; and Schulz, 1983), Selectone-K plugs (Michael, 1965; Coles & Rice, 1965), and Wilson Sound Silencer plugs (Abel et al., 1982) and wax-impregnated plugs (Pollack, 1957). Other studies have examined the effects of earmuffs of speech perception in noise (Abel et al., 1980, 1982; Howell & Martin, 1975; Lindeman, 1976; Rink, 1979).

E-A-R plugs are made of expandable polyvinyl foam. Wearer comfort, low cost, ease of fitting, and good attenuation characteristics have made E-A-R plugs a common choice for hearing conservation programs in the military and industry (Gasaway, 1985).

Chapter 3

Methods

Subjects

Sixteen normal-hearing individuals and sixteen individuals with sensorineural hearing impairments served as subjects. The subjects were assigned to a normal-hearing or a hearing-impaired group on the basis of hearing sensitivity. The subjects were between the ages of 18 and 60 and had at least an eighth grade education.

The subjects were selected from volunteers from the surrounding community and from clientele of the Kansas State University Speech and Hearing Center. After being informed of the experimental procedures, the subjects were asked to sign informed consent forms (see Appendix B). All subjects' external ear canals were examined by otoscopy for conditions (excessive cerumen or infection) which would contraindicate the insertion of E-A-R plugs. Oto-admittance screening, including tympanometry and acoustic reflex measurement, were performed on all subjects. Pure tone thresholds were evaluated audiometrically. The subjects' bilateral speech reception thresholds and speech discrimination scores on the Northwestern University Auditory Test #6 (NU-6) were obtained using taped stimuli. Uncomfortable loudness levels for the taped test stimuli (speech in a background of pink noise) were obtained for all subjects. Those individuals with uncomfortable loudness levels of 95 dB SPL or less were excused from the study.

The normal-hearing group was made up of individuals who met the following criteria:

1. normal otoscopic examination with no evidence of infection or excessive cerumen,
2. oto-admittance screening results within normal limits,
3. pure tone air thresholds no worse than 20 dB HL at 250, 500, 1000, 2000, 3000, and 4000 Hz,
4. word discrimination scores no worse than 90% on NU-6 word lists at 35 dB SL,
5. loudness tolerance level in excess of 95 dB SPL for the taped test stimuli.

The hearing-impaired group was made up of individuals who met the following criteria:

1. normal otoscopic examination with no evidence of infection or excessive cerumen,
2. tympanograms within normal limits and acoustic reflex results consistent with cochlear site of lesion,
3. pure tone air and bone conduction thresholds no worse than 50 dB HL at 250, 500, and 1000 Hz, and a pure tone average of 2000, 3000, 4000, and 6000 Hz no better than 30 dB HL,
4. word discrimination scores no worse than 50% on

NU-6 word lists at 35 dB SL,

5. loudness tolerance levels in excess of 95 dB SPL for the taped test stimuli.

Stimuli

The RCID Everyday Sentences Lists were used as the test stimuli (see Appendix A). A dubbed taped recording of the recorded version of the RCID Everyday Sentence Lists, University of Maryland #1 (UM Test #1), in a background of pink noise, was employed.

The use of stimuli which is typical of everyday speech is supported by the review of the literature (Brister, 1980; Elkins, 1974; Erber, 1975; Hagerman, 1982; Niemeyer, 1976; Suter, 1978; Williams & Hecker, 1967). The equivalency of the RCID Everyday Sentence Lists across lists and across signal-to-noise ratios has been questioned by investigators (Rippy, et al., 1983; Schulz, 1983; Suter, 1978). Control of list equivalency was achieved by presenting four different lists, with each appearing an equal number of times in each experimental condition (see Table 1). The purpose of presenting all lists in each experimental condition was to prevent a list effect in results. Those lists which evidenced the most inter-subject variability were excluded. Lists A, D, F and G were used as stimuli. These lists were found by Rippy et al. (1983) to result in relatively similar scores at the -3 dB signal-to-noise ratio.

Table 1

RCID Everyday Sentence List and Listening Condition Order

Subject no.		Condition order	
		Protected	Unprotected
#1	List order:	AD	FG
#2		DF	GA
#3		FG	AD
#4		GA	DF
		Unprotected	Protected
#5	List order:	AD	FG
#6		DF	GA
#7		FG	AD
#8		GA	DF

Note. The list/condition order rotation for Subjects #9 through #32 repeated the sequence shown for Subjects #1 through #8.

Studies of speech spectra have measured the distribution of the energy across the speech spectra. Figure 1 shows the French and Steinberg (1946) idealized long average speech spectrum.

Noise

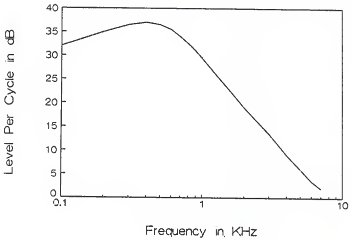
Hearing conservation programs are mandated by the Occupational Safety and Health Administration for work environments which "equal or exceed an 8-hour time-weighted average sound level (TWA) of 85 dB measured on the A scale, or equivalently, a dose of fifty percent" (OSHA, 1981, p. 204). It can be assumed that hearing protectors would most commonly be worn in noise environments in excess of 85 dBA. Because hearing protector use is most common in environments which exceed 85 dBA, a noise intensity greater than 85 dBA is most realistic when simulation of real-life conditions is desired.

