To the Graduate Council:

I am submitting herewith a thesis written by Susan McPhail entitled "The Effects of Unfiltered and Bimodal Filtered Stimulus Conditions on Speech Discrimination in Noise Through Simulated Television Audio Circuitry." I have examined the final copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Arts, with a major in Audiology.

David M. Lipscomb, Major Professor

We have read this thesis
and recommend its acceptance:

Accepted for the Council:

Vice Chancellor
Graduate Studies and Research

THE EFFECTS OF UNFILTERED AND BIMODAL FILTERED STIMULUS CONDITIONS ON SPEECH DISCRIMINATION IN NOISE THROUGH SIMULATED TELEVISION AUDIO CIRCUITRY

A Thesis

Presented for the

Master of Arts

Degree

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ABSTRACT

A comparison was made of speech intelligibility scores for CID Everyday Sentences presented in +10dB signal-to-noise ratio in two listening conditions. Ten subjects with mild-to-moderate high frequency sensory hearing impairments were used. One condition consisted of an unfiltered presentation through simulated television audio circuitry. The second condition presented the stimuli bimodally through simulated television audio circuitry employing a 1000 Hz low band pass filter and a 4000 Hz high band pass filter, with slopes of 18 dB per octave toward the outer frequencies and 65 dB per octave toward the center frequencies.

Analysis of the data revealed a significant difference at the .05 level, indicating intelligibility scores to be better in the unfiltered condition. Also, the intelligibility scores of the hearing-impaired subjects deteriorated considerably in noise when compared to scores obtained in quiet.

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CHAPTER I

INTRODUCTION

The population of the United States is estimated to include approximately sixteen million individuals with hearing impairments (Schow and Nerbonne, 1980). Many of these individuals daily encounter situations in which their speech discrimination ability is diminished due to this impairment. For example, many hearing-impaired listeners find television audio difficult to understand. Several factors contribute to this difficulty. The presence of background noise in homes is typical, and this can have an adverse effect on speech discrimination, especially of hearing-impaired listeners. Also, signal amplification alone does not always greatly improve speech discrimination for persons with sensory impairments. Even so, these listeners frequently attempt to improve intelligibility by employing a television volume setting that is uncomfortably loud for normal listeners. Thus, many times hearing-impaired and normal hearing persons who view television together find that listening levels which are comfortable for all viewers are impossible to achieve.

High volume settings can result in amplitude distortion of the signal as the intensity level extends beyond the dynamic range of the loudspeaker. Goetzinger (1978) reported a decrease in speech discrimination ability in normal hearing listeners when subjected to amplitude distortion. Signals reproduced through television loudspeakers can also contain harmonic and intermodulation distortion. A

study by Zerlin (1960) indicated that such distortion had a more adverse effect on intelligibility scores of sensory subjects when compared with the performance of normal and conductive hearing-impaired subjects. Thomas and Sparks (1971) attributed the reduction in discrimination ability of listeners with cochlear damage to a second-order distortion within the end organ itself which results in further distortion of an acoustic signal, especially at high intensity levels, a problem not encountered by persons with normal sensory receptor areas.

Performance differences in speech discrimination ability between normal hearing and sensory hearing-impaired subjects have also been observed in the presence of background noise (Kryter, 1963). The difference, expressed in decibels, between the sound level of the stimulus and the sound level of the noise is termed the signal-to-noise ratio. As this ratio is decreased, subjects with sensory damage show a greater loss in speech discrimination ability than do normal hearing subjects (Cooper and Cutts, 1971; Shapiro et al., 1972; Shipley, 1972; and Cohen and Keith, 1976). Thus, typical home television viewing environments which normal hearing persons find satisfactory may in fact be adverse listening conditions for many hearing-impaired persons.

The frequency response of the loudspeaker through which the stimulus is presented also plays a role in intelligibility. Although television loudspeakers typically have a limited frequency response range with a high frequency cut-off at 5000 Hz (Feldman, 1979) and so are generally labeled "low fidelity," one study has indicated that a wider frequency response range does not result in better perception

(Drake, 1980). Lowered speech discrimination scores in noise can be at least partly attributed to the masking effects of one frequency region on other regions during stimulation at high intensity levels (French and Steinberg, 1947; Kryter, 1960). Primarily it is the low frequencies (below 1000 Hz) which are responsible for masking the higher frequencies (Bilger and Hirsh, 1956). Since ambient noise normally contains more acoustic energy in these lower frequencies, masking of speech can occur if only the higher frequencies are amplified.

It has been suggested that a bimodal approach may be useful for some hearing-impaired persons (Guberina and Asp, 1981). A bimodal presentation consists of two bands of speech energy separated by a frequency region in which there is little or no acoustic energy. When a low frequency band of speech energy is combined with a higher frequency band, it it possible that overall perception of the higher frequency speech signals could be enhanced (Guberina and Asp, 1981). In addition, the elimination of acoustic energy in the frequency region between the two bands could negate masking in that region and result in adequate perception of speech stimuli at lower intensity presentation levels. Such a bimodal approach is advocated by the Verbo-tonal method and is used routinely in therapy situations. Verbo-tonal clinicians typically vary the filter cut-offs and slopes until the optimal combination for an individual is obtained. Clinical experience has indicated that a presentation employing a 1000 Hz low bandpass and a 4000 Hz high bandpass can be helpful for many persons with sensory impairment. A graphic representation of such a bimodal condition is shown in Figure 1.

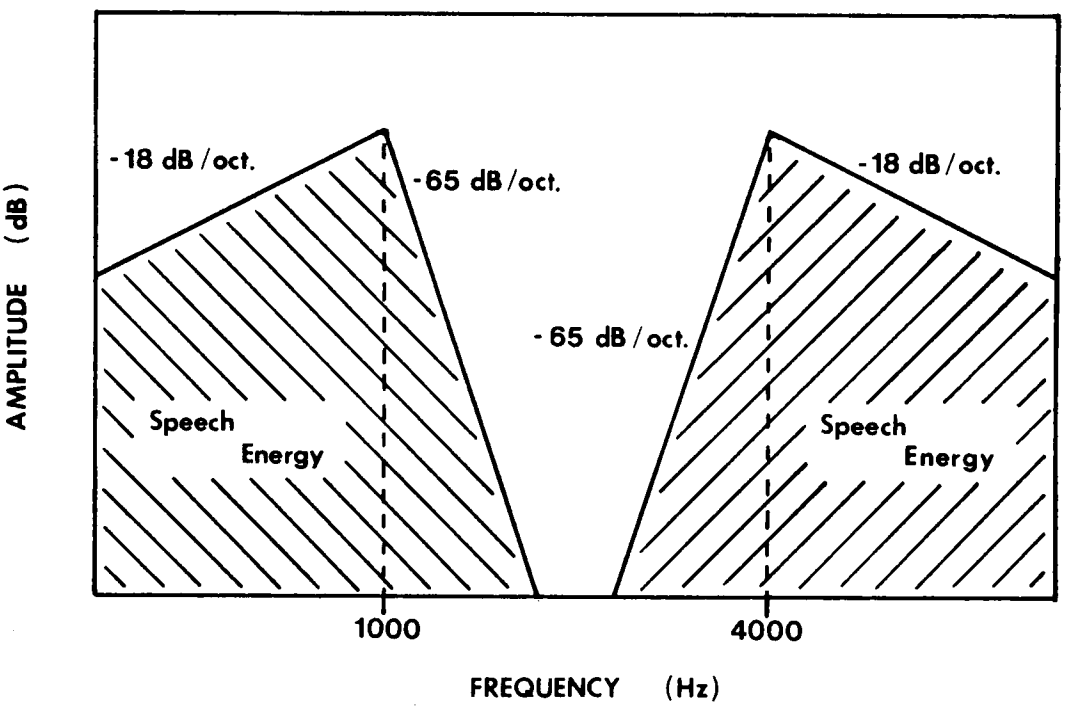


Figure 1. A graphic representation of a bimodal transmission of speech energy. The numbers represent a transmission of speech energy below 1000 Hz and above 4000 Hz, with slopes of 65 dB per octave toward the center frequencies and 18dB per octave toward the outer frequencies. Acoustic energy is greatly reduced in the region between 1000 Hz and 4000 Hz.

Studies of speech discrimination ability utilizing bimodal combinations of low and high frequency bands have shown improved discrimination scores when compared with the scores obtained with the same bands used alone (Palva, 1965; Rosenthal, Lang and Levitt, 1975). Franklin (1969, 1975) reported that speech discrimination ability of both normal and hearing-impaired listeners is improved with use of bimodal frequency bands in contralateral ears in comparison with the same bands used alone.

In order to assess speech discrimination ability, an appropriate test must be used. Normal conversation is characterized by a constantly changing pattern over time (Jerger et al., 1968). Such information can only be provided by sentences. Giolas (1966) reported that CID sentences, when compared with monosyllabic words, result in intelligibility curves which are closer to those obtained with continuous discourse. Therefore, assessment of speech discrimination using sentences rather than monosyllables would appear to provide a more accurate indication of a listener's discrimination ability in a natural environment.

I. PURPOSE

This study investigated the intelligibility of sentence stimuli presented in noise through a simulated television circuit for sensory hearing-impaired listeners. A + 10dB signal-to-noise ratio was employed in order to create a difficult, though not uncommon, listening condition. Speech discrimination scores were obtained utilizing an unfiltered stimulus condition and were compared with scores obtained

in a bimodal stimulus condition employing a 1000 Hz low bandpass and a 4000 Hz high bandpass..

