Portland State University
PDXScholar

1982

One-third octave band augmented speech discrimination testing for normal hearing listeners

Nancy Marie Bowen
Portland State University

Let us know how access to this document benefits you.

Follow this and additional works at: http://pdxscholar.library.pdx.edu/open_access_etds

Part of the Cognition and Perception Commons, and the Speech and Hearing Science Commons

Recommended Citation
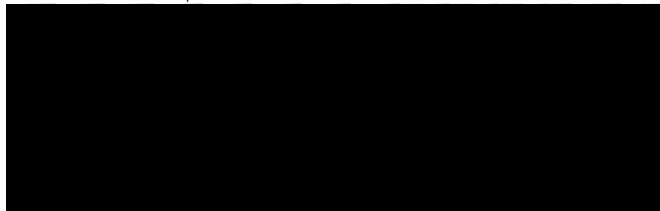
AN ABSTRACT OF THE THESIS OF Nancy Marie Bowen for the Master of Science
in Speech Communication presented February 26, 1982.

Title: One-Third Octave Band Augmented Speech Discrimination Testing
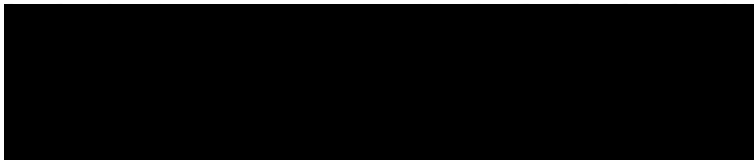   for Normal Hearing Listeners.
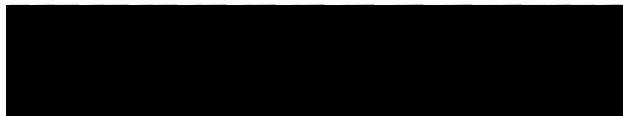
APPROVED BY MEMBERS OF THE THESIS COMMITTEE:

Alamander Hicks, Ph.D., Chairman

James F. Maurer, Ph.D.

Robert E. Jones, Ph.D.

The purpose of this study was to investigate the effects of a
500 Hz and 3150 Hz one-third octave band augmentation on the speech
discrimination ability of normal hearing listeners and whether such
effects vary with signal presentation level. The augmented portion
of monosyllabic words was systematically varied from 5-55dB above the

intensity level of the unfiltered version of the words and presented simultaneously to one ear.

The present investigation revealed that both the 500 Hz and 3150 Hz augmented speech tests precluded perfect discrimination scores in a normal hearing population. The small standard deviations observed in the 3150 Hz augmented condition, regardless of presentation level, suggested that this test may have clinical potential as a diagnostic test. The 500 Hz augmented condition produced a rollover in discrimination ability with increasing intensity disparity level.

It was concluded that the reduced discrimination scores observed in the two augmented conditions were the result of a combination of frequency and intensity distortion, with frequency playing the dominant role. Further, the low frequency distortion component appeared to have a more deleterious effect on speech discrimination ability.

ONE-THIRD OCTAVE BAND AUGMENTED SPEECH DISCRIMINATION TESTING FOR
NORMAL HEARING LISTENERS

by

NANCY MARIE BOWEN

A thesis submitted in partial fulfillment of the requirements
for the degree of

MASTER OF SCIENCE
in
SPEECH
with emphasis in Speech Pathology
and Audiology

Portland State University

1982
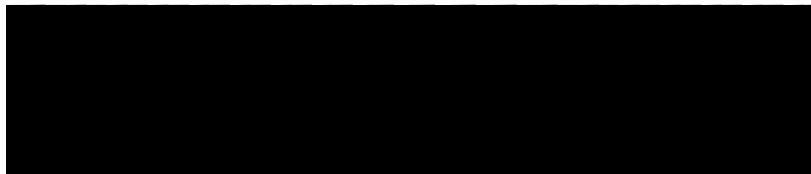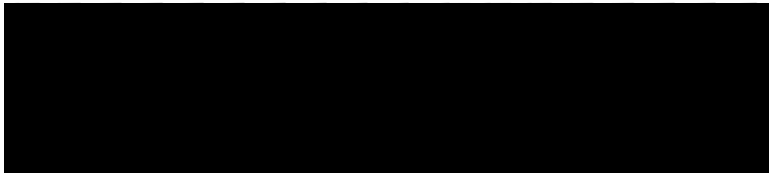
TO THE OFFICE OF GRADUATE STUDIES AND RESEARCH:

The members of the Committee approve the thesis of Nancy Marie Bowen presented February 26, 1982.

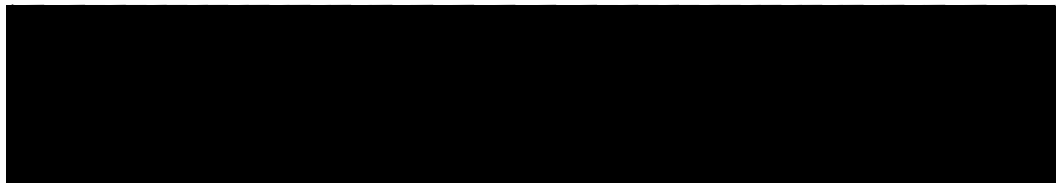Alamander Hicks, Ph.D., Chairman
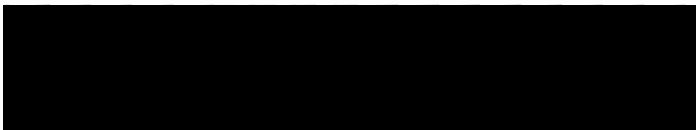
James F. Maurer, Ph.D.

Robert E. Jones, Ph.D.

APPROVED:

Theodore G. Grove, Head, Department of Speech Communication

Stanley E. Rauch, Dean of Graduate Studies and Research

In Dedication and Love

to My Parents

ACKNOWLEDGEMENTS

The completion of this project has required the time and assistance of several individuals, all of whom I owe my sincerest appreciation.

To Dr. Al Hicks, my advisor, key instructor and thesis committee chairman, I offer my deepest gratitude. With his knowledge of research, expertise with the equipment and attention to details, he provided me the technical assistance I needed to develop a viable research study. With his unremitting encouragement, support and time, he gave me the impetus to complete a very long and tedious project. His dedication to teaching and to audiology has been invaluable.

I also extend my gratitude to Dr. James Maurer, who provided the foundation for this investigation. His advice and support were appreciated not only during this research but throughout my graduate years.

I would like to thank Dr. Robert Jones, who took time from a very busy schedule to be a part of my thesis committee from the start. His willingness to provide input to this research certainly facilitated its completion.

For their expert advice in statistics and research design, I would like to thank Dr. Ted Grove and Dr. Jim Paulsen. Through their instruction, I was able to perform my own statistical analysis as well as the interpretation of the results!

Finally, I wish to thank the several students who volunteered their time to participate in this investigation. Their patience, interest and curiousity made this project a very enjoyable experience for me.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

Human audition involves several stages of processing, with the
initial analysis occurring in the auditory periphery. Subsequently,
the peripheral output is processed through an intricate network of
neural pathways, to be ultimately synthesized in the auditory cortex.
Determination of the locus of pathology within the auditory system be-
comes increasingly complex as the site of lesion progresses from the
peripheral ear to the central nervous system (Jerger, 1960). See
Figure 1. Audiometric manifestation of a lesion becomes more subtle
as one moves toward the cortex (Jerger, 1960); consequently, responses
to intensity and frequency become less definitive (Bocca and Calearo,
1963). While peripheral disorders which produce hearing loss may be
identified with simple pure tone stimuli, the differentiation of neural
degeneration requires more complex auditory tasks (Jerger, 1964; Bocca,
1967; Snow, et al., 1977).

Human speech, while considered to be acoustically and temporally
complex, bears with it an extrinsic redundancy, or internal structuring,
based upon the replication of phoneme (speech unit) information (Palva,
1965; Korsan-Bengtsen, 1973; Lundborg, et al., 1975; Snow, et al., 1977;
Stevens, 1978). That is, ordinary speech provides more information to
the listener than is necessary for the perception of a message. This
extrinsic redundancy of speech often allows recognition of a message on

PERIPHERAL   CENTRAL

Outer   Middle   Cochlear   Retrocochlear
Ear   Ear

Cochlea   Brainstem

Cochlea   Eighth Nerve
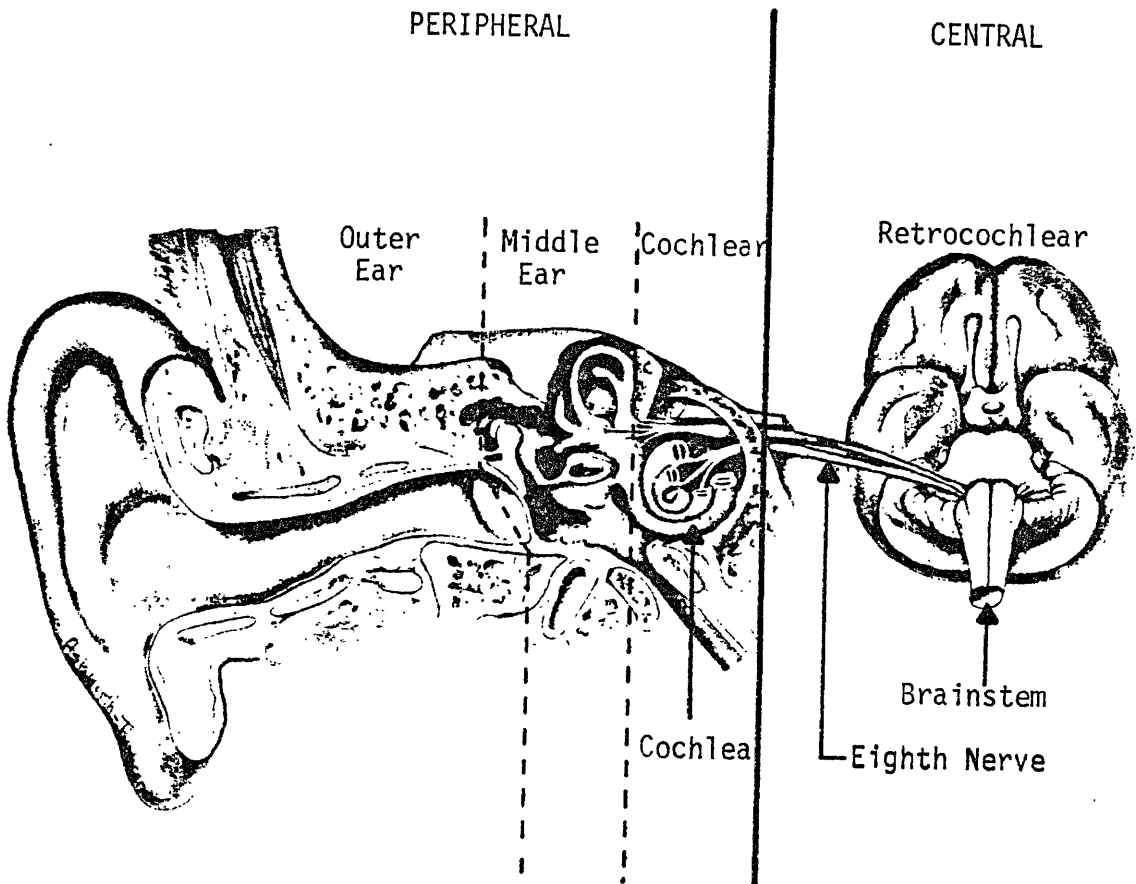
Figure 1. Relationship of the auditory pathway progressing from
the peripheral mechanism through the central nervous system (After
Jacobs and Francone, 1970).

the basis of a single distinctive component. Thus, the loss or distortion of some individual speech elements by the receiver does not necessarily imply that the entire message will be unintelligible or misinterpreted (Lundborg, et al., 1975).