Low frequency noise levels greater than 105 dB SPL were found by Webster (1965) and Pickett (1957) to make verbal communication ineffective. Ninety decibels, measured on the A scale, was chosen as a noise level which would commonly necessitate the use of hearing protectors while still allowing effective verbal communication. Pink noise was used because it closely resembles the noise spectrum most often found in industry with the greatest spectral energy in the low frequencies (Karplus & Bonvallet, 1953).

Sound level measures were made at the level of the listener's ear to determine the proper attenuator dial setting

Figure Caption

Figure 1. Idealized long average speech spectrum adapted from French and Steinberg (1947).


40
35
30
25
20
15
10
5
0
0.1
1
10
Level Per Cycle in dB
Frequency in KHz

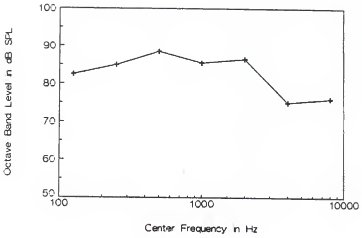
for the noise. Amplifier controls were then taped in place to assure a constant intensity throughout the testing. An octave band analysis of the noise was obtained with a Bruel and Kjael band pass filter set, type 1615 (see figure 2).

A signal-to-noise ratio of -3 dB was used for the experimental condition with the speech at 87 dBA and the noise at 90 dBA. The selections of speech and noise levels and the signal-to-noise ratio were based on the information in the literature review. The goal was to select presentation levels which would typify those levels found in industrial or military settings.

Howell and Martin (1975) and Kryter (1946) found that speakers decreased their vocal intensities in the protected condition because the loudness of the noise was less in the protected condition. The Lombard voice reflex is a phenomenon which supports the findings of Howell and Martin and of Kryter (Chaiklin & Ventry, 1963). The Lombard reflex occurs when speakers increase vocal intensity as the background noise is increased. With hearing protectors attenuating the background noise, the speakers decrease vocal intensity. Howell and Martin found when earplugs were worn in noise, average vocal intensities were 4.2 dB less than when no earplugs were worn. Kryter found the difference to be from 1 to 2 dB. Thus, the -3 dB signal-to-noise ratio was chosen to represent realistic field conditions.

Figure Caption

Figure 2. Octave band analysis of the pink noise spectrum.


Octave Band Level in dB SPL
100
90
80
70
60
50
100
1000
10000
Center Frequency in Hz

The intensity of the speech stimuli was measured with a General Radio Company sound-level meter (Type 1551-C). The peak reading obtained for the RCID Everyday Sentence Lists was used as the decibel level (87 dBA) for the speech stimuli. Because of the rapid variations in the intensities of the speech spectrum, the peak excursion levels were used as the intensity measures for the speech stimuli. This is admittedly an imprecise measure of the intensity. Because of this problem, a pilot study was conducted to see if the adequate data could be obtained with the speech and noise intensity levels set as described.

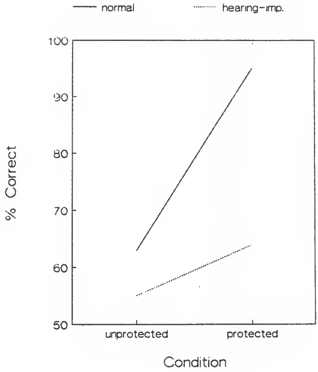
The -3 dB signal-to-noise ratio (noise at 90 dBA and speech at 87 dBA) was used in the pilot study with five normal-hearing and four hearing-impaired subjects. The pilot study showed that, at these intensity levels, no normal-hearing subject scored better than 95% and no hearing-impaired subject scored worse than 50% (see Figure 3). Thus, the -3 dB signal-to-noise ratio was accepted as the level which would not be too easy for the normal-hearing listeners nor too difficult for the hearing-impaired listeners.

Hearing protectors

Polyvinyl earplugs, manufactured by the E-A-R Division of Cabot Corporation, were chosen as the hearing protectores in this study. E-A-R plugs are soft and spongy

Figure Caption

Figure 3. Group means of the pilot study.


normal
hearing-imp.
100
90
80
70
60
50
% Correct
unprotected
protected
Condition

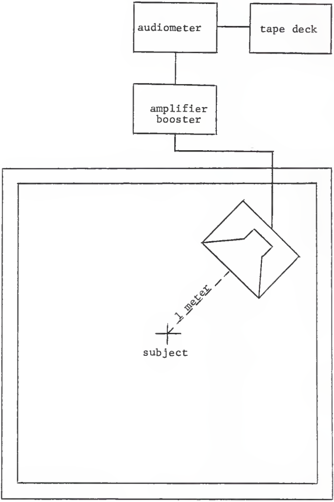
polyvinyl earplugs which are compressed by the user for easy insertion. After insertion into the ear canal, the earplugs expand to conform to the ear canal contours of individual users (E-A-R Corporation, 1978; Gasaway, 1985).

Equipment

The subjects were seated in an Industrial Acoustic Company (Order #101676) sound-isolated chamber for the test procedures. A cassette tape recording of the RCID Everyday Sentence Lists in a background of pink noise was played on a tape deck (Kyocera D-801 Stereo Cassette Tape Deck). The sentences and the pink noise were dubbed onto the cassette in two separate channels so that the intensities of the sentences and the noise could be controlled separately at the audiometer attenuator dials. A calibration tone at the beginning of the tape was used daily to calibrate the taped stimuli. The sentences and the noise were channeled through a Grason-Stadler Instruments 16 audiometer. The audiometer was coupled to an booster amplifier to provide sufficient intensity. The subjects heard the sentences and noise through a single Allison Laboratories Inc. (Model #2056) loudspeaker. Figure 4 is a block diagram of the equipment and subject position. Intensity levels of the sentences and the noise were measured at the approximate level of the ear with a General Radio Company (Type 1551-C) sound-level meter.