II. EXPERIMENTAL QUESTION

The following experimental question was investigated:

Are there differences between the mean intelligibility scores for hearing-impaired subjects obtained in the presence of noise presented at a + 10dB signal-to-noise ratio for two conditions? Comparison conditions were:

1. Listening through simulated television audio circuitry with an unfiltered frequency response range.

2. Listening through simulated television audio circuitry with a bimodal filtered frequency response employing a 1000 Hz low bandpass and a 4000 Hz high bandpass.

CHAPTER II

REVIEW OF LITERATURE

Filtered speech has been used in a number of speech discrimination studies with normal and hearing-impaired listeners. French and Steinberg (1947) reported that normal hearing listeners exhibited varying speech discrimination scores as a function of the cut-off frequency of filtered signals. Equal scores were reported for low-pass and high-pass conditions when the cut-off frequency was 1900 Hz, termed the crossover frequency. Similar results were obtained by Dunlop (1978), who found the crossover frequency for nonsense syllables in quiet to be 2050 Hz. For speech masked by noise, several studies indicated that the crossover frequency is about one octave lower than for speech in quiet, usually between 850 Hz and 1000 Hz (French and Steinberg, 1947; Kryter et al., 1962).

A study by Condon (1975), using high-frequency sensory hearing-impaired subjects, employed filtered Modified Rhyme Test monosyllables with a cut-off frequency of 1900 Hz, and a slope of 0dB to the low frequencies. She found significantly better discrimination scores for the low-pass condition than for the high-pass condition. She further reported that the scores for the low-pass filter condition required 12dB lower sound pressure level than the high-pass filter condition to result in the same sensation level. Condon's findings support a theory by Guberina that the frequency region where hearing-impaired listeners have the greatest sensitivity is also the region they will find speech most

intelligible (Guberina and Asp, 1981). For a majority of hearing-impaired persons, the low frequency region is the area having the greatest amount of residual hearing. Early research by Fletcher (1929) indicated that frequencies below 500 Hz were not necessary in order for normal hearing listeners to correctly perceive speech. However, other researchers (Pollack, 1948; Ling, 1976) have suggested that low frequency information improves intelligibility for hearing-impaired listeners, partly because of the prosodic information present in the low frequencies and partly because the greater amount of acoustic energy in the low frequencies contributes to the audibility of the signal. Rhodes (1966) compared discrimination scores for normal and high-frequency hearing-impaired subjects when the stimuli were presented through a 1000 Hz low-pass filter. He reported that the hearing-impaired subjects identified 29% more consonants than did the normal hearing subjects. Rhodes concluded that persons with high-frequency hearing losses can compensate for their deficiency by learning to use cues that normal hearing individuals do not normally perceive.

While hearing-impaired persons may have residual low frequency hearing, the high frequency region is often subject to recruitment, resulting in a reduced dynamic range in this region. Wide-band amplification, therefore, is of little benefit, as the intensity necessary for high frequency perception cannot be attained before the low frequency sounds become too loud (Villchur, 1973). Guberina (1981) studied discrimination through discrete frequency bands and reported that the intensity level required for perception of high frequency sounds can be reduced when a low frequency band and a high frequency band of speech energy

are presented together. Similarly, Huizing and Taselaar (1961) reported the level necessary to achieve a 50% articulation score decreased by 22dB when a low-frequency (140-280 Hz) and a high-frequency (1128-2256 Hz) speech band were presented dichotically. The application of these findings to television signal processing could result in improved intelligibility for hearing-impaired listeners at lower intensity levels. Thus, normal hearing and hearing-impaired individuals could view television together at volume settings which are comfortable for all listeners.

Other researchers have also investigated combinations of frequency bands and the resulting effects on speech discrimination. Franklin (1969, 1975, 1979) has conducted several studies in which speech stimuli were presented through a low-frequency band (240-480 Hz) and a high-frequency band (1020-2040 Hz). Filters used provided 60-70 dB per octave attenuation. Her results indicated speech discrimination was improved when the two bands were presented together as compared to the same bands presented alone. In normal hearing subjects, the improvement was noted in both monotic and dichotic conditions, whereas in hearing-impaired subjects, the improvement was only present in the dichotic condition.

A study by Rosenthal, Lang and Levitt (1975) produced similar results when speech was filtered through a high band of 1100-2200 Hz and through each of three low bands of 55-110, 110-220, and 220-440 Hz, with attenuation of approximately 72 dB per octave. In all cases, the low-frequency bands were most effective when presented with the high-frequency band, both monotically and dichotically. Linden (1964) and

Palva (1965) also reported improvement of intelligibility when a low-frequency band was combined with a high-frequency band, with no significant difference between the monotic and dichotic conditions.

Since these studies have been conducted either monotically or dichotically under earphones, the results cannot be generalized to a sound field condition. A study designed to evaluate non-hearing aid users in a sound field condition in the presence of unfiltered competing noise would possibly require different frequency cut-offs and slopes. Research has indicated that a binaural advantage in noise is experienced by both normal hearing and hearing-impaired persons (Moncur and Dirks, 1967; Nabelek and Pickett, 1974). Therefore, it would seem reasonable that a binaural listening condition would allow assessment of functional auditory skills by providing subjects access to cues normally available to them.

In addition to frequency considerations, speech discrimination testing is influenced by the type of stimuli employed. Materials vary primarily in terms of redundancy and response constraints (Webster, 1978). Response constraints range from closed sets, or a limited number of responses, to completely open sets. Redundancy refers to the amount of information contained in the stimulus, ranging from non-sense syllables, which contain very little information, to sentences, which contain a considerable amount of redundancy. Because of this added information, intelligibility increases as speech elements are lengthened. Gerber (1974) reported that sentences are about 15% more intelligible than words in isolation. A study by Miller et al. (1951) indicated that sentences are intelligible at lower intensity levels than are isolated words.

Although sentences provide a more natural listening task than do some other materials (Hirsh et al., 1952) as well as higher face validity (Berger, 1977), relatively few sentence tests are available. The most popular tests in use clinically are phonetically balanced monosyllabic word lists (Martin and Pennington, 1971), presumably for their ease in administration and scoring (Edgerton, 1979). However, their adequacy in assessing functional communication skills has been questioned (Speaks et al., 1970). Because of the brevity of monosyllables, Speaks and Jerger (1965) felt their use inhibits evaluation of a listener's ability to perceive the changing patterns of speech over time. The use of sentences allows a listener to take advantage of cues normally used in understanding connected speech (Giolas and Duffy, 1973). Speech discrimination ability for monosyllables and samples of continuous discourse were compared by Giolas and Epstein (1963), using normal hearing subjects. They stated that the scores obtained with monosyllables could not be used to accurately predict scores obtained with continuous discourse.

Sentences were designated as appropriate material for evaluating functional speech discrimination ability by the National Research Council Committee on Hearing and Bio-Acoustics (CHABA). CHABA further stated that the sentences should be representative with respect to length, grammatical structure, vocabulary and redundancy. Sentence lists were developed at the Central Institute for the Deaf (CID) in agreement with CHABA's criteria (Silverman and Hirsh, 1955). These criteria were established in an effort to increase homogeneity among sentence lists. Research efforts have shown the relative

intelligibility of a word depends partially upon its phonemic composition, since some phonemes are more susceptible to masking than others (Kalikow et al., 1977). Lists should also reflect the frequency of occurrence of speech sounds in the language, since a positive correlation exists between this frequency and the correct identification of a word in an open set discrimination task (Howes, 1957).

Giolas (1966) compared discrimination scores for CID sentences to scores for a sample of continuous discourse resembling conversational speech. He found that error curves for the sentences were much closer to the continuous discourse curve than were the curves for monosyllables reported in a previous study (Giolas and Epstein, 1963).

Other tests have been developed in an attempt to increase the difficulty of sentence material. Jerger et al. (1968) introduced the Synthetic Sentence Identification test, consisting of a closed set of ten non-meaningful sentences. Nakatani and Dukes (1973) developed nonsense sentences containing words of the appropriate grammatical classification in four positions of each sentence. While such materials remove contextual cues and so increase the difficulty of the task, their usefulness lies in areas other than assessment of functional auditory ability, since the elimination of linguistic and contextual information makes the task unrealistic in terms of everyday communication.

Another factor which can affect speech discrimination testing is the presence or absence of noise. Since background noise is an inescapable aspect of everyday life, research in this area has been considerable.

Several studies have indicated that sensory hearing-impaired listeners are more susceptible to the masking effects of noise with regard to speech discrimination ability than are normal hearing listeners (Cooper and Cutts, 1971; Shapiro et al., 1972; Keith and Talis, 1970). In other words, hearing-impaired individuals require more favorable signal-to-noise ratios than do normal hearing persons. Cooper and Cutts (1971) compared the ability of normal hearing and sensory hearing-impaired subjects to understand speech in quiet and with varying levels of recorded cafeteria noise. As the signal-to-noise ratio decreased, a greater variation in discrimination scores was noted in the hearing-impaired group. Cooper and Cutts felt this difference was the result of some factor other than the effect of simple masking.

Shapiro et al. (1972) used monosyllabic stimuli to compare discrimination scores of normal hearing and sensory hearing-impaired subjects at varied signal-to-noise ratios. They reported that the scores of the hearing-impaired subjects were significantly poorer than the scores of the normal hearing subjects in all conditions tested. The researchers concluded that discrimination scores in noise for hearing-impaired listeners could not be predicted from scores obtained without noise.