Furthermore, the multiplicity of neural fibers and connections which characterize the central auditory pathways provides an intrinsic redundancy for the incoming signal (Bocca and Calearo, 1963; Palva, 1965; Lundborg, et al., 1975; Snow, et al., 1977). The abundance of neural structures allows the central auditory system to perceive and identify patterns of incoming phonemes and words with a different outline for each message. Since the central auditory system is capable of integrating the patterns of a message, a whole speech message may be efficiently recognized even when it lacks one or more constituents (Bocca, 1967; Lundborg, et al., 1975).

It is not surprising then, that simple auditory discrimination tasks fail to define central lesions (Snow, et al., 1977). Due to the high extrinsic redundancy of conventional speech materials coupled with the inherent intrinsic redundancy of the central auditory pathways, lesions in the brainstem and auditory cortex elude detection. That is, given normal peripheral hearing, the central auditory system is not sufficiently taxed when traditional speech materials are employed for auditory testing (Bocca, 1967; Jerger, 1973; Korsan-Bengtsen, 1973; Snow, et al., 1977). Conventional speech discrimination testing therefore remains futile in the identification of central auditory disorders.

CHAPTER II

REVIEW OF THE LITERATURE

Tests which variously degrade or distort speech stimuli, thereby reducing extrinsic redundancy, have been reported to indirectly assess the integrity of the central auditory pathways (Bocca, et al, 1955; Carhart, 1965; Bocca, 1967; Korsan-Bengtsen, 1973; Lundborg, et al., 1975; Snow, et al., 1977). That is, the loss of extrinsic redundancy produces similar effects on speech perception as reduced intrinsic redundancy. Consequently, it is possible to compare the problems of speech recognition when the internal redundancy of speech is reduced, as in certain central lesions, with problems resulting when the external redundancy is reduced by intentionally distorting speech stimuli. While distorted speech results in reduced speech discrimination performance in normal as well as hearing impaired listeners, the effect is more dramatic in persons with central auditory pathologies. This finding may be explained by a dual reduction in redundancy, intrinsic and extrinsic, in individuals with lesions of the central auditory tracts (Bocca, 1967; Lundborg, et al., 1975; Snow, et al., 1977).

DISTORTED SPEECH TESTING

Speech signals may be made less redundant by intentionally distorting their frequency (pitch) or intensity (loudness) parameters. Since both the frequency and intensity of speech are evident features in

single words as well as ongoing discourse, the physical manipulation
of these parameters has undergone a great deal of research. For the
most part, the following discussion will be based upon investigations
utilizing single word stimuli in distorted speech testing.

Frequency Distortion

Speech can be degraded by eliminating a portion of the frequency
spectrum through electronic filtering. For example, a low-pass filter
will pass only frequencies below a certain cut-off frequency, thus
eliminating the higher frequency acoustic information normally present
for the understanding of a spoken message. The amount of distortion
depends upon the cut-off frequency (Hz) and the filter rejection rate
(dB/octave), or rate at which the filter attenuates frequencies above
and/or below the cut-off frequency. Low-pass, high-pass and various
band-pass filtered conditions (Figure 2) have been utilized in speech
discrimination experiments in an effort to: 1) assess the effective-
ness of communications equipment, 2) simulate in normal hearing listen-
ers the effects of various hearing impairments (Hirsh, et al., 1954;
Danhauer, et al., 1977) and 3) reduce the extrinsic redundancy of
speech stimuli, thereby taxing the central auditory pathways (Korsan-
Bengtsen, 1973; Snow, et al., 1977).

Working with the Bell Telephone Laboratories, French and Steinberg
(1947) developed a graph or an "articulation index" for the purpose of
illustrating the effects of varying amounts of filtering on speech dis-
crimination ability. According to their data, the optimum presentation
level was approximately 55dB HL for meaningless syllables under condi-
tions of low-pass or high-pass filtering. Figure 3 illustrates the
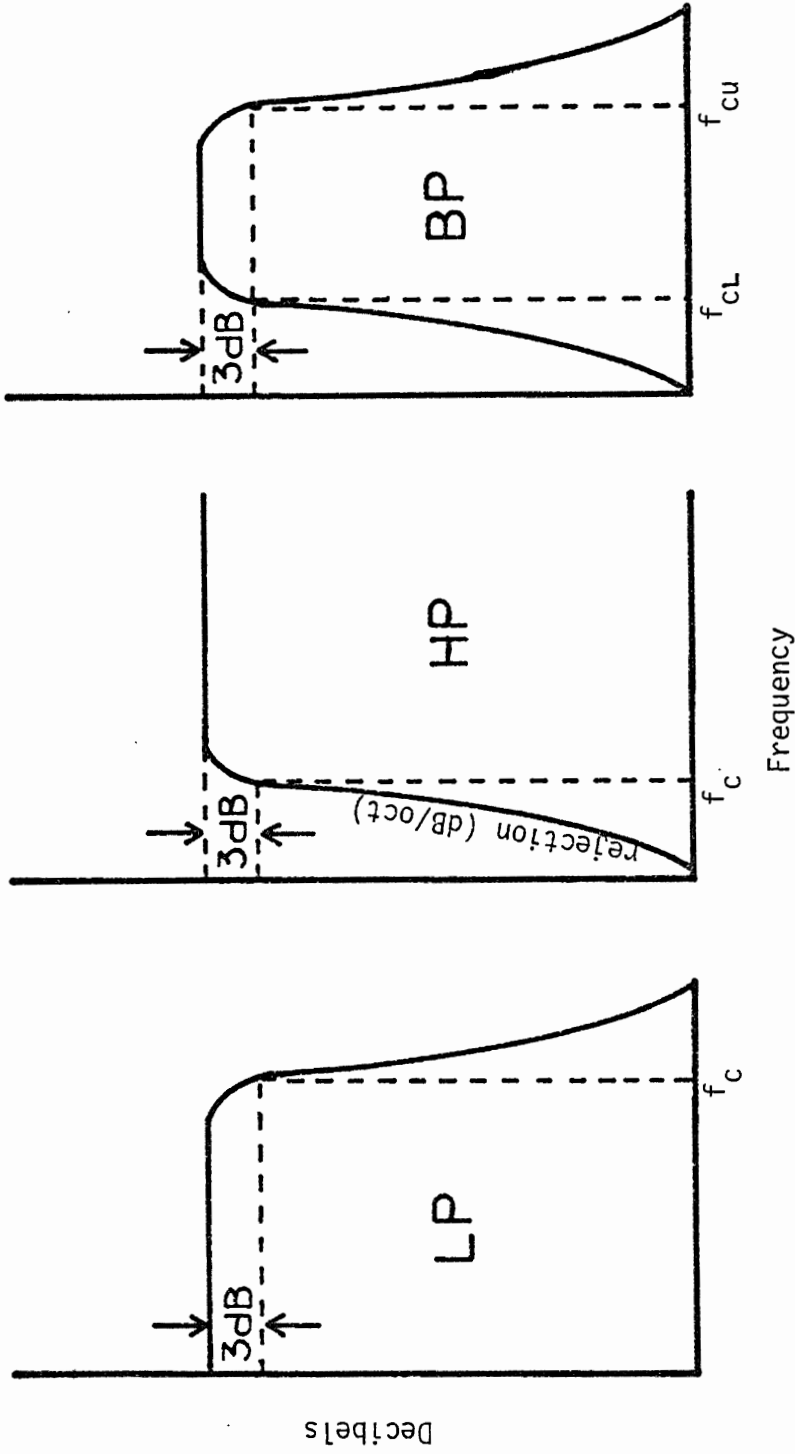
Figure 2. Frequency response plots of low-pass (LP), high-pass (HP) and band-pass (BP) filters. Cut-off frequencies (f_c) are shown; f_{cu} and f_{cL} indicate upper and lower cut-offs, respectively, for the band-pass filter. Both coordinates are logarithmic -- decibel units (ordinate) versus log frequency (abscissa) (Durrant and Lovrinic, 1977).
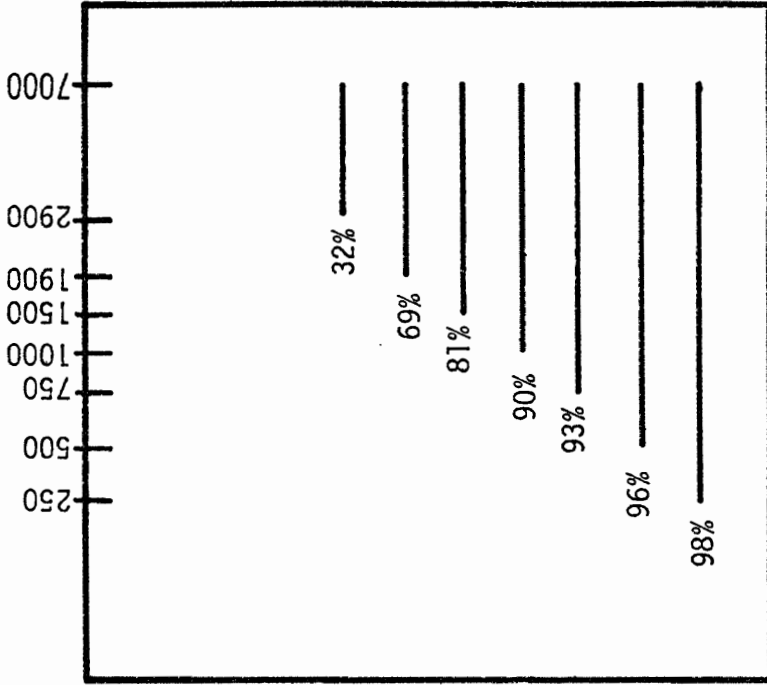
High-Pass Low Cut Filters