Figure Caption

Figure 4. Block diagram of the subject position in the experimental situation.


audiometer
tape deck
amplifier
booster
1 meter
subject

Procedures

Preceding the subject selection process, each subject read and signed a consent form which outlined the procedures and risks (see Appendix B). Hearing evaluations for each subject were then administered as outlined in the subject selection section of this report. Subjects not meeting the criteria for either the normal-hearing or the hearing-impaired categories were excused from the study.

Control of learning effect was maintained by alternating the protected and unprotected conditions. Half of the subjects from each group (normal-hearing and hearing-impaired groups) heard the stimuli in the protected condition first and then in the unprotected condition. The presentation order of the conditions was reversed for the other half of the subjects, with the unprotected condition preceding the protected condition (see Table 1).

To familiarize the subjects with the task, List I from the RCID Everyday Sentence Lists was presented in pink noise to the subjects who listened in the unprotected condition. The speech and noise presentation levels for the familiarization task were the same as those used in the experimental presentations.

The examiner inserted the E-A-R plugs into the subjects' ear canals to insure proper fit. Individual attenuation values for the E-A-R plugs were measured by obtaining protected and unprotected thresholds in a sound field. Narrow bands of noise with the center frequencies of 250, 500, 1000, 2000, 3000, 4000, and 6000 Hz were used as the stimuli. The attenuation values were calculated by finding the differences between the protected and unprotected thresholds at each frequency. The calculations were made according to the Acoustical Society of America Standard Method for the Measurement of Real-Ear Protectors and the Physical Attenuation of Earmuffs (ASA, 1975).

Following the determination of earplug attenuation values, the subjects were instructed to avoid adjusting the E-A-R plugs in the ear canal. With the E-A-R plugs in place, the subjects listened to two tape recorded RCID Everyday Sentence Lists in the pink noise background. The subjects recorded the sentences in writing as perceived on response forms provided by the examiner (see Appendix C). The same listening and recording procedures were used in the unprotected condition, with the subjects listening to two more RCID Everyday Sentence Lists lists in a pink noise background.

The subjects' responses were scored in the manner outlined by Giolas and Duffy (1973) and by Hinkle (1979). These investigators allowed for contractions or spelled out contractions, identifiable misspelled words, and changes in plurality to be counted as correct. Each list contained 50 key words. The speech intelligibility score was the percentage of key words which were identified correctly. The scores for the open and protected conditions were compared across the hearing-impaired and the normal-hearing groups.

Chapter 4

Results

The results of the investigation conducted to answer the research questions in Chapter 1 will be presented in this chapter. The research questions were:

1) is there a statistically significant difference between sentence intelligibility scores in pink noise in the unprotected and the protected conditions in the normal-hearing group?
2) is there a statistically significant difference between the sentence intelligibility scores in pink noise in the unprotected and protected conditions in the group of subjects with sensorineural hearing impairments?
3) is the effect of the hearing protectors different for the hearing-impaired group than for the normal-hearing group? In other words, is the magnitude and direction of the change from the unprotected to the protected condition different for the two groups?

A fourth question concerns the list equivalency of the RCID Everyday Sentence Lists. Information was drawn from the analysis of the data to answer questions concerning the list equivalency of the RCID Everyday Sentence Lists utilized in this study.

Statistical analysis of the data was accomplished using the Statistical Analysis System (SAS) 4x4x2x2 repeated measure analysis of variance (ANOVA) for the data within each group.

The reader is reminded that each listener heard four RCID Everyday Sentence Lists, two in the unprotected condition and two in the protected condition. The lists were ordered so that all lists appeared in each experimental condition an equal number of times. The list order is shown in Table 1.

For the interested reader, Appendix D contains some of the raw data collected during this study. Included in Appendix D are attenuation values (see Tables D-1 and D-2), comparisons of the attenuation values found in this study to the values given by the manufacturer of E-A-R plugs (see Figure D-1), and the mean and range of the pure tone thresholds for the hearing-impaired group (see Figure D-2).

Normal-hearing group

The ANOVA showed a significant list effect at the .05 level. The condition effect was shown to be highly significant ($p < .0001$). No other significant effects were noted by the ANOVA (see Table 2).

The Fischer Protected Least Significant Difference was utilized to determine if any significant differences existed in the mean scores obtained across listeners for each list. This analysis showed that all lists did not give equivalent mean scores. These results are shown in

Table 2

Normal-Hearing Group 4x4x2x2 Repeated Measures Analysis of Variance

Source	DF	MS	F Value
List order	3	417.0833	3.78
Condition order	1	484.0000	4.39
List order x condition order	3	412.5000	1.25
Subject (list order x condition order)	8	110.2500	
Condition	1	6805.2500	66.39*
Condition x subject (list x condition)	15	102.5166	
List	3	342.9166	3.88*
Condition x list	3	169.5833	1.92
Error	26	88.4038	

*$p < .05$.

Table 3. The mean scores for List A and List B were not significantly different from each other nor were the mean scores for Lists G, D, and F.

Hearing-impaired group

The ANOVA for the hearing-impaired group showed a significant list effect at the .05 level. The condition effect was also found to be significant at the .05 level. The ANOVA revealed no other significant effects (see Table 4).