Carhart and Tillman (1970) compared speech discrimination ability of monosyllables in noise for normal hearing, sensory hearing-impaired, and conductive hearing-impaired subjects. They found that the sensory impaired group's discrimination ability was significantly more affected by the competing noise than the other two groups.

Cohen and Keith (1976) reported that progressively unfavorable signal-to-noise ratios resulted in increasingly poorer scores for sensory impaired subjects as compared to normal hearing subjects. A study by Shipley (1972) yielded similar results. Persons with noise-induced hearing losses had considerably more difficulty perceiving speech in noise than did normal hearing listeners. Keith and Talis (1970) also reported increased variability in discrimination scores between sensory hearing-impaired and normal hearing subjects as the signal-to-noise ratio was decreased.

Speech perception in noise depends, in part, on the intensities and spectra of the speech and the noise (Webster, 1978). Thus, the type of competing noise used, in combination with the type of stimuli employed, will also influence the discrimination task. Bode (1980) stated that general agreement has not been reached concerning the type of noise which should be used for clinical and research purposes. Some noises may be more suitable for one purpose than for another. Most types of noise in common use contain most of their acoustic energy in the low frequencies. Such noises can be used to simulate actual listening conditions due to the fact that most environmental sounds also consist primarily of low-frequency energy (Niemeyer, 1967). Kryter et al. (1962) reported that low-frequency concentrations of noise are typical in a home environment. Therefore, because of the masking properties of low-frequency sounds, adverse listening conditions may commonly exist in most homes.

In summary, the following points from the literature review are considered relevant to this study:

1. Low-frequency speech energy can enhance the perception of higher frequency speech sounds for hearing-impaired listeners.

2. Combinations of low-frequency and high-frequency speech information can result in adequate perception of speech at reduced intensity levels for hearing-impaired listeners.

3. A binaural listening advantage in noise is experienced by normal hearing and hearing-impaired individuals.

4. As speech components are lengthened, intelligibility increases.

5. Sentence material yields a more realistic measure of everyday speech discrimination ability than do monosyllabic stimuli.

6. Speech discrimination scores of sensory hearing-impaired listeners deteriorate more rapidly as the signal-to-noise ratio decreases than do scores of normal hearing individuals.

7. Intelligibility scores of sensory hearing-impaired listeners in noise cannot be accurately predicted from scores obtained in quiet.

8. Hearing-impaired persons require more favorable signal-to-noise ratios to achieve maximum speech discrimination scores than do normal hearing listeners.

CHAPTER III

PROCEDURES

In order to investigate the experimental question stated in Chapter I, the following experimental design was constructed.

I. SUBJECTS

Ten subjects with sensory hearing impairment were used in the study. All subjects were native English speaking adults less than sixty years of age. The following selection critera were employed:

1. The following pure tone air conduction threshold ranges were established to reflect a moderately sloping, mild-to-moderate high frequency sensory hearing loss:

500 Hz:	5dB to 30dB
1000 Hz:	10db to 40dB
2000 Hz:	15dB to 50dB
4000 Hz:	30dB to 65dB

Mean better-ear hearing levels and ranges for frequencies 500 Hz through 4000 Hz are shown in Figure 2. The mean thresholds of 18.5 at 500 Hz, 19 at 1000 Hz, 25.5 at 2000 Hz and 48.5 at 4000 Hz are in compliance with the established criteria.

2. No greater than 10dB threshold difference between ears for any frequency was allowed.

3. Speech discrimination scores of 90% or better in each ear for CID W-22 monosyllables were required. The better-ear scores ranged from 92% to 100%, with a mean score of 97%.

4. Non-hearing aid users were selected.

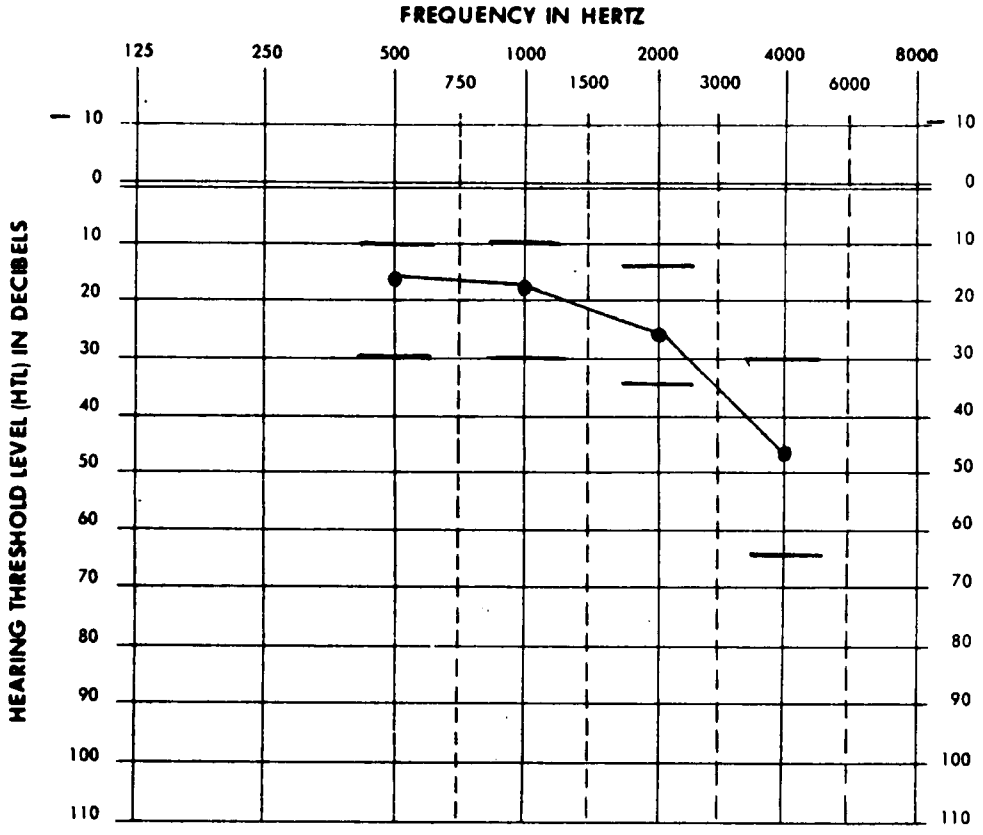


Figure 2. Mean better-ear air conduction thresholds and ranges for 500 Hz through 4000 Hz for ten Ss.

5. Adults 30 to 59 years of age were chosen from patient files at The University of Tennessee Hearing and Speech Center. Ages and better-ear three-frequency average of subjects are shown in Table I. The mean age was 47.8 and the mean three-frequency average was 21 dB.

The hearing aid restriction was included in order to prevent variable signal distortions as a result of individual amplification systems. The speech discrimination criterion was designed to reduce the possibility of reduced discrimination ability due to advancing age, which has been noted as early as the fifth decade (Feldman and Reger, 1967; Mills, 1978). No controls were imposed with regard to sex of the subjects since previous research results have indicated there are no differences in speech discrimination ability between male and female listeners (Goetzinger et al., 1961). Written consent was obtained from each subject for release of the test data in reporting the results of this investigation. The informed consent form appears as Appendix A.

II. MATERIALS AND INSTRUMENTATION

Subject selection testing was conducted in a two-room, acoustically treated hearing test suite at The University of Tennessee Hearing and Speech Center. A Grason Stadler 1701 audiometer, calibrated for routine clinical use, was employed.

Experimental procedures utilized a test room containing carpet and furnishings similar to that found in a typical television viewing environment. A scaled room diagram and the block diagram for experimental instrumentation appear as Figure 3.

TABLE I

AGE AND BETTER-EAR THREE-FREQUENCY AVERAGE OF SUBJECTS

Subject No.	Age (Years)	Better-Ear Average at 500, 1000, and 2000 Hz (dB)
1	53	23.3
2	56	20.0
3	33	28.3
4	58	15.0
5	57	30.0
6	52	16.7
7	59	16.7
8	33	13.3
9	47	20.0
10	30	26.7
Mean	47.8	21.0