7000 — 2900 — 1900 — 1500 — 1000 — 750 — 500 — 250 —

32%

69%

81%

90%

93%

96%

98%
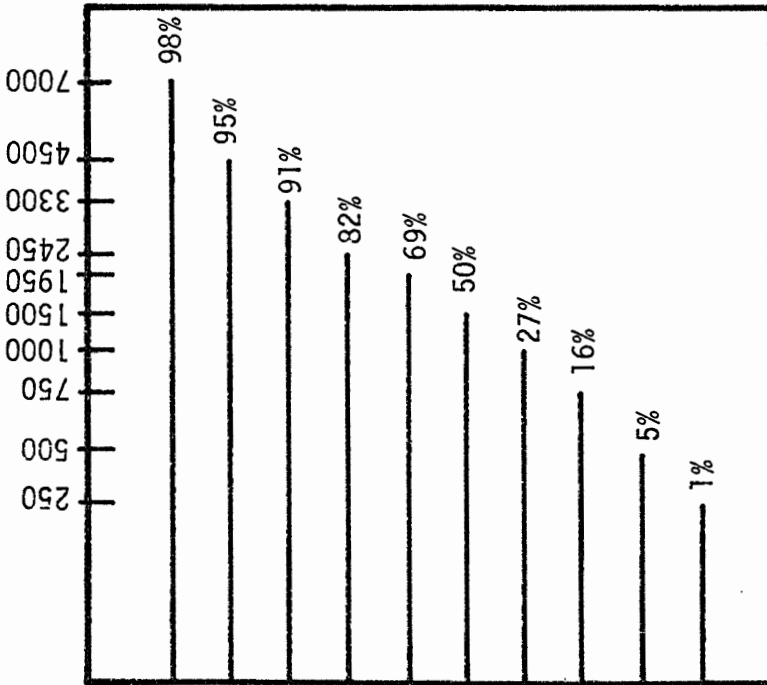
Low-Pass High Cut Filters

98%

95%

91%

82%

69%

50%

27%

16%

5%

1%

7000 — 4500 — 3300 — 2450 — 1950 — 1500 — 1000 — 750 — 500 — 250 —

Figure 3. Maximum discrimination for syllable articulation for low- and high-pass filter conditions as related to the cut-off frequency. The discrimination scores were derived from the curves of French and Steinberg, 1947, at a presentation level of 55dB HL (Goetzinger, 1978).

speech discrimination ability of normal hearing listeners for both low-
and high-pass filtered syllables. As can be seen in this figure, syl-
lable discrimination decreases progressively as more high frequencies
are eliminated. Further, these authors found that the low- and high-
pass articulation curves intersected at 1900 Hz with discrimination
scores of 69% (Figure 4). Thus, it appears that at 1900 Hz, the intel-
ligibility for meaningless syllables is equal when either the lower or
higher frequencies are rejected.

Hirsh, et al. (1954) compared normal hearing listeners' discrimi-
nation ability for meaningless syllables to different kinds of words
and sentences under low- and high-pass filtering at a 75dB HL presenta-
tion level. As illustrated in Figure 5, their data reveals that the
articulation curves for all the different test materials appear to cross
at about the same frequency, 1700 Hz. The discrimination scores, how-
ever, become higher as the number of syllables in the test material in-
creases. The curves indicate that discrimination ability for nonsense
syllables is 75% and improves to 100% for three-syllable words at the
1700 Hz intersection point. These discrimination scores are slightly
higher than those obtained by French and Steinberg (1947).

In a later study, Wang, et al. (1978) reported a range of cross-
over points for high- and low-pass filtered syllable articulation curves
which agreed with those obtained by both French and Steinberg (1947) and
Hirsh, et al., (1954). Using a 75dB HL intensity level, Wang, et al.
noted that the point of intersection ranged from 1750-2000 Hz with dis-
crimination ability varying between 75-88% correct. This suggests that
variations in equipment and methodology may influence speech
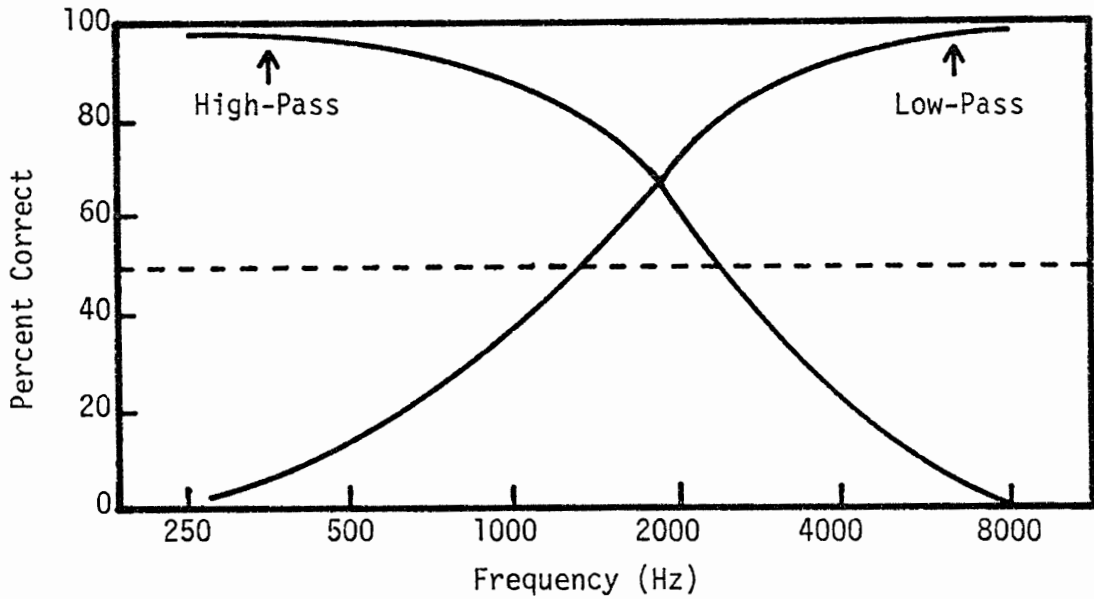
Figure 4. Effect of low-pass and high-pass filtering on the discrimination of meaningless syllables using a presentation level of 55dB HL from data obtained by French and Steinberg, 1947 (Palva, 1965).
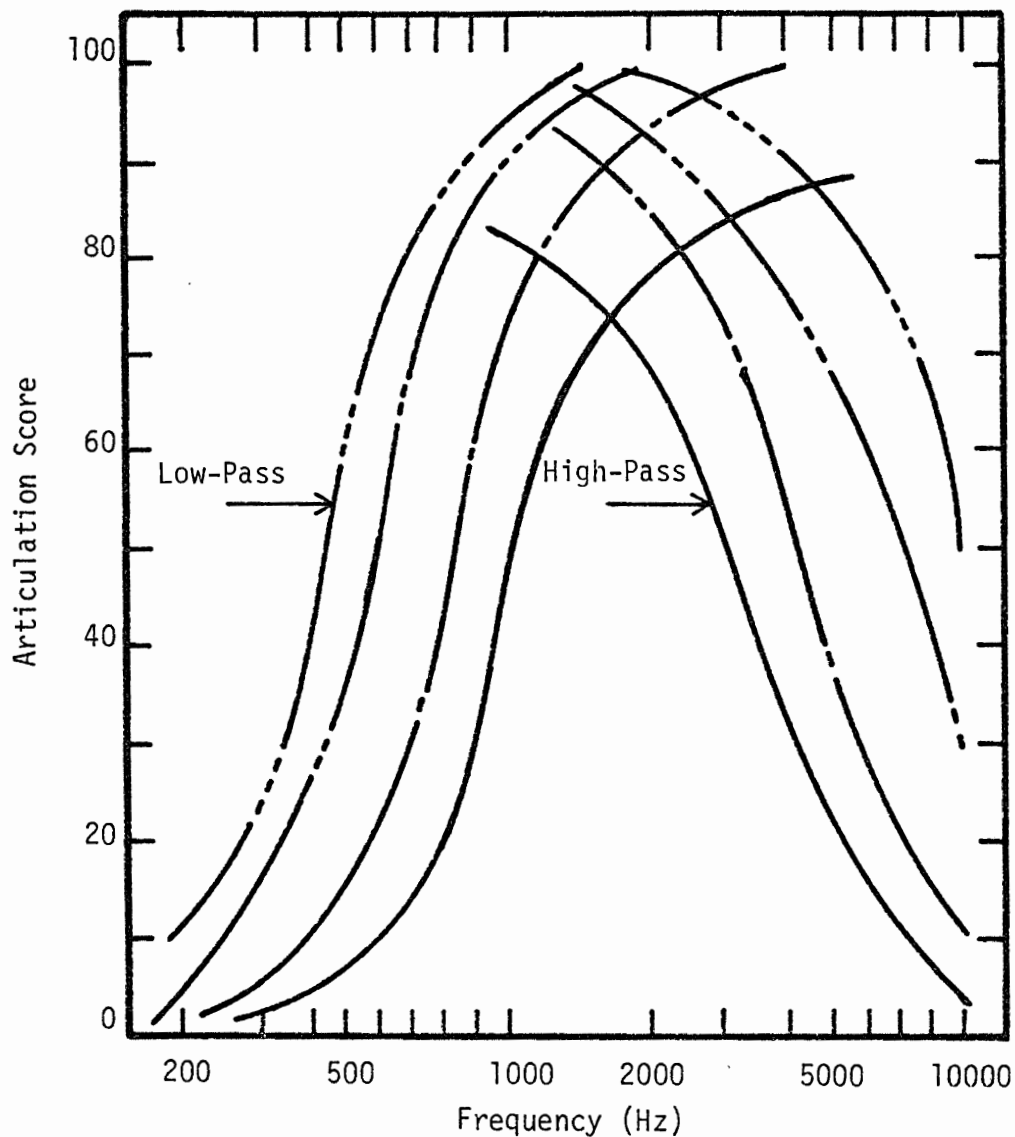
Figure 5. Idealized functions of the relations between articula-
tion score and the cut-off frequency for low- and high-pass
filtering. The solid lines refer to nonsense syllables, while the
broken lines refer to words, with the number of dashes in each
break indicating the number of syllables in each word. A fre-
quency rejection rate of 60dB/octave was used (Hirsh, et al.,
1954).

discrimination ability under varying filter conditions.