An analysis of the list effect using the Fischer Protected Least Significant Difference showed inequivalencies in the RCID Everyday Sentence Lists. Table 5 shows the differences in the hearing-impaired mean scores. The results showed that the mean scores on List A were significantly different from performance on Lists G, D and F. Mean scores for Lists G and D were not significantly different from each other; mean scores for Lists D and F were not significantly different from each other. The difference between the mean scores for Lists G and F were found to be significant for the hearing-impaired group.

Although the significant differences between the mean scores for the lists were not the same for normal-hearing and the hearing-impaired groups, it should be noted that the order of difficulty for the lists was the same for both groups (i.e., there was no interaction between condition

Table 3

Fischer's Protected Least Significant Difference for Normal-Hearing Means

Grouping		Mean	List
	A	79.125	A
B	A	73.875	G
B		70.875	D
B		69.375	F

Note. Means with the same letter are not significantly different.

Table 4

Hearing-Impaired Group 4x4x2x2 Repeated Measures Analysis of Variance

Source	DF	MS	F Value
List order	3	57.5625	0.09
Condition order	1	45.5625	0.07
List order x condition order	3	439.7291	0.69
Subject (list order x condition order)	8	638.6875	
Condition	1	1958.0625	8.26*
Condition x subject (list x condition)	15	237.1958	
List	3	446.7291	4.88*
Condition x list	3	5.0625	0.06
Error	26	91.4855	

*$p < .05$.

Table 5

Fischer's Protected Least Significant Difference for Hearing-Impaired Means

Grouping		Mean	List
	A	73.375	A
	B	61.250	G
C	B	57.250	D
C		51.750	F

Note. Means with the same letter are not significantly different.

and list). The order of difficulty was Lists A, G, D, F with List A being the easiest and List F being the most difficult.

Comparisons between the normal-hearing and the hearing-impaired groups

The mean scores in the unprotected and the protected conditions for each group were compared. For both groups, the mean score was greater in the protected condition. These results are shown in Table 6 and in Figure 5.

A t test was used to determine if the difference between the unprotected and protected scores was different for the two groups (Dixon & Massey, 1957). The standard error of this difference was computed by pooling the two error sums of squares from the analysis of variance for each group. This statistic was significant at the .05 level, suggesting that the degree of change from the unprotected to the protected condition was different for the normal-hearing and the hearing-impaired groups (see Table 7).

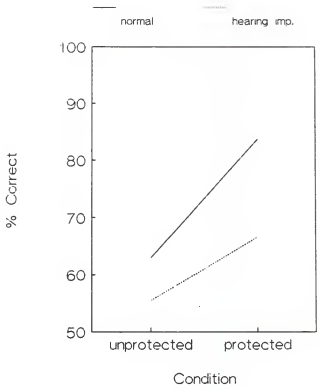
Table 6

Mean Scores for Normal-Hearing and Hearing-Impaired in the Unprotected and the Protected Conditions

Group	Condition		Diffenence
	Unprotected	Protected	
Normal-Hearing	63.0	83.625	20.625
Hearing-Impaired	55.50	66.563	11.063

Figure Caption

Figure 5. Mean scores of the normal-hearing and the hearing-impaired groups.



normal
hearing imp.
100
90
80
70
60
50
% Correct
unprotected
protected
Condition

Table 7

t Test for Comparing Differences of Mean Scores of Normal-Hearing and Hearing-Impaired Groups

Group	N	Mean	t	Significance Level
Normal-hearing	16	20.625	2.075	.05
Hearing-impaired	16	11.063		

Chapter 5

Discussion

This study was conducted to examine the common complaint among users of hearing protectors that speech is more difficult to understand in noise when hearing protectors are worn. Results from other laboratory examinations of this problem have differed in their manipulation of experimental variables such as hearing protectors, speech stimuli, noise spectra, and the hearing sensitivity of the subjects. Selection of the variables for this study was made with the intent to match the test conditions as closely as possible to real world employment conditions.

Within this framework the experimental questions were pursued. These questions, stated in full in the introduction and review sections of this paper, asked if normal-hearing and hearing-impaired individuals showed significant statistical differences in intelligibility scores in noise between the unprotected and the protected conditions. The next question naturally followed the examination of the within group effects. This question asked if there are differences between the effects of hearing protector use on the speech intelligibility scores of the normal-hearing group and the hearing-impaired group. Though not formally stated as a research question at the outset of this study, data were collected and analyzed concerning the equivalency of the RCID sentence lists used as speech stimuli in this study.

The data indicate the following:

1) the performance of the normal-hearing group on the speech intelligibility in noise task was significantly better in the protected condition than in the unprotected condition.

2) the performance of the hearing-impaired group on the speech intelligibility in noise task was significantly better in the protected condition. However, the change in speech intelligibility from the unprotected to the protected condition was only approximately half of that shown by the normal-hearing group.

3) comparisons of the effects of the protective devices on the speech intelligibility in noise task showed significant difference between the performance of the normal-hearing and the hearing impaired groups. The direction of the change was the same for the two groups, with both groups showing improvement from the unprotected to the protected condition. The change in speech intelligibility, with the normal-hearing group almost doubling the change in speech intelligibility shown by the hearing-impaired group, was found to be significantly different in

the comparisons of the two groups.

Comparisons of the results of this study to the results of similar studies are done with the acknowledgment that the dissimilarities in methodologies are many.