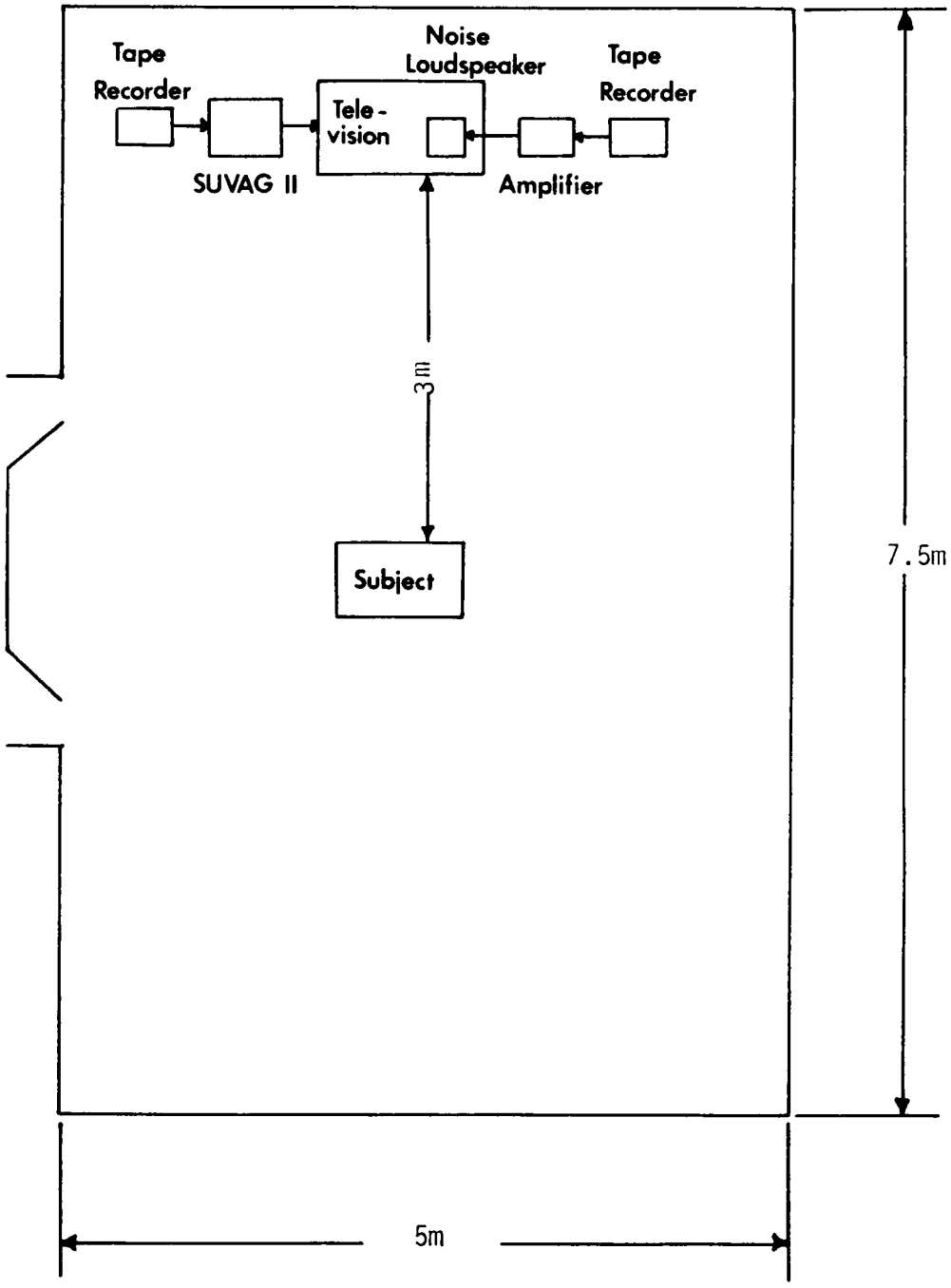


Figure 3. Experimental room and equipment.

The test stimuli consisted of recordings of two CID Everyday Speech sentence lists each containing ten sentences obtained from Auditec of St. Louis. The sentences included a varying number of key words in each for a total of fifty words per list to be scored. Two additional sentence lists were used for retest purposes. The sentence lists appear as Appendix B.

The two sentence lists were presented from a Panasonic Cassette Tape Recorder, Model RQ-323AS, through a SUVAG II Filter Set, which was then routed through a Magnavox console television, Model RK5056. One list was presented on a direct setting of the SUVAG II, resulting in an unfiltered frequency response range, and the other list was presented on a filter setting of 1000 Hz low pass, 4000 Hz high pass, with slopes of 18dB per octave toward the outer frequencies and 65dB per octave toward the center frequencies, as depicted in Figure 1, page 4. A test recording was made of random sentences in each condition and analyzed using a Voice Identification Unit, Model 700, in order to assure that the filter settings were correctly reproduced. Samples of the test recording are shown in Figure 4. Figure 4 (A) demonstrates that acoustic energy in the frequency region between 1000 Hz and 4000 Hz is eliminated. Figure 4 (B) shows the same sentence unfiltered and demonstrates the presence of continuous acoustic energy through 4000 Hz. The increased amplitude above 4000 Hz as seen in Figure 4 (A) is due to measurement artifact. The filtering of some high amplitude low frequency sounds caused the VU meter of the Voice Identification Unit to peak lower than for the unfiltered measurement. Consequently, adjustment of

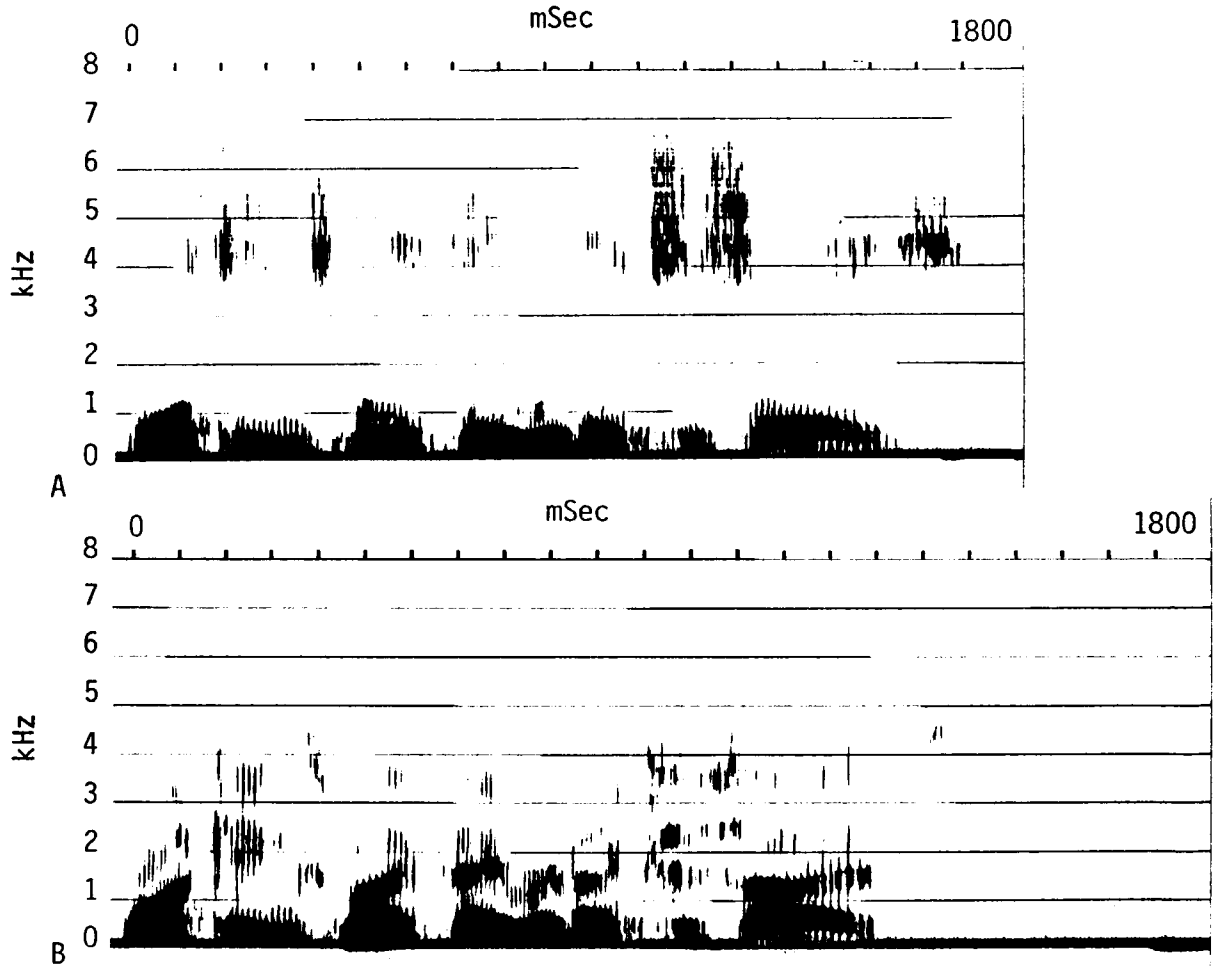


Figure 4. (A) Sonogram of sentence "Walking's my favorite exercise" in bimodal filtered condition (1000 Hz low pass, 4000 Hz high pass). (B) Sonogram of same sentence in unfiltered condition.

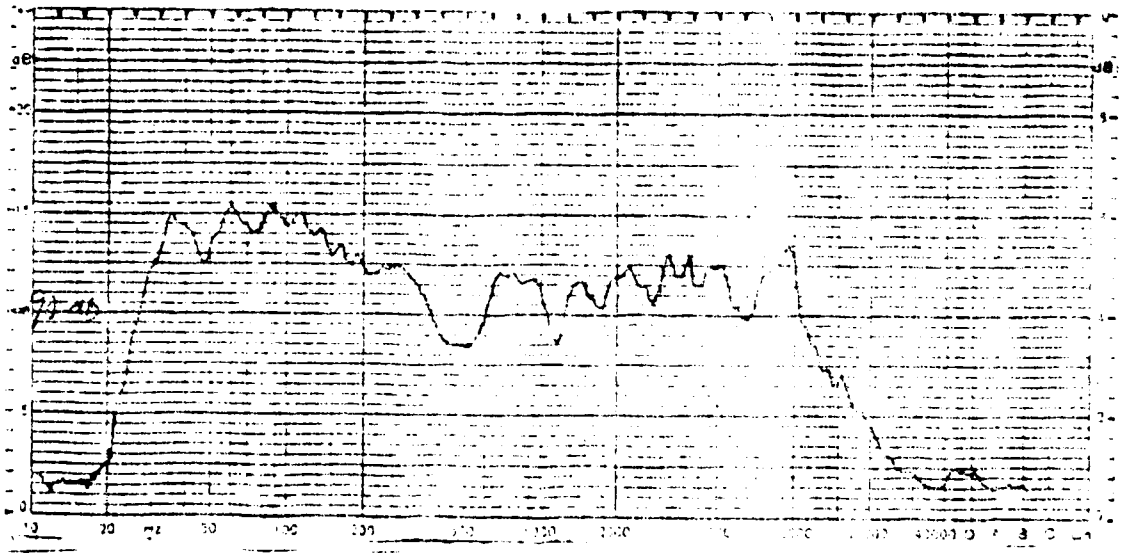
the vu meter to a setting equal with the unfiltered recording resulted in greater amplitude of the high frequency sounds.