Owens (1961) investigated the effects of differences in word familiarity on intelligiblity under varying conditions of low-pass filtering. Normal hearing listeners were presented monosyllabic word lists which were distorted by means of low-pass filters with cut-off frequencies of 540-3120 Hz and rejection rate of 30dB/octave. A presentation level of 50dB above the detection threshold for each specific word list was utilized. In general, it was noted that when using low-pass filtering with cut-off frequencies between 780-2040 Hz, the difference in intelligibility between common words (39-94%) and less common words (9-64%) was most pronounced. When the distortion became severe, as in the 540 Hz low-pass condition, even familiar words were unintelligible (24%). Owens' observation that speech discrimination performance decreases as more of the high frequencies are filtered out is in agreement with the scores reported by both French and Steinberg (1947) and Hirsh, et al. (1954) in Table I.

Subsequent researchers have agreed that, in general, low-pass filtering causes significant decrements in speech discrimination performance as the range of speech frequencies is decreased for normal hearing listeners (Sanders and Goodrich, 1971; Wang, et al., 1978; LaCroix and Harris, 1979). Furthermore, there is growing evidence that acoustic cues at or above 2000 Hz are necessary for understanding speech, particularly when speech is made less redundant through filtering (Kryter, 1962a and b; Liden, 1967; Sher and Owens, 1974; Chari, et al., 1977; LaCroix and Harris, 1979; Skinner, 1980).

Narrow-band filtering of monosyllabic words seems to have

TABLE I

COMPARISON OF DISCRIMINATION SCORES OBTAINED FROM LOW-PASS (LP)
FILTERED MEANINGLESS SYLLABLES, MONOSYLLABIC WORDS
AND BOTH FAMILIAR AND UNFAMILIAR MONOSYLLABIC
WORDS (After Owens, 1961).

Cut-Off Frequency (Hz LP)	Discrimination Scores	Cut-Off Frequency (Hz LP)	Discrimination Scores
French and Steinberg (1947)		Owens (1961) - Unfamiliar Words	
1950	70%	2040	64%
1500	50%	1560	47%
1000	27%	960	21%
750	15%	780	9%
Hirsh, et al. (1954)		Owens (1961) - Familiar Words	
2000	90%	2040	94%
1500	80%	1560	85%
1000	63%	960	63%
700	50%	780	39%
500	20%	540	24%

undergone limited research. Kryter (1960) investigated monosyllabic word intelligibility with speech filtered through several band-pass filters of varying widths having a rejection rate of 70dB/octave. Table II shows the speech discrimination data obtained for several band-pass filter conditions having bandwidths of 500 Hz each as well as for various wider (1500-6900 Hz) band-pass filter conditions using a 55dB HL presentation level. It can be seen from Table II that speech discrimination ability varied as a function of the position of the center frequency for the 500 Hz band-pass conditions. As demonstrated by Hirsh, et al. (1954) and Wang, et al. (1978), the frequency region around 1500-1750 Hz appeared to contribute the most to speech intelligibility. Overall, Table II shows that the filter conditions having the wider bandwidths produced the highest discrimination scores, with the widest band-pass condition (100-7000 Hz) producing normal discrimination performance (95%). While the remaining three wide band-pass conditions contained the same number of frequencies (1500 Hz), discrimination performance decreased as the upper and lower cut-off frequencies increased.

In a study of the effects of narrow-band filtering on normal hearing listeners' monosyllabic word discrimination, Castle (1964) employed filters having center frequencies of 1080, 1560 and 1920 Hz and rejection rates of ≥30dB/octave. Normal speech discrimination performance (97-99%) was obtained when a bandwidth of 240 Hz centered at 1560 and 1920 Hz and a bandwidth of 480 Hz centered at 1080 Hz were employed using a single filter. However, Castle reported that when connecting more than one filter in series to achieve a greater frequency rejection rate, poorer performance resulted (approximately 52-78%) for the 240 and

TABLE II

A COMPARISON OF THE MEAN PERCENT CORRECT SCORES FOR MONOSYLLABIC WORDS
FILTERED THROUGH VARIOUS BANDPASS SYSTEMS HAVING A REJECTION
RATE OF 70dB/OCTAVE (After Kryter, 1960).

Center Frequency of 500 Hz Band-Pass Filter	Mean Percentage of Words Correct
250 Hz	13.00
750 Hz	32.00
1000 Hz	27.00
1250 Hz	31.00
1500 Hz	37.00
1750 Hz	36.00
2000 Hz	20.00

Upper and Lower Cut-Off Frequencies for Band-Pass Filter	Mean Percentage of Words Correct
100-7000 Hz	95.00
100-1600 Hz	65.00
500-2000 Hz	62.00
1000-2500 Hz	53.00

480 Hz band-pass conditions, regardless of the center frequency used.

Normal hearing listeners' perception of one-third octave band filtered speech was investigated by Chari, et al. (1977). These researchers filtered both meaningless syllables and monosyllabic words through one-third octave bands centered at 500, 1000, 2000, 3150 and 4000 Hz at a rejection rate of 50dB/octave. They reported no significant difference between syllable and word intelligibility and obtained maximum discrimination performance (50%) at the frequency band centered at 2000 Hz using a presentation level of 65dB HL. A comparison of the data obtained by these authors with data from the studies by Kryter (1960) and Castle (1964) may be seen in Figure 6. Chari, et al. noted that the peak in intelligibility at the one-third octave band centered at 2000 Hz was in agreement with Castle's data, as well as the scores reported by French and Steinberg (1947). Kryter, on the other hand, obtained reduced discrimination scores for the band centered at 2000 Hz. It was noted that the differences in scores between the data obtained by Chari, et al. and the scores reported by Kryter might have been due to the fact that Chari, et al. used fewer vowels in their word stimuli compared to Kryter.

Liden (1964) measured normal listeners' speech intelligibility for narrow-band filtered words at several intensity levels. Using a low frequency band-pass filter (560-715 Hz) with center frequency of 640 Hz, Liden found discrimination scores to be only 7-14% at low intensity levels (30-40dB HL). However, speech discrimination ability rose to 30-46% with increasing intensity (50-60dB HL). The intelligibility of speech through a high frequency band-pass filter (1800-2200 Hz) with center
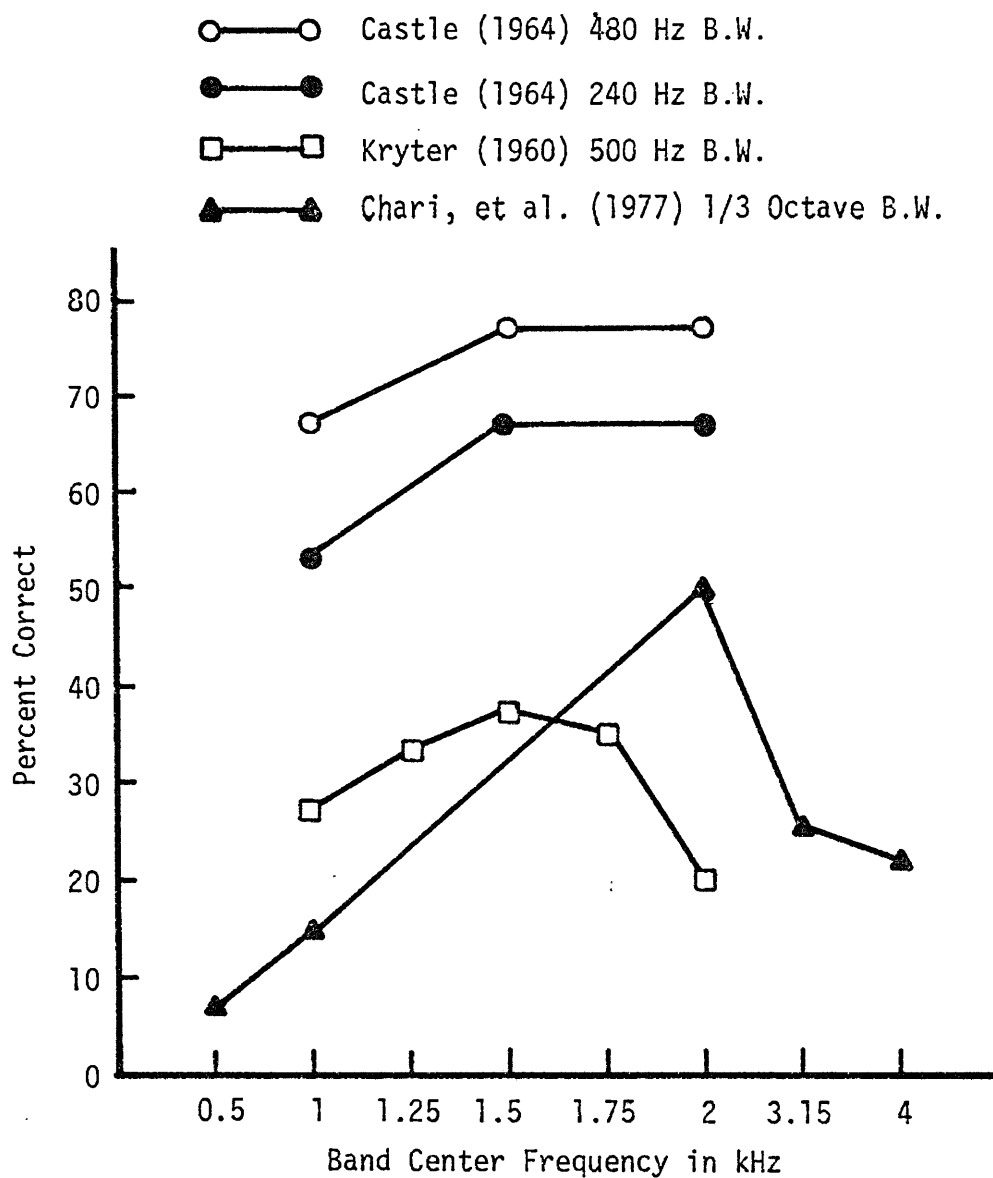
Figure 6. A comparative representation of intelligibility scores obtained utilizing narrow-band filtering (After Chari, et al., 1977).

frequency of 2000 Hz also revealed a steady increase in discrimination scores with rising intensity. Liden reported a wide range of speech discrimination scores as a function of intensity for the low frequency band-pass condition (7-46%), while comparatively little overall variation in performance was noted in the high frequency band-pass condition (4-21%). It is interesting to note that the scores obtained for the 60dB HL intensity level using the 2000 Hz band-pass filter (22%) were similar to those reported by Kryter (1960), who used a presentation level of 55dB HL.