The two previous studies most similar in methodologies to the present study were those done by Brister (1979) and Schulz (1983). Both of these studies employed the RCID Everyday Sentence Lists in a background of pink noise. Brister concluded that at negative signal-to-noise ratios, the protected condition gave superior speech intelligibility scores for normal-hearing subjects. Schulz, in acknowledging the inequivalencies of the RCID Everyday Sentence Lists as the confounding factor which lead to the acceptance of the null hypothesis in her study, leads one to question the reliability of Brister's study.

The questioning by Schulz of the equivalency of the RCID Everyday Sentence Lists prompts further questioning of the equivalency in noise of other speech stimuli used in previous studies. The need for equivalent measures of speech perception led to the control for list effect used in this study. The need to control for the possibility of a learning effect dictated that each subject could not hear each list more than once. Each sentence list appeared in all conditions an equal number of times, effectively removing the problem of speech stimuli inequivalency. The need for this type of control was emphasized by the ANOVA of this study which showed a list effect.

Normal-hearing group

The conclusion that speech perception is improved, or at least not negatively affected, when normal-hearing individuals wear hearing protectors is supported by previous studies (Abel et al., 1980; Howell & Martin, 1975; Kryter, 1946; Pollack, 1957; Rink, 1979; Williams et al., 1971). Researchers have obtained these results while varying noise spectra, signal-to-noise ratios, speech stimuli, manner of presentation of speech stimuli (live voice and tape recorded), reverberancy conditions, and type of hearing protectors.

Two studies reported results which conflict with the findings of this study and the other studies cited above. Perhaps the use of unconventional stimuli (i.e., Navy 'fire' orders in the background of machine-gun noise) explains why Coles and Rice (1966) obtained results which may support the conclusion that speech is better understood in noise in the unprotected condition. Chung and Gannon (1979), while finding an advantage for the protected condition at a 10 dB signal-to-noise ratio, reported that subject performance at the low signal-to-noise ratio of -5 dB was negatively affected when hearing protectors (earmuffs) were worn.

Considering the evidence presented in the studies previously conducted, the normal-hearing group performed in a predictable manner in this present study. Only the magnitude of change in this group was not anticipated. As reported in the results section of this paper, the degree of improvement in mean scores from the unprotected to the protected condition was highly significant for this group. As can be drawn from the preceding discussion, the protected condition advantage was not consistently found to be as great in other studies as it was in this study.

Hearing-impaired group

Consistency between the results of this study and the results reported by other researchers using hearing-impaired subjects is lacking. None of the other researchers (Abel et al., 1980; Abel et al., 1982; Chung & Gannon, 1979; Coles & Rice, 1965; Lindeman, 1976; Rink, 1979;), who included a hearing-impaired group in their studies of protected speech perception in noise, found an advantage for the protected condition. All except Rink found that hearing protectors produced a deleterious effect on speech perception in noise. Rink reported equivalent scores for the unprotected and protected conditions. An examination of the stimuli used in the previous studies helps to account for opposing findings.

The first variable to consider is the noise stimulus. Pink noise was chosen for this study because the low frequency emphasis has been found to be characteristic of factory and military noise. Other researchers (Abel et al., 1980, 1982; Lindeman, 1976;) used white noise in their studies while only Chung and Gannon matched this study by using pink noise. The white noise used by Rink (1979) was filtered to include only the spectral energy between 350 and 2800 Hz. Coles and Rice (1966) did not report the spectrum of the noise used in their study. The interactions between a typical sensorineural hearing loss and different noise spectra must be considered. Masking by pink noise is more pronounced in the low frequencies where the energy of the noise is the greatest. Masking in the higher frequencies by white noise can be expected to be greater than by pink noise because white noise has equal energy across the spectrum. It has been shown by Pickett (1957) that, for a given level of intelligibility, listeners can tolerate a more intense overall low frequency than white noise. Pickett showed a white noise environment of 95 dB yielded the same intelligibility score (90%) as a low frequency noise environment of 105 dB. Pink noise gives less interference in the high frequencies than does white noise. Because it is typically the high frequencies which are affected by sensorineural hearing loss, a pink noise masker would perhaps give the hearing-impaired an advantage that a white noise masker would not.

Reasons for the differences between results of this study and the results from the Chung and Gannon (1979) study are not as easy to pinpoint. While pink noise was used by Chung and Gannon, other experimental variables (signal-to-noise ratios, type of hearing protector, speech stimuli) differed from those used in this current study and may have contributed to the discrepancies.

A comparison of the methods used in the Chung and Gannon (1979) study to those used in this current study reveals variables which account for some of the differences in results. While pink noise was used by Chung and Gannon, other experimental variables (signal-to-noise ratios, type of hearing protectors, and speech stimuli) differed from those used in this study. Particular attention needs to be given to the differences in the speech stimuli (i.e., the single words in the Chung and Gannon study and the sentences in this study). As stated earlier in this report, single words are the stimuli of choice when testing speech discrimination; sentences are the stimuli of choice when testing speech intelligibility. Kryter (1962) showed that for a given intensity, sentences give a higher percentage correct than single words. Kryter also found that sentences give a steeper articulation function than single words. The single word discrimination task is more difficult than sentence listening which involves contextual cues.

The presentation levels of the stimuli used by Chung and Gannon (1979) were determined by the sensation level of the individual subjects. All subjects heard the stimuli at

40 and 65 dB SL. It follows that only those hearing-impaired subjects with poor speech reception thresholds would have listened to the stimuli at levels approximating those used in this study. Again, cross-study comparison is complicated by differing methods.