Competing noise, consisting of recorded twenty-person speech babble, was presented from a Sony Cassette Tape Recorder, Model TC-65, through a custom-built power amplifier, then routed through a Bang and Olufsen S45 loudspeaker. Frequency response curves of this loudspeaker and the Magnavox television loudspeaker were obtained in the experimental environment and are shown in Figure 5. An external audio-output modification on the television set allowed tape recorded material to be presented through the internal audio-circuitry of the set. Octave band analysis of the speech babble competing noise presented through the Bang and Olufsen loudspeaker was accomplished with a Rion NA-21 precision sound level meter and indicated acoustic energy concentrations primarily below 1000 Hz (Figure 6). A Bruel and Kjaer Type 2226 sound level meter was placed at the approximate location of each subject's ear prior to each experimental session in order to establish and monitor the correct presentation levels and signal-to-noise ratio.

III. EXPERIMENTAL METHOD

Routine audiometric procedures were used to obtain pure tone air and bone conduction thresholds and discrimination scores for CID W-22 monosyllables in quiet for all potential subjects. For the ten subjects who met the selection criteria (see page 16), the following procedures were employed.

MAGNAVOX MODEL RK5056 TELEVISION



BANG AND OLUFSEN S45 LOUDSPEAKER FOR NOISE PRESENTATION

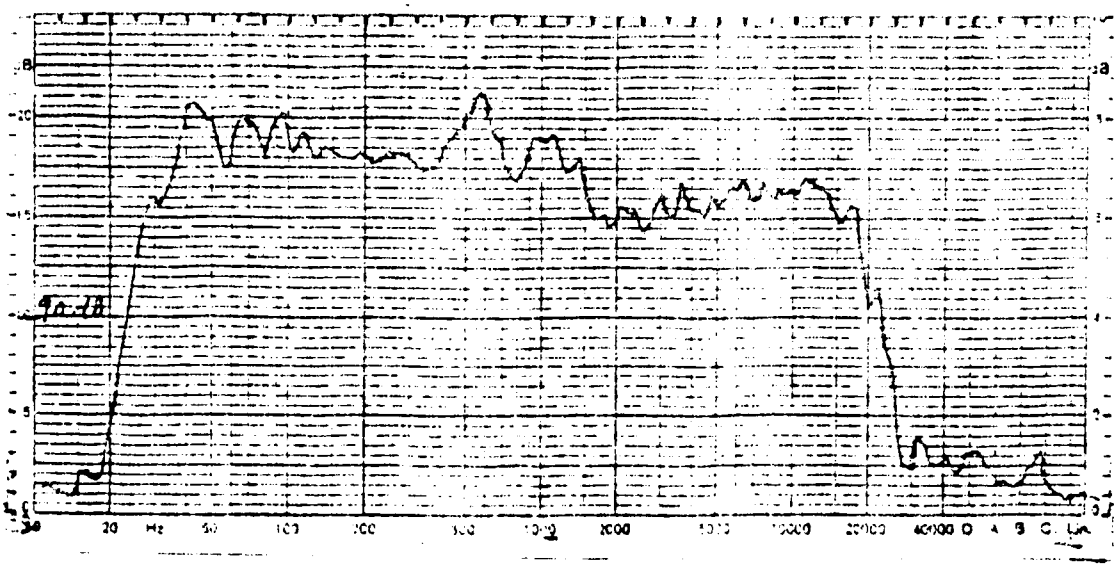


Figure 5. Frequency response curves for experimental television and competing noise loudspeaker.

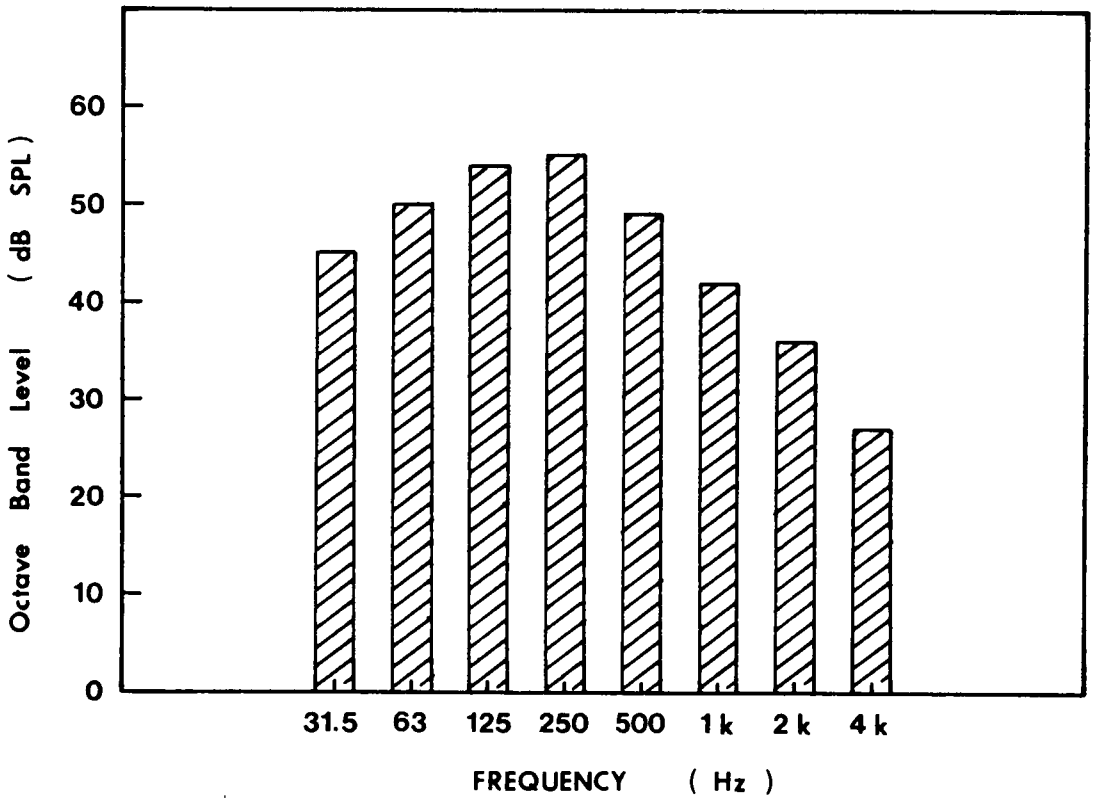


Figure 6. Octave-band spectra of competing speech babble at a 50 dBA presentation level.

The subject was seated in the test room facing the television and the competing noise loudspeaker at a distance of three meters. The carpeted room (dimensions: $7.5m_L$ x $5m_W$ x $2.3m_H$) contained furnishings typical of a home television viewing environment. The speech stimuli were presented at a level of 60dBA for all subjects in both conditions. Suter (1978) indicated such a level to be representative of a slightly raised conversational level. A constant presentation level was used, since individuals viewing television in groups may be unable to adjust the volume to a preferred level.

Competing noise was presented at a level of 50dBA in order to maintain a +10dB signal-to-noise ratio, felt to represent a common listening condition which may be difficult but not atypical for some hearing-impaired listeners. An even more adverse condition of +5dB may often be present in many homes (Kryter et al., 1962).

Prior to testing, written instructions were provided and reviewed with each subject. The written instructions are shown in Appendix C. Subjects were urged to guess when they were uncertain of a word. Four recorded practice sentences were presented in noise in order to familiarize the subject with the talker's voice, the noise, and the task to be accomplished. Answers to these sentences and the actual test sentences were recorded by the subject on the answer form provided to them, which appears as Appendix D. Experimental conditions were reversed for each subject. For example, subject number 1 listened first to the unfiltered presentation, then to the bimodal condition. Subject number 2 then heard the bimodal condition first, followed by the unfiltered stimuli. This counterbalanced procedure was employed

employed in order to reduce the influence of practice effects, which may occur as subjects gain test experience. Fifty key words per list were scored, with each word counting two points toward a possible 100 percent.

IV. TREATMENT OF DATA

Three subjects were selected at random and retested, using the above procedures, in both listening conditions in order to assess test-retest reliability. A Pearson Product-Moment Correlation Coefficient was calculated for each condition.

All subjects' scores were used to find the mean scores for each condition. These scores were then subjected to a t-test for related measures (Bruning and Kintz, 1977). An alpha level of .05 was used to designate a statistically significant difference.

CHAPTER IV

RESULTS AND DISCUSSION

The data analyzed in this study were obtained from a group of ten subjects (Ss) who demonstrated a mild-to-moderate high frequency sensory hearing loss. Speech discrimination scores for recorded sentences obtained for each S were calculated on a percent correct basis. The experimental question was: Are there differences between the mean intelligibility scores for hearing-impaired Ss obtained in the presence of noise presented at the +10dB signal-to-noise ratio for two conditions? Comparison conditions were:

1. Listening through simulated television audio-circuitry with an unfiltered frequency response range.

2. Listening through simulated television audio-circuitry with a bimodal filtered frequency response of 1000 Hz low-pass and 4000 Hz high-pass.

Results of the data analysis will be discussed as follows: (1) reliability of measurement; (2) over-all means and ranges; (3) statistical analysis; and (4) discussion.