In a much earlier study, Pollack (1948) observed that at high intensity levels, speech intelligibility was better when frequencies below 350 Hz were omitted. Pollack explained that at weak intensity levels, low frequencies add to the overall power of the words thereby making speech audible, whereas at high intensities, the strong low frequencies mask the weaker high frequency sounds.

A classic study by Bocca, et al. (1954) was possibly the earliest investigation utilizing filtered speech to identify the presence of a central auditory disorder. These investigators used low-pass filtered disyllabic words with a cut-off frequency of 800 Hz. Results consistent with a follow-up study (Bocca, et al., 1955) demonstrated that normal subjects revealed similar scores of approximately 60-80% for each ear. However, patients with confirmed temporal lobe lesions demonstrated a substantial reduction in discrimination ability in the ear contralateral to the lesion in comparison to the normal subjects (Figure 7). Subsequently, other investigators have also reported considerably lower discrimination scores (by approximately 12-20%) in the ear opposite the
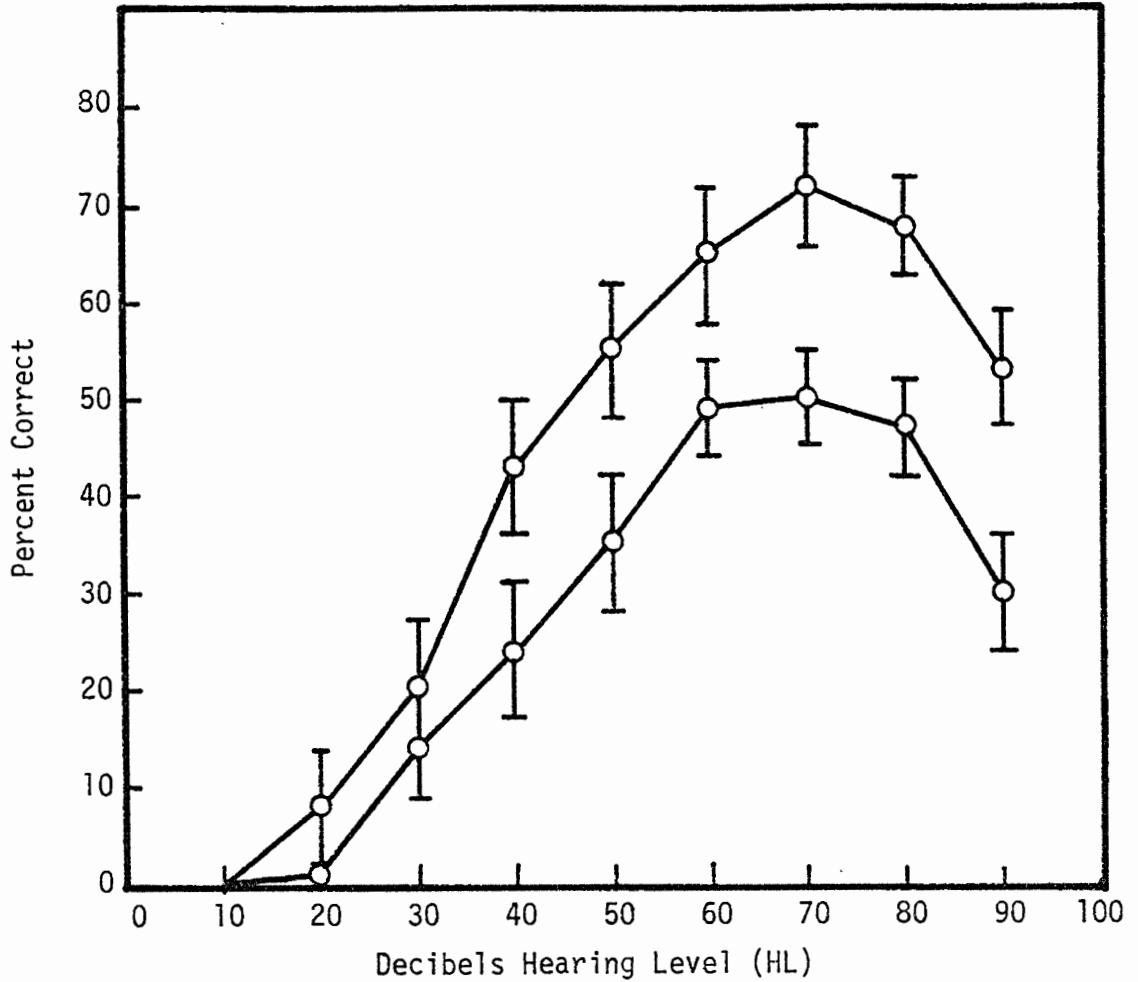
Figure 7. Average discrimination scores for filtered voice (words or short sentences) in the homolateral ear (upper curve) and con-tralateral ear (lower curve) for persons with temporal lobe lesions, taken from data obtained by Bocca, et al., 1954. Vertical lines indicate statistical variability (Bocca and Calearo, 1963).

affected side when presenting monaural low-pass filtered speech to
patients manifesting central auditory lesions (Jerger, 1960 and 1964;
Bocca, 1967; Hodgson, 1967). Further, Lidén (1964) observed similar
results when using two different band-pass filtered conditions (560-
715 Hz and 1800-2200 Hz).

Welsh, et al. (1969) investigated the effects of aging on the per-
ception of filtered speech. A high-pass filter with a 2160 Hz cut-off
frequency and a low-pass filter with a cut-off frequency of 540 Hz, both
having a rejection rate of 60dB/octave, were utilized to create distor-
tion in monosyllabic words. At a presentation level of 70dB above the
threshold for unfiltered speech, the scores for young normal hearing
listeners (30.9%) were slightly better than those for elderly normal
hearing subjects (27.4%) in the high-pass filtered condition. This
difference, however, was not statistically significant. Both groups'
discrimination scores were poorer for the low-pass filtered condition
than for the high-pass condition, however, the performance for the
younger subjects (24.3%) was significantly better than that of the aged
subjects (11.8%). Previously, Kirikae, et al. (1964) also found a sig-
nificant reduction in discrimination ability (by approximately 15%) in
aged listeners than for younger subjects when presenting low-pass fil-
tered words at a cut-off frequency of 1200 Hz and sensation levels of
40-80dB.

Aging listeners have even been reported to demonstrate reduced
speech discrimination utilizing unfiltered speech materials (Willeford,
1971). This reduction in speech discrimination performance has been
attributed to the normal neural degeneration known to occur throughout

the auditory system with the aging process (Schuknecht, 1974; Gang, 1976; Jerger and Jerger, 1976). Thus, this loss of intrinsic redundancy associated with aging creates a compounding effect when combined with the loss of extrinsic redundancy through acoustic filtering.

The wide variations in filtered speech discrimination scores reported throughout the literature may well be attributed to the age differences in experimental populations, differing intensity levels, as well as variations in filter cut-off frequencies and rejection rates employed by individual researchers. In general, speech discrimination ability has been reported to decrease progressively as more high frequencies are eliminated from the speech spectrum through acoustic filtering (Owens, 1961; Wang, et al., 1978; LaCroix and Harris, 1979). In fact, acoustic information at or above 2000 Hz appears to be necessary for speech intelligibility (Liden, 1967; Sher and Owens, 1974; LaCroix and Harris, 1979; Skinner, 1980). When speech is distorted through narrow-band filtering, the speech discrimination performance by normal hearing listeners is significantly reduced (Kryter, 1960; Chari, et al., 1977). These low performance scores by normal listeners often preclude meaningful comparisons with scores obtained from hearing impaired individuals. While gross comparisons have been made between the speech discrimination performance of normal hearing persons and individuals with retrocochlear disorders, no standard method for identifying various retrocochlear pathologies has been proposed. As a result, filtered speech tests have not been widely accepted among clinical audiologists. Consequently, researchers have focused on other means, such as intensity distortion, in an effort to develop predictive tests for

persons with suspected retrocochlear lesions.

Intensity Distortion

Another method of experimentally degrading speech that has shown promise in determining neural lesions is loudness degradation (Palva, 1965; Lundborg, et al., 1975). With loudness degradation, the physical intensity of the signal is increased to a point where external redundancy becomes reduced. Further increases in intensity will continue to reduce the external redundancy of the speech stimuli. Persons manifesting lesions of the central auditory pathways are much more sensitive to breakdowns in the external redundancy of speech resulting from increases in intensity. This breakdown is evidenced by a reduction in speech discrimination ability at even moderately high (80-90dB HL) intensity levels (Jerger, et al., 1966; Jerger and Jerger, 1971).

A procedure for the measurement of speech discrimination ability as a function of increased intensity has been described by Jerger and Jerger (1967 and 1968). Speech stimuli consisted of lists of 50 monosyllabic words of high familiarity, containing an equal representation of all the phonemes (speech sounds) of the English language. These 50-word lists were presented in 5-20dB increments starting at an intensity level as low as 0dB HL and extending to 100dB HL. This performance-intensity (PI) function test procedure has since undergone slight modifications. For instance, Jerger and Jerger (1971) presented half-lists (25 words) in 10-20dB increments starting from that intensity level yielding a discrimination score of approximately 20% and continuing to a maximum intensity level of 90dB HL. Other investigators have utilized intensity increments as small as 4-6dB and varying intensity ranges

(Schultz and Streepy, 1967; Gang, 1976; Dirks, et al., 1977). Addition-
ally, investigators have employed different lists of monosyllabic words
in their PI test procedures, however, all the lists have been reported
to contain phonetically balanced (PB) words.

Performance-intensity function (PIPB) testing has proven to be a
valuable tool in the differentiation of cochlear (peripheral) and retro-
cochlear (central) disorders (Jerger, et al., 1966; Jerger and Jerger,
1967, 1971, 1974a and 1975; Dirks, et al., 1977; Jerger and Hayes, 1977).
That is, after reaching a maximum speech discrimination score (PB max),
further increases in the intensity of the speech stimuli produce a
marked reduction ("rollover") in speech discrimination ability. In the
normal ear, increases in the loudness of speech do not impair perform-
ance on speech discrimination tasks (Jerger and Jerger, 1967; Schultz
and Streepy, 1967; Dirks, et al., 1977). However, individuals with
cochlear hearing losses may exhibit mild rollover (Jerger and Jerger,
1967, 1971 and 1974a; Dirks, et al., 1977), or in some instances, even
significant rollover, comparable to that of persons with retrocochlear
disorders (Dirks, et al, 1977). A comparison of performance-intensity
(PIPB) test scores for persons with normal hearing, cochlear hearing
loss and retrocochlear impairment may be seen in Figure 8.