Comparisons between the normal-hearing and the hearing-impaired groups

The third research question in this study focused on the differences between the two groups in the degree and direction of change from the unprotected to the protected condition. This study found a difference in the amount of change between the two groups, but the direction of change was the same for the two groups. The other studies which included both the normal-hearing and the hearing-impaired groups (Abel et al., 1980; Chung & Gannon, 1979; Rink, 1979) agreed with the findings of this study that the two groups changed differently from the unprotected to the protected condition. However, the other studies (with the exception of the Chung and Gannon study which reported mixed results) found differences in both the degree and direction of the change. Comments made above in the discussion of the hearing-impaired group apply in this section also. Differences in methodologies, particularly in the use of different noise spectra, suggest that cross-study comparisons should be made cautiously.

Equivalency of the RCID Everyday Sentence Lists

The review of the literature indicated inequivalencies across the RCID Everyday Sentence Lists (Rippy et al., 1983; Schulz, 1983; Suter, 1978). The decision to order the word lists so that each sentence list appeared in all conditions an equal number of times was made to control for a learning effect. The possibility of a learning effect would have existed if subjects had heard the same list more than one time. This method was successful in that the inequivalencies in the lists were compensated for by having all lists appear in all conditions an equal number of times. The list effect found in the ANOVA should be noted, however, because it confirms the findings of other researchers and because it has implications for the laboratory and clinical use of the RCID Everyday Sentence Lists. The lists as they are currently available are not equivalent and should not be used as equivalents. More study with larger subject groups is needed to find if the specific lists found to be equivalent in this study and others (Rippy et al, 1983; Suter, 1983) are indeed equivalent. It is comforting to note that both the normal-hearing and the hearing-impaired mean scores were ranked in exactly the same order in this study.

Applications

Applications from the laboratory to field conditions have been a consideration throughout this report. Test conditions were chosen which would represent common conditions encountered in the workplace. The use of the RCID Everyday Sentence Lists, pink noise, E-A-R plugs, and a negative signal-to-noise ratio are examples of this. Still, there are questions in this area which need to be addressed. These questions deal with laboratory versus on-site effectiveness of hearing protectors, visual cues, reverberant conditions, effects of the degree and shape of the hearing loss, noise spectra, and variability in signal-to-noise ratio.

Hearing protectors. The hearing protectors used in this study were chosen for their popularity and excellent attenuation characteristic. User acceptance for the short period of time that each subject wore the protectors was good, and the average attenuation values paralleled those advertised by the manufacturers (see Appendix D, Figure D-1). These should be viewed as optimal conditions which may not be characteristic real world situations. One example demonstrates this problem. The E-A-R plugs were inserted by the examiner who was anxious to insure effective attenuation. Optimal attenuation was insured by the examiner visually checking E-A-R plug placement and by reinsertion the E-A-R plug if narrow band noise testing indicated less than optimal attenuation. Some subjects, who were regular users of the E-A-R plugs in their employment, demonstrated for the examiner their "skill" in

E-A-R plug insertion. This informal observation revealed that the users were generally unaware of proper insertion techniques which lead to less than perfect fit. Thus, variability in the insertion skills of users in the workplace has implications which impact on speech perception questions but which also go beyond the scope of this study into the issue of cochlear protection.

User preference and product availability often dictates the type of hearing protector used. E-A-R plugs are unacceptable or unavailable to some individuals. The results of this study may not hold true for other types of hearing protectors. This is an unresolved question for future study.

Visual cues. The use of tape recorded speech stimuli in this study removed the visual cues which are typically available in communication. Rink (1979) demonstrated an improvement in speech perception abilities when listeners in noise were given visual cues. It would be expected that, if visual cues had been present in both the unprotected and the protected conditions in this study, the effect would have been to raise the scores equally in both the unprotected and the protected conditions. Thus, the effect on the direction and the degree of change would have been negligible.

Reverberancy. Reverberancy in the listening environment is another real world variable which needs to be addressed. The subjects in this study were seated in a sound treated chamber which dampened sound to an extent not typically found in the workplace. Kryter (1946), in his pioneering work on this topic, compared the results obtained in an anechoic chamber to those obtained in reverberant conditions. His subjects showed a greater magnitude of improvement from the unprotected condition to the protected condition in the reverberant conditions. Based on the results, one might expect that the results found in this study would be accentuated in reverberant conditions.

Effects of the degree and shape of the hearing loss. The hearing-impaired listeners in this study were not classified by degree and shape of hearing loss because of the small sample size. Predictably, the more severely hearing-impaired subjects scored lower in both the unprotected and the protected conditions than did those with milder impairments. However, preliminary examination of the data from the hearing-impaired group did not reveal any consistent trends in the change from the unprotected to protected condition as a function of the degree or shape of the hearing loss. Sample sizes large enough to allow for categorization of hearing impairments are needed to resolve this issue.

Noise spectra. As stated earlier, pink noise was selected for this study as the noise most typical of everyday factory and military noise. Obviously, the noise encountered daily by workers may not fit the typical pattern. A quick mental inventory of occupations which are carried out noisy environments can bring to the reader's mind exceptions to the "typical" pink noise environment. Variability in types and spectra of workplace noise dictates caution in assuming that the results of this study are applicable to every noise environment.