I. RELIABILITY OF MEASUREMENT

Three Ss were randomly selected and retested in both listening conditions, using different lists (C and D), immediately following the experimental session. A Pearson Product-Moment Correlation Coefficient was calculated for each condition to evaluate retest reliability

(Bruning and Kintz, 1977). For the unfiltered condition, the calculation yielded a correlation coefficient of -.72. The coefficient for the bimodal filtered condition was .23. Both coefficients suggest poor retest reliability. Some possible factors which may have contributed to the lack of reliability will be presented in the discussion section.

II. OVERALL MEANS AND RANGES

The mean score for the bimodal filtered condition was 64 percent. The range of scores was wide, from 12 percent to 90 percent, for a score range of 78 percent. The unfiltered condition yielded a mean score of 81 percent, with scores in a narrower range from 56 percent to 100 percent. For this condition, the score range was 44 percent. Raw scores for each subject in each condition, means for each condition, and ranges are shown in Table II. The raw scores indicate percent of correct responses out of a possible 100 percent. For the purposes of this study, the term "better" with regard to scores refers to a higher percentage of correct responses.

III. STATISTICAL ANALYSIS

A t-test was calculated utilizing the speech discrimination scores obtained in the two experimental conditions (Bruning and Kintz, 1977). This computation is summarized in Table III. A t value of 2.52 significant at the .05 level, indicated there was a difference between the mean intelligibility scores obtained in the two listening conditions. Thus, in answer to the experimental question, hearing-impaired Ss demonstrated better mean speech intelligibility scores in

TABLE II

RAW DISCRIMINATION SCORES IN TWO LISTENING CONDITIONS

Subject No.	Unfiltered Condition %	Bimodal Filtered Condition %
1	62	12
2	96	80
3	80	72
4	88	76
5	56	32
6	84	90
7	100	80
8	86	80
9	80	32
10	80	90
Mean	81.2	64.4
Range	56-100	12-90

TABLE III

SUMMARY OF t-TEST FOR RELATED MEASURES FOR TWO LISTENING CONDITIONS

Mean Score Unfiltered (%)	Mean Score Filtered (%)	Difference (%)	df	t	p
81.2	64.4	16.8	9	2.42	<.05

simulated television audio-circuitry with an unfiltered frequency response range when compared with mean intelligibility scores in simulated television audio-circuitry with a bimodal filtered frequency response of 1000 Hz low-pass and 4000 Hz high-pass.

IV. DISCUSSION

Results of the statistical analysis indicated better speech intelligibility for the hearing-impaired Ss when the stimuli were presented in the unfiltered condition as compared to the bimodal filtered condition. An examination of the raw data supports this interpretation. As shown in Figure 7, eight of the ten Ss obtained higher (in percent correct) speech discrimination scores in the unfiltered condition than they did in the bimodal filtered condition. Furthermore, of these eight Ss, five displayed a difference between the two conditions of 15 percentage points or more. The range of differences for the eight Ss between the two conditions was 6 to 50 percentage points and the mean difference in percentage points was 23.

Differences between raw scores in the two conditions are shown in Table IV for the eight Ss who scored higher in the unfiltered condition. The greatest difference in scores between the two conditions occurred in S_1 (50 percent) and S_9 (48 percent). These percentage differences yield a mean difference for these two Ss of 49 percent. The remaining six Ss who exhibited better scores in the unfiltered condition revealed score differences between the two conditions of 16 percent (S_2), 8 percent (S_3), 12 percent (S_4), 24 percent (S_5), 20 percent (S_7), and 6 percent (S_8). The mean of these

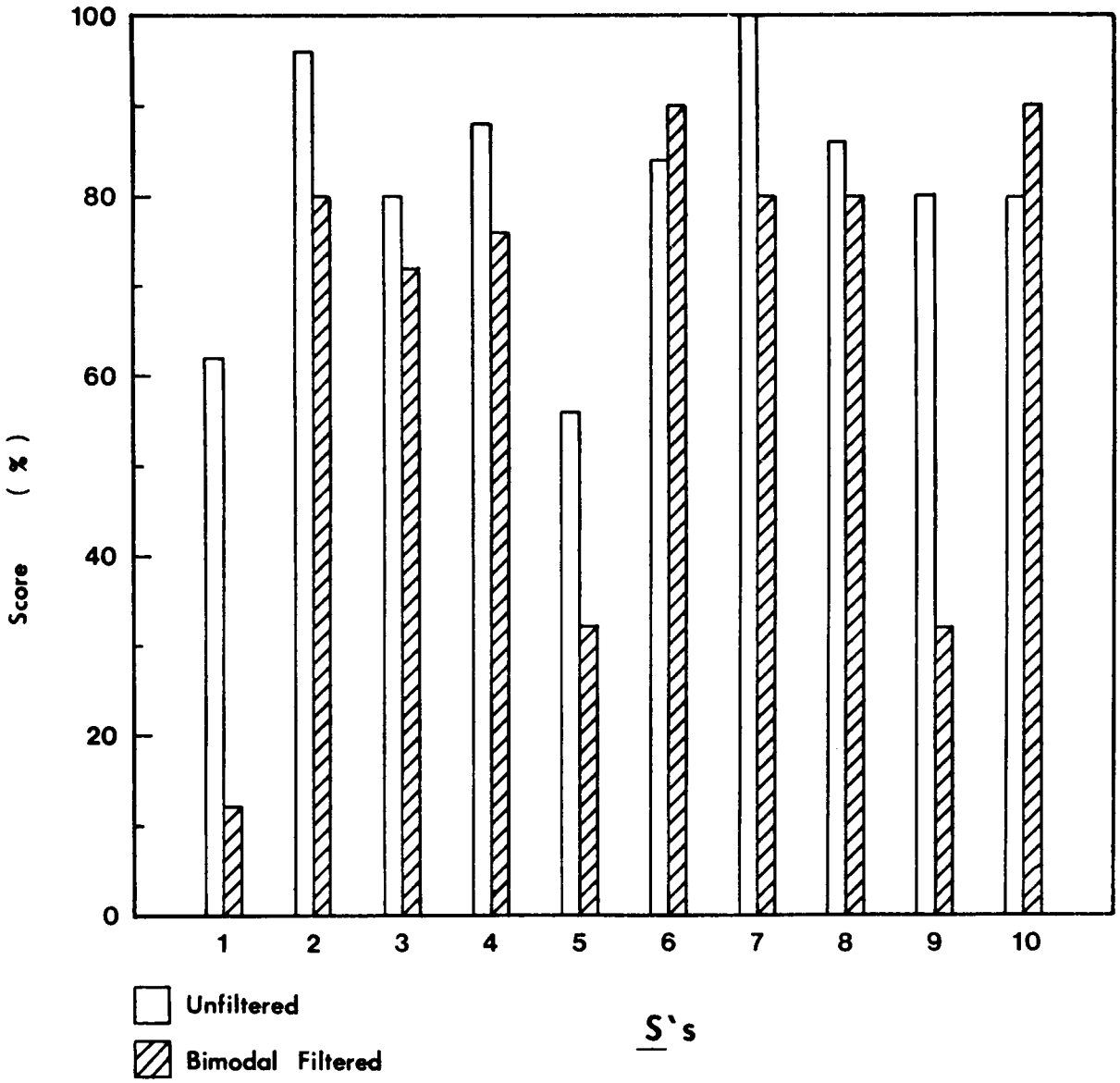


Figure 7. Individual raw discrimination scores in the two listening conditions.

TABLE IV

DIFFERENCES BETWEEN RAW SCORES IN TWO CONDITIONS FOR Ss WHO SCORED BETTER IN UNFILTERED CONDITION

Subjects	Greater Difference Between Scores in Two Conditions (%)	Subjects	Lesser Difference Between Scores in Two Conditions (%)
S1	50	S2	16
S9	48	S3	8
		S4	12
		S5	24
		S7	20
		S8	6
Mean Difference	49.0		14.3

score differences is 14 percent. Thus, it appears from this inspection of the raw data that the scores of the two Ss (S_1 and S_9) who exhibited extreme differences in scores (e.g., 48 and 50) between the two conditions may have influenced the mean scores for the two conditions. Also, two Ss (S_1 and S_5) obtained extremely low scores in both conditions (e.g., 12%, 62%, 32%, 56%), further affecting the mean score.
score differences is 14 percent. Thus, it appears from this inspection of the raw data that the scores of the two Ss (S_1 and S_9) who exhibited extreme differences in scores between the two conditions may have influenced the mean scores for the two conditions. Also, two Ss (S_1 and S_5) obtained extremely low scores in both conditions, further affecting the mean scores.

Referring again to Figure 7, it can be observed that two of the total ten Ss (S_6 and S_{10}) exhibited better scores in the bimodal condition than the ulfiltered condition. However, much narrower score differences between the two conditions were found in these two Ss. The greatest difference in percentage points was 10 (S_{10}), with S_6 demonstrating a score difference between the two conditions of 6 percent. The mean difference between the two conditions is 8 percent for these two Ss.

Another consideration in interpreting the results of this study is the fact that a constant bimodal filter setting was employed. In therapy situations, verbo-tonal clinicians typically vary slopes and frequency cut-offs in an attempt to find the optimal condition for each individual. The use of a single condition for a number of individuals may not result in maximum intelligibility scores for all Ss.

For instance, the 18dB per octave slope toward the low frequencies for the 1000 Hz bandpass filter may not have coincided with the area of residual hearing for some Ss, in which case optimal performance was probably not possible.