Jerger and Jerger (1971) compared the performance-intensity func-
tions (PIPB) of subjects with cochlear and retrocochlear disorders. In
general, their results revealed little or no rollover (approximately
0-30%) in cochlear disorders, pronounced rollover (approximately 30-68%)
in all eighth nerve disorders and varied degrees of rollover (0-65%) in
temporal lobe and brainstem disorders in the ear contralateral to the
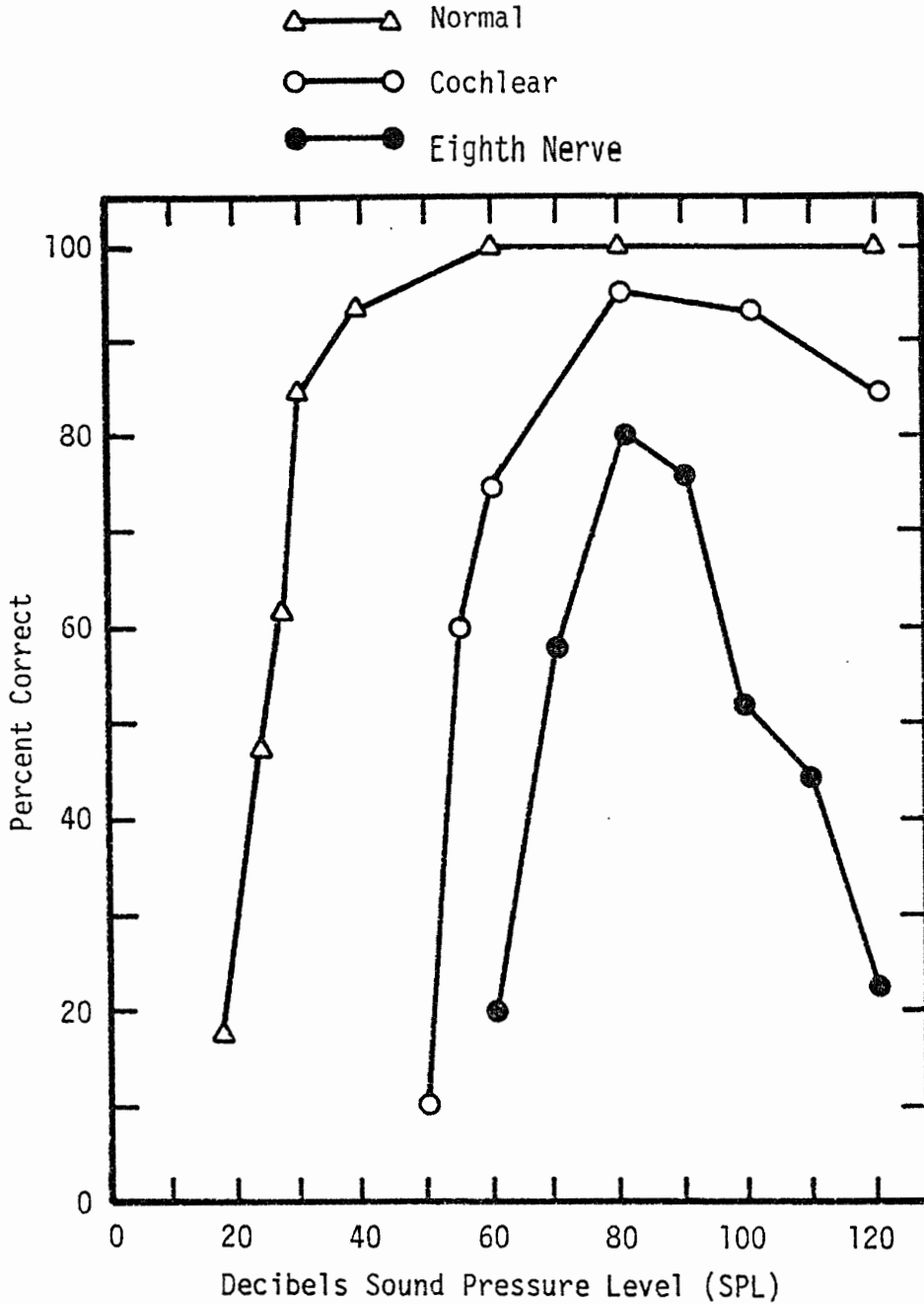
Figure 8. Performance-intensity (PI) functions for PB-50 word
lists for persons with normal hearing, cochlear hearing loss and
eighth nerve damage (Jerger and Jerger, 1976).

affected side. According to these investigators, approximately 70-80%
of eighth nerve disorders will demonstrate significant rollover.

In an investigation of 16 patients with brainstem lesions, roll-
over of 24-64% was observed by Jerger and Jerger (1974b). Subsequently,
Jerger and Jerger (1975) compared PIPB scores for cochlear versus retro-
cochlear disorders and proposed that a reduction in discrimination abili-
ty in excess of 30% from the maximum discrimination score (PB max) for
standardized word lists suggests a neural site of lesion. For example,
a person who obtained an 85% discrimination score at 65dB HL would be
diagnosed as having a neural lesion if his speech discrimination fell
below 55% at any subsequent presentation level above 65dB HL. Thus, the
amount of rollover was determined by subtracting the lowest speech dis-
crimination score obtained at an intensity above the optimum speech dis-
crimination performance (PB min) from the PB max score.

Another method of quantifying the magnitude of the rollover phenom-
enon was proposed by Jerger and Jerger (1971). They constructed a for-
mula in which each rollover score (PB max-PB min) was divided by the
PB max performance. The resulting rollover index eliminated the biasing
effect of differing PB max scores in determining rollover and created a
sharper delineation between rollover effects of cochlear and eighth
nerve hearing losses. Indices of 0.40 or less indicated a cochlear site
of lesion, whereas the lowest eighth nerve index was found to be 0.45.
This formula, however, did not appear to eliminate the overlap in scores
between these two groups and brainstem pathologies.

While the experimental use of performance-intensity function (PIPB)
testing has proven to be a valuable tool in the isolation of advanced

retrocochlear pathologies, several limitations have been noted in its clinical application. The most obvious limitation lies in PIPB test administration. Of critical importance to the estimation of PB max is the selection of an appropriate presentation level. It is evident that to plot an entire articulation curve for each patient would be extremely time-consuming for regular clinical purposes. While several investigators have recommended a single intensity level for establishing high word intelligibility for most patients, the lack of agreement concerning a specific intensity level has left clinicians with no standard method for measuring PB max (Carhart, 1965; Schultz and Streepy, 1967; Tillman and Olsen, 1973; Geffner and Donovan, 1974). Furthermore, when encountering a variety of clinical patients, the determination of PB max for all or even the majority of cases at any one presentation level could lead to underestimation of PB max (Jerger and Jerger, 1974a; Dirks, et al., 1977; Orchik, et al., 1979).

Additional considerations regarding PIPB testing have arisen from investigation of the PB words themselves. Carhart (1965) compared speech discrimination scores as a function of intensity for normal hearing listeners for two different voice recordings of the same PB word lists. It was noted that the intensity level required to produce PB max performance for the two recordings differed by 15dB. Thus, it appears that such variables as the characteristics of the speaker's voice and quality of the recordings may influence speech discrimination performance and alter the PIPB function (Carhart, 1965; Dirks, et al., 1977; Orchik, et al., 1979). Further, with the use of different PB word lists among clinics, it has been suggested that both the PB max score

and the slope of the rollover function may vary (Dirks, et al., 1977).

Audiometric configuration and degree of hearing loss have also been reported to play a significant role in PB word intelligibility (Liden, 1967; Geffner and Donovan, 1974; Bilger and Wang, 1976; Jerger and Jerger, 1976b). Investigating the role of varying audiometric configurations, Geffner and Donovan (1974) reported that subjects with severe high frequency hearing losses demonstrated depressed performance scores. Similarly, Liden (1967) demonstrated that speech discrimination becomes progressively worse as the extent of high frequency hearing loss increases beyond 2000 Hz. Thus, there appears to be a dependence of PB word discrimination on high frequency hearing sensitivity.

It has found that the frequency of occurrence and the magnitude of rollover are greater in an aged population than in a general clinic population (Jerger and Jerger, 1971; Gang, 1976; Shirinian and Arnst, 1980). Some researchers reason that abnormal rollover in the aged supports the diagnostic significance of the rollover phenomenon. That is, since diagnostic auditory tests identify the site of lesion, elderly patients may show substantial rollover due to the partial eighth nerve degeneration associated with aging (Jerger and Jerger, 1976a; Dirks, et al., 1977). Gang (1976), however, reported that elderly subjects manifesting substantial rollover in speech discrimination ability failed to demonstrate positive findings on other diagnostic tests for eighth nerve degeneration. Hence, Gang concluded that the substantial rollover effects observed among aged listeners constituted a significant limitation in the diagnostic value of the rollover test for the elderly population.

The predictive accuracy of the rollover index for differentiating between cochlear and retrocochlear disorders appears to be positively related to the developmental stage of the retrocochlear pathology. Jerger, et al. (1974) observed fewer retrocochlear signs on auditory tests for patients whose acoustic tumors were detected at a very early stage than for those with larger tumors detected at more advanced stages. A subsequent investigation revealed that patients with well-developed retrocochlear tumors appear to provide an optimal condition for measuring significant rollover (Dirks, et al., 1977).

It appears that presently available narrow band-pass filtered and intensity distorted speech tests, intended to identify retrocochlear pathologies, have enjoyed only questionable predictive accuracy. Problems surrounding depressed normative data and/or considerable overlap between various pathological performances continues to plague research in this area. Since neither narrow band-pass filtered or intensity distorted speech tests alone appear to be particularly sensitive to the early detection of retrocochlear lesions, a combination method is proposed.

The present study proposes that by enhancing (augmenting) only the intensity of one-third octave band filtered portions of word stimuli, a speech signal could be sufficiently degraded in order to preclude a perfect speech discrimination score by normal hearing listeners. Such a speech discrimination task would likely be more sensitive to the subtle signs associated with retrocochlear lesions, since these lesions would be manifested by a departure from the mean performance of normal hearing listeners.

Further, it is reasoned that by augmenting (enhancing) the intensity of one-third octave discreet frequency bands within the word stimuli, an examination of components contributing to loudness degradation may be made. It is hypothesized that the breakdown in speech discrimination ability noted in individuals with neural hearing disorders may be the result of harmonic (specific frequency) distortion created when speech is presented at very intense levels. While previous investigators have employed phonetically balanced word lists in performance-intensity function testing, the relative contribution of different speech sounds within the words to the rollover phenomenon is not well known. Since it is unknown whether the suggested distortion component is high frequency (consonant) or low frequency (vowel) in nature, each possibility should be examined.