Summary

Efforts to successfully conserve hearing in industry and in the military depend in part on the acceptance of hearing protectors by the workers. A common complaint of individuals who wear hearing protectors is that speech in noise is more difficult to understand in the protected condition. This study was an investigation of that complaint.

The unprotected and protected mean speech intelligibility scores (using the Revised Central Institute for the Deaf Everyday Sentence Lists) in pink noise of normal-hearing and hearing-impaired were examined. It wa anticipated that these data would provide information about the direction and the magnitude of change from the unprotected to the protected condition for each group. Comparisons between the two groups could then be made.

The results of this study showed a protected condition advantage in speech intelligibility scores in pink noise for both the normal-hearing and hearing-impaired groups. Comparisons of the two groups indicated that the groups differed in the magnitudes of change from the unprotected to the protected conditions. The normal-hearing group showed twice the improvement of the hearing-impaired group from the unprotected to the protected condition, indicating that the effect of E-A-R plugs on speech intelligibility in noise is different for normal-hearing and hearing-impaired listeners.

Hearing conservation efforts in the workplace may be strengthened with the evidence that wearing E-A-R plugs does not diminish the ability of the workers to understand speech in noise.

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Appendix A

Revised Central Institute for the Deaf

Everyday Sentence Lists

List A

1. Walking's my favorite exercise.
2. Here's a nice quiet place to rest.
3. Our janitor sweeps the floors every night.
4. It would be much easier if everyone would help.
5. We say "good morning" and begin to work.
6. Open the window before you go to bed.
7. Do you think she should stay here?
8. How do you feel about changing?
9. When the time comes, we will go.
10. It's too late to move out of the way.

List D

1. If you want to go its all right.
2. Throw these old Time magazines out.
3. Do you want to wash up in the stream.
4. It's a real dark night so watch your driving.
5. I'll carry your package for you.
6. Don't you forget to shut off the water.
7. Mountain fishing is my idea of a good time.
8. Fathers used to spend more time with their children.
9. Be careful not to break the glasses.
10. I'm sorrier than you for the mistake.

List F

1. Music always makes me cheer up.
2. My brother's in town for a short while.
3. We live a few miles off the main road.
4. This suit needs to go to the cleaners.
5. They ate enough green apples.
6. Have you been sick all this week?
7. Where have you been working lately?
8. There's not enough table room in the kitchen.
9. It's hard to see where he is.
10. Look out for new business.

List G

1. I'll see you right after lunch.
2. I'll see you later this afternoon.
3. White shoes are awful to keep clean.
4. You stand over there until I move.
5. There's a piece of cake left for dinner tonight.
6. Don't wait for me at the front corner.
7. It's no trouble at all to tell.
8. Hurry up with the morning paper.
9. It didn't say anything about a big rain.
10. That drugstore phone call's for you.

List I

1. Where can I find a place to park?
2. I like those big red apples.
3. You'll get fat by eating candy.
4. The color show's over in the fall.
5. Why don't they paint their other walls?
6. How come you always get to go first?
7. What are you hiding under your coat?
8. I should always buy new cars.
9. What's wrong with sugar and cream in my coffee?
10. I'll wait just one minute.

Appendix B

Client Consent Form

Hearing conservation programs often must depend on the use of hearing protective devices. One of the common complaints of individuals who wear hearing protectors in noisy environments is that speech is more difficult to understand when hearing protectors are worn. This study is an investigation of that complaint.

The benefits of this study to the individual subjects will be in learning how well he/she understands everyday speech in noise with and without hearing protectors. Also, the subject selection process will provide each subject with information about his/her own hearing sensitivity. Hearing conservation efforts will be benefited as information is learned about the effects of E-A-R plugs on everyday speech perception in noise.

The subjects will be seated in a sound-isolated chamber during most of the testing period. Prior to the experimental procedures, the subjects will be given a hearing evaluation to determine suitability as subjects. The hearing evaluation will include:

a. an otoscopic examination which is performed by visually examining the ear canals with a light

b. middle ear function testing which involves measuring the pressure in the middle ear by sealing off and changing the air pressure in the outer canal and by observing the response of the middle ear to loud tones

c. a test with headphones to determine the minimum intensity at which the subject can hear tones

d. a test with headphones to determine the minimum intensity at which the subject can understand words

e. a test of the subject's ability to understand words when the words are heard at a comfortable loudness level

f. finding the subject's loudness tolerance level by gradually increasing the loudness of the noise until the subject says that the noise is "too loud".

All of the preceding procedures are routinely used by health professionals in standard hearing evaluations.

The subject will then listen through loudspeakers to narrow bands of noise which sound much like radio static. The subject will indicate when the noise is just barely heard. The examiner will then insert E-A-R plugs into the ear canals. With the E-A-R plugs in place, the subject will again indicate when they can just barely hear the noise. The investigator will compare the responses with and without the E-A-R plugs to determine the effectiveness of the hearing protector for each subject. The E-A-R plugs will not be adjusted after this time because to adjust or reinsert the plugs may change the effectiveness of the plugs for that individual.

With the plugs in place, the subject will record in writing a list of sentences which will be heard in a background of static type noise. The plugs will then be removed and the same procedure will be followed with another sentence list with no hearing protection. The noise will be presented at 93 dB SPL and the sentences will be presented at 89 dB SPL for a combined intensity of 94.5 dB SPL. The Occupational Safety and Health Administration (OSHA, 1981) presently allows for exposure to 95 dBA for four hours, but proposed guidelines, if adopted, would cut exposure time at 95 dBA to two hours. Only during the time that the subject listens to the sentences and noise without the E-A-R plugs will the maximum intensity of 94.5 dB SPL reach the eardrum. The E-A-R plugs will prevent the maximum intensity from reaching the eardrum during the time that the E-A-R plugs are in place in the ear canal. The length of time that the eardrum will be exposed to the maximum intensity will be 10 to 12 minutes, the length of time needed to listen to the sentence lists.