The frequency cut-offs and slopes chosen for this study were based on clinical experiences in verbo-tonal therapy. Even so, the choice was somewhat arbitrary since such therapy typically involves hearings aids, in which any competing noise is filtered along with the stimulus. In this study, non-hearing aid users were stimulated in a sound field experimental condition in the presence of separate, unfiltered competing noise. Since earlier studies of bimodal presentations were conducted with earphones and without competing noise, actual comparison cannot be made between this study and those which preceded it (Franklin, 1969, 1975; and Rosenthal, Lang, and Levitt, 1975).

Examination of the data can also be made with regard to speech discrimination scores obtained with monosyllables in quiet compared with the scores obtained with sentences in the two experimental conditions of +10dB signal-to-noise ratio, one the unfiltered condition and the other the bimodal filtered condition. For the CID W-22 monosyllables, scores ranged from 92 to 100 percent, with a mean score of 97 percent. For the sentences in noise, the unfiltered condition yielded a mean score of 81 percent while the bimodal filtered condition mean score was 64 percent. Figure 8 shows the comparison of the mean CID W-22 score in quiet with the mean scores for sentences in noise and indicates the scores in noise to be poorer. These results are consistent with the results of other studies (Carhart and Tillman, 1970;

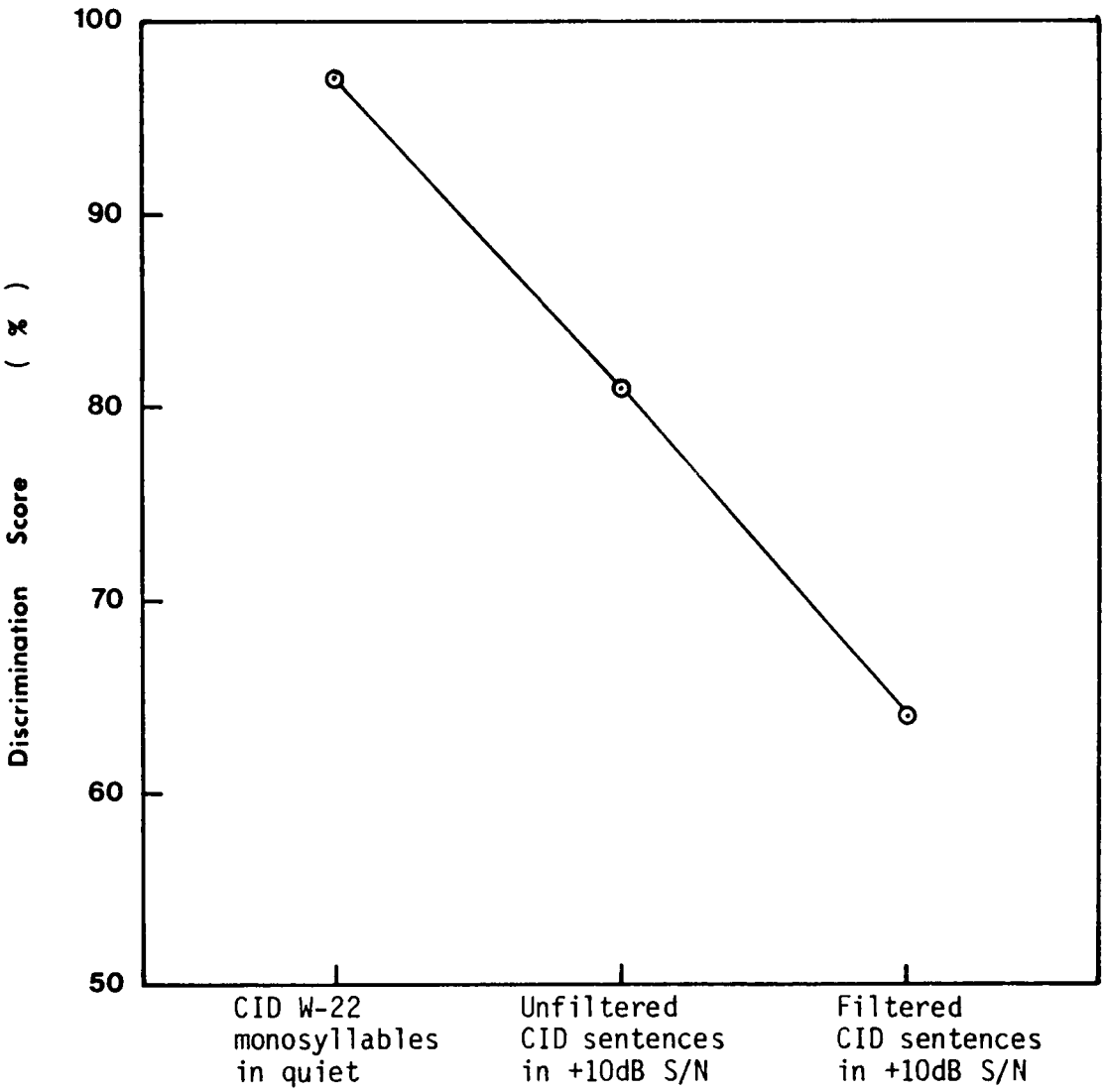


Figure 8. Comparison of mean scores obtained in quiet with mean scores obtained in noise.

Cooper and Cutts, 1971; Cohen and Keith, 1976) which demonstrate that speech discrimination ability of sensory hearing-impaired Ss deteriorates in conditions of noise. The results of the present study also support the conclusion of Shapiro et al. (1972) that discrimination ability of hearing-impaired Ss in noise could not be predicted from scores obtained in quiet.

However, because of the poor retest reliability indicated by the correlation coefficients, any interpretation of these data must be made cautiously. In many cases, poor reliability can be the result of a learning effect from one test experience to another. Such situations can be observed in the raw data, since retest scores would show consistent improvement compared to scores from the original test condition. The raw data on reliability in this study, as shown in Figure 9, did not reflect evidence of a learning effect. The raw scores indicated that while S_9 showed improved scores in both conditions in the retest situation, the scores of S_4 deteriorated in both conditions. Also, S_6 demonstrated an improved score in the unfiltered condition, but a poorer score in the bimodal filtered condition during the retest. Thus, the poor retest reliability did not seem to be due to a learning effect.

One factor which could have influenced reliability is a lack of homogeneity between the sentence lists. Equivalency of sentence lists can vary as a function of factors such as the talker's voice, recording procedure, form and degree of distortion, and scoring technique. Giolas and Duffy (1973) did not find a high degree of equivalency among ten CID sentence lists presented through a low-pass filter to normal

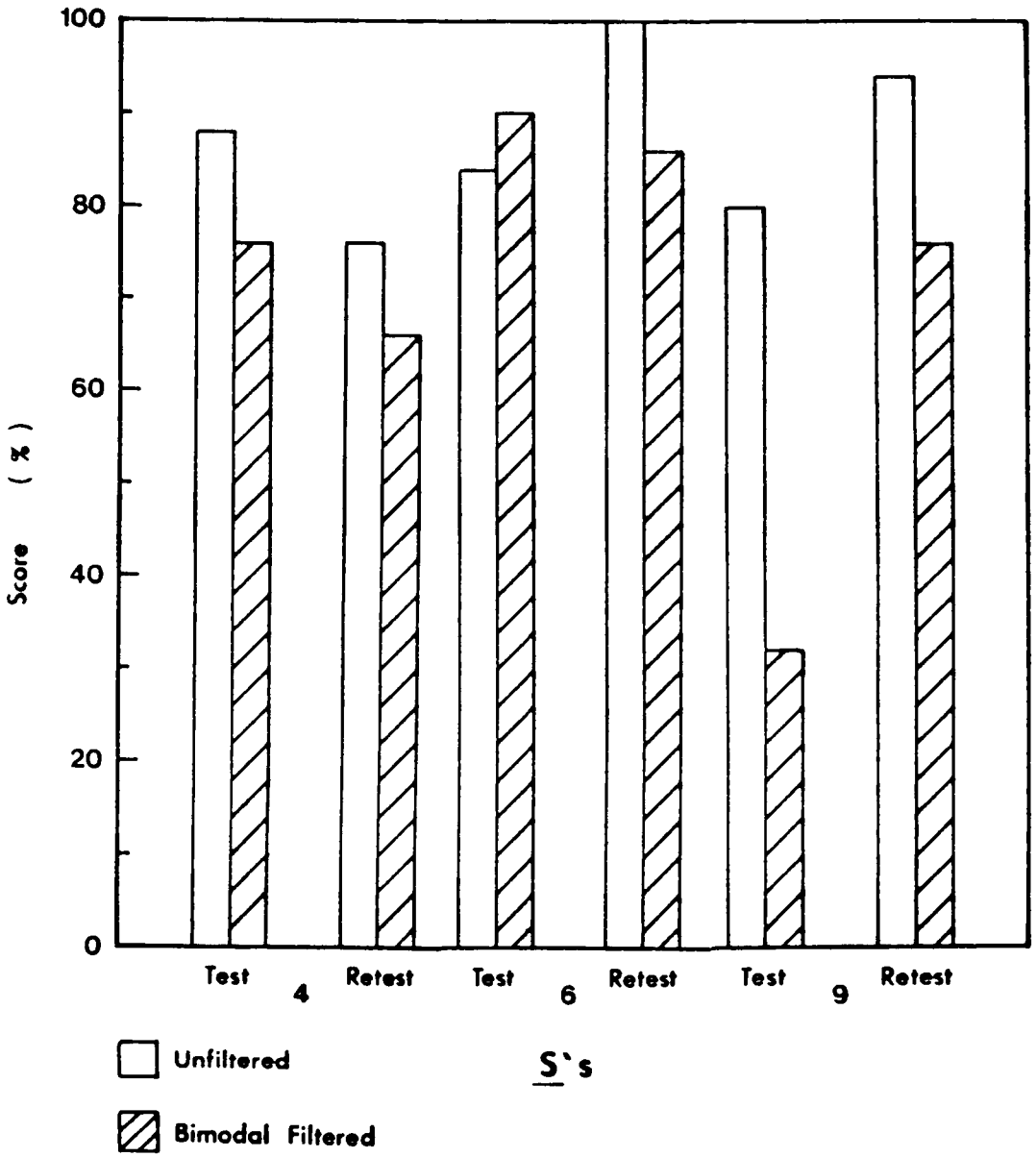


Figure 9. Test-retest raw discrimination scores of three Ss used in reliability assessment.

hearing Ss. Since the sentence stimuli used in this study varied widely with respect to length and content, it can be expected that lack of homogeneity between lists played a role in the poor reliability.