Recently, Maurer, et al. (1981) employed one-third octave band-pass augmentation to monosyllabic word lists in an effort to examine the effects of frequency-specific auditory augmentation. These authors observed large standard deviations in the performance of normal hearing listeners under low band-pass (500 Hz) augmentation. While decidedly smaller standard deviations were noted in the high frequency band-pass (3150 Hz) augmented listening condition, there was no significant relationship between the intensity of the augmentation and speech discrimination ability. Further, these authors observed a significant order effect, causing discrimination scores to improve as a function of the presentation order of augmented material. These authors concluded that more research was needed in order to overcome the artifact of order and to define the optimal presentation intensity level for augmented

speech discrimination testing.

Since there is no historic precedence for this type of augmented speech discrimination test in the reported literature, it is necessary to establish normative data as a first step toward standardization of this test. Once such norms are well defined, it will be possible to make diagnostic inferences when persons with suspected retrocochlear lesions perform poorly on augmented discrimination tasks.

PURPOSE

The purpose of this study was to investigate the speech discrimination ability of normal hearing listeners in response to speech stimuli which have been separately augmented at two selected one-third octave filter bands and presented at varying intensity levels.

The question was three-fold:

1) What effect does a 500 Hz one-third octave band augmentation have on speech discrimination ability for normal hearing listeners?

2) What effect does a 3150 Hz one-third octave band augmentation have on speech discrimination ability for normal hearing listeners?

3) How is the speech discrimination ability of normal hearing listeners affected by variation in intensity presentation levels of a one-third octave band augmentation centered at 500 Hz compared to a one-third octave band augmentation centered at 3150 Hz?

CHAPTER III

METHODS

Subjects

Thirty-six normal hearing subjects between the ages of 19-29 years
were selected from the student population at Portland State University.
No subject was used in this study who reported a familial history of
deafness, positive record of ear disease or manifested any abnormal
auditory processing difficulty. All subjects utilized in this study had
normal hearing as measured by standard air conducted pure tone and
speech testing procedures. Each subject had an auditory sensitivity
within 15dB of audiometric zero (ANSI, 1969) for the test ear at octave
test frequencies of 0.25 through 8.0 kHz and an interaural difference no
greater than 15dB HL at any test frequency. Further, the speech recep-
tion threshold by air conduction was within 10dB HL of the average pure
tone threshold for each ear. Strict attention was given to good speech
discrimination ability (90% or better) in both the test and nontest ears.

Procedure

All potential subjects were given an audiological assessment util-
izing standard clinical procedures. Each subject was queried regarding
any familial history of deafness or positive record of ear disease prior
to any testing to confirm his or her eligibility for this investigation.
Only one ear per subject was used for the experimental test conditions.
The selection of a right or left test ear was determined randomly by

flipping a coin to determine whether the right or left ear would be used for subject #1; thereafter, the ear used followed an alternate pattern. Thus, an equal number of right and left ears was used. Each of the subjects was assigned an individual number to maintain anonymity for all experimental data collected.

The subjects wore earphones while seated in a double-walled suite and instructed to write down each recorded word exactly as they heard it. In the event that a subject was uncertain of a word, he or she was encouraged to guess. Subjects were provided with answer sheets for their written responses. To prevent the possible intervening effects of a temporary threshold shift, a minimum two minute rest period was given between each test condition. The written responses constituted the raw data by which total percentage correct responses were determined for each experimental condition.

In order to insure that the experimental data reflected only the test ear responses, contralateral masking was employed during all listening conditions. Wide band masking noise, which has a spectral composition similar to speech, was presented to the nontest ear at a level 20dB below the test ear stimuli.

Speech discrimination test materials consisted of recorded mono-syllabic word lists (Campbell, 1965). Each subject was presented three 50-word lists, one was augmented at a one-third octave band-pass with center frequency of 500 Hz, another was augmented at a one-third octave band-pass with center frequency of 3150 Hz and a third was augmented unfiltered. Under each one-third octave band pass listening condition, the left channel output (unfiltered word) was set at a sensation

level of 45dB above each subject's speech reception threshold, while the output from the right channel (the augmented only portion of the word) was delivered at a level between 5-55dB above the level of the unfiltered word in the left channel. The sensation level of the augmented version of the words was selected using the following criteria: 1) the sensation level could not be louder than 5dB below a subject's uncomfortable listening level, 2) only sensation levels of 5, 15, 25, 35, 45 or 55dB above the unfiltered word level were selected and 3) exactly six subjects were presented with test material at each sensation level so that if one level had reached quota, a lower level was chosen. These criteria assured an equal number of experimental conditions at each sensation level.

These two intensity disparate signals were fed to the same ear by delivering the output from the right and left channels simultaneously into one earphone. The third word list (augmented unfiltered) served as the control and was delivered through both channels at the same sensation levels as the filtered augmented words in the other two experimental conditions. All testing and data were expressed in the numerical value of the intensity dials even though mixing right and left channels produced slightly less (approximately 10dB) sound pressure level (SPL) output.

The intensity disparity levels for this investigation were selected after reviewing the findings of a previous augmented speech study utilizing a sample of 28 normal hearing listeners (Maurer, et al., 1981). It was found that a sensation level of 45dB re speech reception threshold was most often chosen as a comfortable listening level for

unfiltered, unaugmented speech. Further, a wide range of scores and standard deviations were obtained utilizing augmentation at disparity levels of 25-55dB above the unfiltered word level. Therefore, it seemed propitious to examine the intelligibility function created when the augmented portion of the words was presented: 1) at an intensity level slightly above (5dB) the level of the unfiltered words, 2) at a level widely disparate with the unfiltered words and 3) at several intensity increments between these two extremes. Since a possible "rollover" in discrimination ability with increased intensity was suspected, sensation levels between 5-55dB above the unfiltered word level were delivered at 10dB increments. In addition, it was reasoned that by examining the resulting articulation function, an optimum sensation level for augmented speech discrimination testing for normal hearing listeners might be obtained.

The presentation order of the three experimental conditions (two filtered augmentations and one unfiltered augmentation) was predetermined such that each experimental condition was presented an equal number of times in all three positions for each listening level. The order of presentation was determined in a random fashion by rolling a die.

In order to avoid the practice effects created by the adaptation to a novel listening task, the adaptation to loud suprathreshold stimuli and the adjustment to a written response mode, five practice words preceded each 50-word list. Each of the three 50-word lists were preceded by a different set of practice items which were augmented according to the experimental condition they preceded. In addition, each practice word was followed by its unaugmented version in order to provide the

subject with immediate feedback. Further, a brief set of recorded
instructions was included before each experimental condition.

Instrumentation

A stimulus tape was recorded on a stereo cassette recorder. The
speech stimuli consisted of two 25 monosyllabic word lists (lists N and
P; Campbell, 1965), which exhibit high "parallel forms" reliability with
respect to discrimination difficulty (Adam, 1978). In addition, these
two word lists have demonstrated a high interlist correlation with res-
pect to phonemic content and word familiarity (Campbell, 1965). That
is, a listener should obtain the same speech discrimination score with
either list, regardless of the presentation mode.

In order to avoid the learning effect created by a serial pre-
sentation of the same word list for three experimental conditions, the
two 25-word lists were combined and the 50 words were randomly ordered
three times by means of a table of random numbers (Freund, 1973). The
three randomly ordered 50-word lists were spoken by a male with a gener-
al American dialect through the microphones of a dual channel audiometer
(Maico, Model MA 24B). The output from the right channel to the audio-
meter was fed through a one-third octave filter (Bruel and Kjaer, Model
1616) with a rejection rate of 50dB/octave, where only the selected
frequency band was fed to the right channel of a stereo cassette record-
er (Hitachi, Model D 90-S). The output from the left channel of the
audiometer was fed through directly to the left channel of the cassette
recorder without filtering. See Figure 9. Thus, the stereo cassette
tape contained an unfiltered version of each word on the left channel,
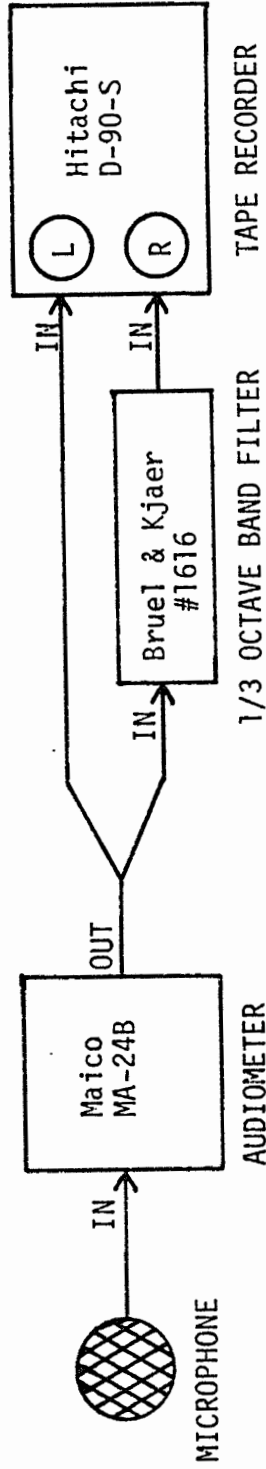coincident with the one-third octave spectral information recorded on

Figure 9. Schematic for recording one-third octave band augmentation.

the right channel. This master tape recording was made utilizing a high
bias (70 μsec), low noise metal tape (Maxell, MX C-60). For each of
the augmented test conditions, the right and left channels were always
delivered to the same ear simultaneously, resulting in an augmented
presentation.

This two channel recording technique allowed independent manipula-
tion of the intensity relationship between the word and its one-third
octave augmentation component. For the unfiltered augmented test con-
dition, the stimulus words were recorded through the audiometer directly
onto both channels of the stereo cassette tape recorder, bypassing the
one-third octave filter. Right and left channels containing this unfil-
tered augmented word list were also delivered simultaneously to the same
ear.

The three experimental conditions were rerecorded six times by
means of a second cassette recorder (Technics, Model RS-263AUS) and a
low noise, high bias tape (Maxell, UDXL II C-90). This allowed all
possible combinations of presentation order for each experimental con-
dition.

The stereo cassette tape output (Technics, Model RS-263AUS) was
jacked into a dual channel audiometer (Maico, Model MA 25B) such that
the right channel controlled the output from the right channel of the
cassette recorder and the left channel controlled the output from the
left channel of the cassette recorder. The output from the audiometer
was patched through a double-walled acoustic suite (Industrial Acoustics
Company, Model 1403) to the test ear via a single earphone from a pair
of standard audiometric headphones (Telephonics, Model TDH 39) mounted

in foam rubber cushions (Acoustic Research, Model MX 41). The second earphone delivered wide band masking noise from a masking generator (Beltone, Model NB 102) to the nontest ear.