I understand that the potential risk involved in this study will be exposure to intense sounds. However, the exposure time of 10 to 12 minutes is well below the 2 hours per day exposure time which the Occupational Safety and Health Administration (OSHA, 1981) has proposed as acceptable for workers exposed to 95 dBA.

I understand that my participation is voluntary and that I am free to refuse to participate or to withdraw at any time from the study without prejudice or loss of benefits. Mary Wade and Dr. Harry Rainbolt, project supervisor, will be willing to answer any questions concerning the procedures involved. They can contacted by calling the Kansas State University Speech and Hearing Center at 532-6879. A copy of this consent form is available upon request. I understand that no subjects will be identified by name in the results of this study and that all records will be kept confidential in accordance with the policy of the Kansas State University Speech and Hearing Center.

By signing this, I affirm that I have read and understood the above statement and have been fully advised concerning the procedures used in this study. My signature declares that I have voluntarily agreed to participate.

Subject Date

Examiner Date

Appendix C

Response Form

Subject Name:	Date:
CID Sentence List Order:	Classification:
Condition Order:	Subject Number:

List:	Condition:
1.	
2.	
3.	
4.	
5.	
6.	
7.	
8.	
9.	
10.	

List: Condition:

1.

2.

3.

4.

5.

6.

7.

8.

9.

10.

List: Condition:

1.

2.

3.

4.

5.

6.

7.

8.

9.

10.

List: Condition:

1.

2.

3.

4.

5.

6.

7.

8.

9.

10.

Appendix D

Subjects' Raw Data

Table D-1

Attenuation Data for the Normal-Hearing Group

Subject Number	.25K Hz	.5K Hz	1K Hz	2K Hz	3K Hz	4K Hz	6K Hz
1	20	25	25	40	45	45	50
2	25	35	35	40	50	45	45
3	30	35	30	35	35	40	35
4	25	35	30	40	40	40	45
5	30	35	45	45	45	40	45
6	35	45	40	45	40	45	35
7	25	35	35	40	45	35	50
8	30	35	35	40	40	40	45
9	30	30	30	45	40	40	40
10	20	30	25	40	45	25	35
11	30	40	40	50	45	35	45
12	30	35	35	35	40	35	25
13	35	40	35	40	45	40	40
14	20	30	30	40	45	45	45
15	25	25	25	45	45	40	45
16	25	35	35	45	40	40	40
Group Mean	27	34	33	42	43	39	42

Note. Attenuation in dB.

Table D-2

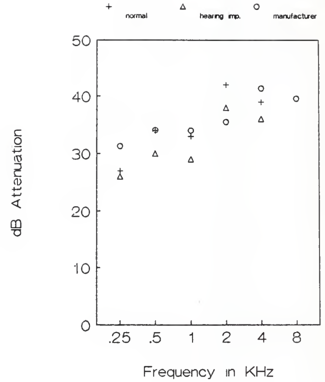
Attenuation Data for the Hearing-Impaired Group

Subject Number	.25K Hz	.5K Hz	1K Hz	2K Hz	3K Hz	4K Hz	6K Hz
17	5	0	20	35	35	30	15
18	30	40	35	50	45	50	40
19	25	25	30	40	45	40	45
20	25	25	30	30	40	35	20
21	30	35	35	50	45	40	30
22	40	40	40	40	35	35	35
23	35	35	25	35	30	40	35
24	25	35	30	45	35	30	35
25	25	40	30	30	30	40	40
26	30	35	35	40	40	30	25
27	30	35	30	40	40	50	>35
28	30	35	25	25	30	30	25
29	30	20	20	45	35	35	25
30	15	30	25	30	40	30	25
31	5	20	20	40	35	30	30
32	30	35	30	30	35	35	35
Group Mean	26	30	29	38	37	36	40

Note. Attenuation in dB.

Figure Caption

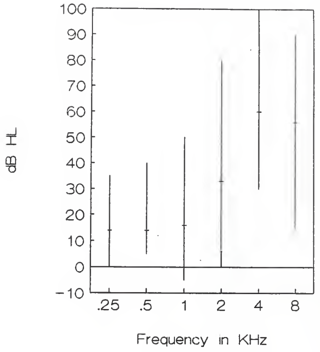
Figure D-1. E-A-R plug attenuation data with comparisons to to the manufacturer's data.



+ normal
Δ hearing imp.
○ manufacturer
50
40
30
20
10
0
dB Attenuation
.25
.5
1
2
4
8
Frequency in KHz

Figure Caption

Figure D-2. Mean and range of thresholds of the hearing-impaired group.


100
90
80
70
60
50
40
30
20
10
0
−10
dB HL
.25
.5
1
2
4
8
Frequency in KHz

SPEECH INTELLIGIBILITY IN NOISE OF NORMAL-HEARING AND HEARING-IMPAIRED INDIVIDUALS WEARING E-A-R PLUGS

by

Mary A. Wade

B.S., Kansas State University, 1986

AN ABSTRACT OF A MASTER'S THESIS

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KANSAS STATE UNIVERSITY
Manhattan, Kansas

1986

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