Another factor which could have affected the reliability of the present study is the response technique employed. Ss were required to listen to the sentence and then write what they had heard. Thus, Ss were forced to remember the entire sentence as they wrote their response. Since some sentences were fairly lengthy (up to twelve words) while others were short, it is possible that some Ss responded more accurately, with regard to what they actually heard, for some sentences than for others. Such a response technique may have created fatigue in some Ss, resulting in inaccurate recording.

Due to the complexity of scoring involved in such a response, scoring could not be accomplished until after the entire task was completed. This precluded monitoring of Ss' responses and prevented verbal encouragement during testing which could have increased S motivation and reduced fatigue.

Another factor which has been found to affect reliability of speech discrimination tests is the presence of competing noise. A study by Gengel et al. (1981) indicated that speech discrimination scores obtained in noise may not be a reliable measure of an individual's actual discrimination ability.

Thus, the response technique, in combination with the lack of sentence list homogeneity and the presence of competing noise, could have contributed to the inconsistency of the test-retest scores. Other factors may have played a role, for example the emotional state of the Ss could have affected their responses.

CHAPTER V

SUMMARY AND CONCLUSIONS

I. SUMMARY

The purpose of this study was to compare speech intelligibility for sensory hearing-impaired Ss in noise in two listening conditions: an unfiltered frequency response range, and a bimodal filtered frequency response of 1000 Hz low-pass and 4000 Hz high-pass.

Ten adults between the ages of 30 and 59 participated in the study. All Ss exhibited mild-to-moderate high frequency sensory hearing impairments.

The experimental question investigated the possibility of differences between intelligibility scores obtained in +10dB signal-to-noise ratio in the two experimental conditions.

The results of the study are summarized as follows:

1. The test procedure employed in the study was found to have poor reliability when subjected to test-retest correlation analysis.

2. There was a significant difference at the .05 level between mean intelligibility scores obtained in noise in the two experimental listening conditions, with better scores in the unfiltered condition as compared to the bimodal filtered condition.

II. CONCLUSIONS

The following conclusions were suggested by the result of this study:

1. The experimental procedure is not reliable with regard to test-retest accuracy.

2. Mean speech discrimination scores in a +10dB signal-to-noise ratio of sensory hearing-impaired Ss were found to be better in an unfiltered listening condition as compared with scores obtained in a bimodal filtered listening condition.

3. The speech discrimination scores of sensory hearing-impaired Ss were found to deteriorate in noise when compared to scores obtained in quiet.

4. Speech discrimination ability of sensory hearing-impaired Ss cannot be accurately predicted from scores obtained in quiet.

III. LIMITATIONS OF THE STUDY

The following limitations are evident in this study:

1. The constant speech level, although typical of everyday conditions, does not necessarily yield maximum speech discrimination scores for all Ss, thus limiting comparisons between Ss as well as information with regard to optimal perception.

2. The sample size of ten Ss limits generalization of these results to a population.

3. The use of a single bimodal filter setting may not allow maximum speech discrimination ability for all Ss.

4. The present procedure is limited in comparison to previous research due to differences in test materials and listening conditions.

5. Because of the written response, scoring could not be accomplished as the test was performed, preventing verbal encouragement and monitoring of S response.

IV. IMPLICATIONS FOR FURTHER STUDY

Further research is suggested in the following areas:

1. A replication of this study assessing speech discrimination ability at a most comfortable level (MCL) for each S.

2. A replication involving assessment of speech discrimination ability at varying bimodal filter settings, since settings providing optimal conditions may be different from one individual to another. In particular, the slope toward the low frequencies for the low band-pass filter should be investigated, since the area of greatest residual hearing must be included for a bimodal presentation to be helpful.

3. A replication of this study comparing speech discrimination scores for the two conditions in noise at a fixed presentation level using hearing-impaired Ss wearing individually fitted hearing aids. This design, by allowing Ss to adjust the intensity level of MCL via the hearing aids, would provide information regarding optimal speech discrimination performance as a function of the interaction between the two filter conditions and the hearing aids.

4. A replication of this study using sentence material such as the Kent State University Speech Discrimination Test, which, because of its multiple choice, closed set design, would allow more reliable responses by reducing the effect of auditory memory. Such material would also allow for immediate scoring, which could also improve

reliability since S responses could be monitored and motivation increased by verbal encouragement.

5. A replication of this study in which Ss are asked to make a quality judgement as to which condition sounds the clearest or most acceptable to them.

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APPENDICES

APPENDIX A

WRITTEN INFORMED CONSENT DOCUMENT

You are asked to participate in a study to assess the intelligibility of television broadcasts in the presence of background noise. You will participate in one experimental session, approximately one hour in length, to include:

1. A brief hearing test.
2. Listening to twenty recorded sentences and responding by writing each sentence as accurately as possible.

I understand and agree to the following:

1. Individual identities will be kept confidential, as will all data obtained.
2. All test results will be available to me upon request.
3. The sound levels will not exceed those typical of a home television listening environment.
4. Tests will be conducted by qualified individuals.
5. I am free to withdraw consent and discontinue participation in the study at any time.
6. Refusal to participate will not affect any future contact I may have with the University of Tennessee Hearing and Speech Center.
7. I understand that although this study may not benefit me, it may provide information which will be of future value for hearing-impaired persons.
8. This project has been approved by the University of Tennessee, Committee on Research Participation and potential subjects are not at risk.
9. Any further questions concerning these procedures will be answered by contacting:

David M. Lipscomb, Ph.D.
Phone: 974-4123 (office)
573-9013 (home)

Signature _____

Date _____

APPENDIX B

CID EVERYDAY SENTENCES

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. Good morning.
6. Open your window before you go to bed.
7. Do you think that she should stay out so late?
8. How do you feel about changing the time when we begin work?
9. Here we go!
10. Move out of the way!

LIST B

1. The water's too cold for swimming.
2. Why should I get up so early in the morning?
3. Here are your shoes.
4. It's raining.
5. Where are you going?
6. Come here when I call you.
7. Don't try to get out of it this time.
8. Should we let little children go to the movies by themselves?

9. There isn't enough paint to finish the room.
10. Do you want an egg for breakfast?

LIST C

1. Everybody should brush his teeth after meals.
2. Everything's all right.
3. Don't use up all the paper when you write your letter.
4. That's right.
5. People ought to see a doctor once a year.
6. Those windows are so dirty I can't see anything outside.
7. Pass the bread and butter please.
8. Don't forget to pay your bill before the first of the month.
9. Don't let the dog out of the house.
10. There's a good ball game this afternoon.

LIST D

1. It's time to go.
2. If you don't want these old magazines, throw them out.
3. Do you want to wash up?
4. It's a real dark night so watch your driving.
5. I'll carry the package for you.
6. Did you forget to shut off the water?
7. Fishing in a mountain stream is my idea of a good time.
8. Fathers spend more time with their children than they used to.
9. Be careful not to break your glasses.
10. I'm sorry.

APPENDIX C

INSTRUCTIONS TO SUBJECTS

LOUDSPEAKER INTELLIGIBILITY TEST

INSTRUCTIONS:

The purpose of this experiment is to test various loudspeaker systems, rather than your ability to understand speech. No one is expected to understand all the words, so do not be frustrated when you find some difficult to hear.

You will hear some sentences in a background of noise. Try to ignore the noise and concentrate on listening to the voice. After each sentence is spoken, write what you think you heard on the answer sheet. If you are not sure of some of the words, please guess.

First you will hear four practice sentences. Write these on the answer sheet on the practice lines A-D. Then there will be two groups of ten sentences for a total of twenty sentences. Write these on the lines 1-20.

It is important that you face straight ahead when listening to the sentences; however, you are free to move your head to write.

Remember to guess when you are not sure of the words.

APPENDIX D

RESPONSE FORMS

SUBJECT # _____

Practice (A-D)

A. _____

B. _____

C. _____

D. _____

Test (1-20)

1. _____

2. _____

3. _____

4. _____

5. _____

6. _____

7. _____

8. _____

9. _____

10. _____

11. _____

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16. _____

17. _____

18. _____

19. _____

20. _____

VITA

Susan Anne McPhail was born in Fayetteville, North Carolina on January 2, 1951. She graduated from Pine Forest High School in 1969. In 1972 she received a Bachelor of Arts degree in Sociology from North Carolina State University. After several years as a social worker with the Tennessee Department of Human Services, she entered graduate school at The University of Tennessee in 1980. She was awarded a graduate assistantship in September 1981. She received a Master of Arts degree in Audiology in December 1982.