Calibration

The output at the earphones for both right and left channels of the audiometer was electro-acoustically calibrated prior to each experimental testing session to reflect the current ANSI (1969) standards using a precision sound level meter (Bruel and Kjaer, Model 2203) and an artificial ear (Bruel and Kjaer, Model 4152). A prerecorded segment of speech spectrum calibration noise was utilized to calibrate the speech circuit. In addition, a speech spectrum calibration signal preceded each recorded experimental condition to allow VU monitor adjustments prior to the presentation of each word list.

CHAPTER IV

RESULTS

The purpose of this study was to investigate the effects of a
500 Hz and 3150 Hz one-third octave band augmentation on the speech
discrimination ability of normal hearing listeners and whether such
effects vary with signal presentation level. Data was collected and
analyzed for subject responses to monosyllabic words at six signal
intensity disparity levels. The augmented portion of the word was
systematically varied from 5-55dB above the intensity level of the un-
filtered version of the word. Each subject also listened to an unfil-
tered augmented version of the task at a predetermined disparity level
in order to provide a nonfiltered comparison score.

The raw performance data (percent correct scores) for each of the
three augmented listening conditions were tabulated and analyzed using
an Analysis of Variance, Two-Factor Mixed Design for Repeated Measures
on One Factor (Bruning and Kintz, 1977). The results of this analysis
revealed that: 1) intensity disparity level significantly affected the
overall performance scores (p<.001), 2) subjects' speech discrimination
performance varied significantly as a function of type of augmentation
(p<.001) and 3) there was a significant interaction effect between the
intensity disparity level and type of augmentation on speech discrimina-
tion ability (p<.001). Further analysis was performed in order to deter-
mine the nature of the interactions between augmentation and disparity

level on speech discrimination performance.

Speech discrimination data for the 500 Hz augmented listening condition indicated that optimum performance (96%) was obtained when the augmented portion of the word was 5dB louder than the unfiltered counterpart, or at a 5dB disparity level. Table III reveals that as the disparity level increases, discrimination ability decreases (rolls-over) to a minimum of 50% at the 55dB disparity level. While the percent performance differences between successively increasing disparity levels appear in several instances to be significant, the Scheffe post hoc test for differences between means indicated that only the performance difference between the 25dB and 35dB disparity levels was statistically significant (p<.05). Statistical significance (p<.05) was also found between the lowest disparity level (5dB) and the disparity levels of 35dB and greater. The lack of statistical significance between successively increasing disparity levels is probably best accounted for by the large standard deviations in four of the six presentation levels.

The 3150 Hz augmentation data indicated that the optimum performance (97%) occurred at the 25dB disparity level (Table III). A reduction in speech discrimination ability at successively smaller as well at successively larger disparity levels from the 25dB level was observed. A similar variation in the standard deviations for the mean performances was also noted on both sides of the 25dB disparity level, that is, standard deviations increased both above and below this disparity level. However, these differences in mean performance were not found to be statistically significant. All mean performance scores for the 3150 Hz augmented listening condition, with the exception of the 55dB disparity

TABLE III

A COMPARISON OF THE MEAN PERCENT CORRECT SCORES AND STANDARD DEVIATIONS
FOR THE 500 Hz, 3150 Hz AND UNFILTERED AUGMENTED
EXPERIMENTAL CONDITIONS AT EACH OF THE
SIX DIFFERENT INTENSITY
PRESENTATION LEVELS

Augmented Listening Condition	Percentage of Words Correct	*Disparity Level in dB HL					
		5	15	25	35	45	55
500 Hz 1/3 octave band-pass	$\overline{X}$	96.00	89.33	89.67	69.33	64.00	50.00
	S.D.	2.53	17.50	4.08	13.49	19.92	19.72
3150 Hz 1/3 octave band-pass	$\overline{X}$	94.67	96.67	97.00	96.00	91.00	88.67
	S.D.	4.32	3.01	2.45	4.29	5.76	6.65
Unfiltered	$\overline{X}$	97.76	99.67	98.00	96.33	97.00	93.67
	S.D.	2.34	0.82	3.10	4.27	3.29	1.97

* For each listening condition, the words were presented at two
separate intensity levels simultaneously, such that the unfiltered
portion of the words was delivered at 45dB above the subjects'
speech reception thresholds and the augmented portion of the words
was delivered at one of the experimental intensity disparity levels.

presentation level, fell within the range of normal speech discrimination ability of 90-100% (Goetzinger, 1978).

The unfiltered augmented performance data fell within the normal limits for speech discrimination ability across all disparity levels (Table III). No systematic variation in either the mean performance scores or standard deviations was observed across the experimental disparity levels. Further, there were no statistically significant differences found between the mean performance scores at any two intensity disparity levels for this listening condition.

A comparison of the three augmented listening conditions revealed that when the disparity level between the word and its augmented portion was slight (5dB), there appeared to be very little difference in discrimination ability regardless of the frequency of the augmentation. However, the t test for correlated means did reveal a statistically significant difference between the unfiltered augmentation and both the 500 Hz and 3150 Hz one-third octave band augmentation scores at the 5dB disparity level (p<.025 and p<.05, respectively). With disparity levels of 35dB and greater, there was a significant difference between the 500 Hz augmented condition and both the 3150 Hz and unfiltered augmented conditions. For each of the three highest disparity levels, 35, 45 and 55dB, the 500 Hz augmented list produced significantly poorer discrimination performances (p<.005). In addition, a statistically significant difference was found between mean performances for the 500 Hz and unfiltered augmented conditions at the 25dB disparity level (p<.005).

A statistically significant difference between discrimination scores at the 15dB disparity level was revealed only when comparing the

3150 Hz and unfiltered augmented listening conditions (p<.025).
Significant mean performance differences were also found at the 45dB
(p<.025) and 55dB (p<.05) disparity levels between the 3150 Hz and
unfiltered augmentation data.

Table IV lists the mean performance scores and standard deviations
according to order of presentation for each augmented listening condi-
tion. Although each experimental condition was presented an equal num-
ber of times in the first, second and third positions, a systematic
order effect was observed for the 3150 Hz augmentation. The discrimina-
tion performance for this condition varied significantly between the
first and third positions (p<.005) as well as between the second and
third positions (p<.05). No statistical significance was found in the
difference between the mean performances for the first and second
positions. A systematic order effect was not observed for either the
500 Hz or unfiltered augmented conditions.

TABLE IV

THE MEAN PERCENT CORRECT SCORES AND STANDARD DEVIATIONS ACCORDING
TO ORDER OF PRESENTATION FOR EACH OF THE THREE
AUGMENTED EXPERIMENTAL CONDITIONS

Presentation Position	Percentage of Words Correct	500 Hz 1/3 Octave Band-Pass	3150 Hz 1/3 Octave Band-Pass	Unfiltered
First	$\overline{X}$	71.83	91.33	96.67
	S.D.	28.24	4.85	2.99
Second	$\overline{X}$	81.17	93.50	98.17
	S.D.	16.76	5.54	3.13
Third	$\overline{X}$	76.17	97.17	96.33
	S.D.	18.79	4.13	3.50

CHAPTER V

DISCUSSION AND CONCLUSIONS

The results from the present study indicate that in a population of young normal hearing listeners, the one-third octave band augmentation of speech test material is sufficient to preclude a 100% speech discrimination performance. While the high frequency augmented condition (3150 Hz) produced performance scores within or near the normal range of speech discrimination ability (90-100%), the mean data indicated that a perfect score would not be expected in a normal hearing population, regardless of intensity presentation level. On the other hand, the low frequency (500 Hz) augmented condition demonstrated a significant rollover in discrimination ability with increasing presentation levels. This rollover phenomenon associated with the 500 Hz augmented condition was statistically significant only at the 35dB disparity level and above. Therefore, the diagnostic value of these presentation levels (35, 45 and 55dB) is questionable, especially given the large standard deviations obtained at each of these levels.

Disregarding the 5dB disparity level for the 500 Hz augmented condition, the 25dB disparity presentation level for both the 500 Hz and the 3150 Hz augmented conditions appears to be an optimum balance between loudness distortion and the distortion created by the filtered augmentation. That is, the mean performance scores for the two filtered augmented listening conditions at the 25dB level represented high

discrimination performance while still employing a substantial amount of frequency augmentation. The desirability of the 25dB disparity level is further supported by the fact that low standard deviations were observed under both filtered conditions. Therefore, a 25dB intensity disparity level would seem to have the greatest utility in a clinical situation, since a small deviation from the normative data would have the greatest likelihood of indicating pathology in the listener. Additionally, this presentation level would offer greater flexibility than higher disparity levels in terms of usable presentation levels on most clinical audiometers.

The generally small standard deviations noted for the mean performance scores across all intensity disparity levels for the 3150 Hz augmentation data suggest that this condition may be potentially significant for diagnosing central auditory disorders. That is, the sensitivity of this augmented word list to slight variations in speech discrimination performance should enhance the identification of subtle discrimination changes associated with early developing retrocochlear lesions.

The present investigation also reveals that the highest speech discrimination performance scores were obtained in the unfiltered augmented condition. Under this condition, normal hearing listeners obtained very high (94-100%) discrimination scores across all intensity presentation levels. The data suggest that this listening condition does not sufficiently tax the auditory pathways of persons with normal hearing.

Since the major variable in the unfiltered augmented condition was intensity, it could be reasoned from the present data that intensity

alone may not be the significant parameter in the rollover phenomenon. Rather, it may be inferred that the reduced discrimination scores observed in the filtered augmented conditions were the result of the combination of frequency and intensity distortion, with frequency playing the dominant role. Further, since the 500 Hz augmentation produced the poorest discrimination performance across all presentation levels (except at the 5dB disparity level), the low frequency distortion component appears to have a more deleterious effect on speech discrimination ability. This observation is consistent with upward spread of masking theories, where higher frequency speech components are masked by their louder low frequency counterparts (Wegel and Lane, 1924; Pollack, 1948; Bess and Townsend, 1977). While the upward spread of masking phenomenon is not new to researchers dealing with speech acoustics, an in-depth content analysis of the words incorrectly perceived under this listening condition may provide valuable insight in the future construction of low frequency augmented word discrimination lists. With a carefully constructed word list, it may be possible to produce higher performance scores with the use of significantly fewer items and therefore be more efficient in the assessment of rollover.

In summary, the one-third octave band augmented speech discrimination tests employed in this investigation appear to preclude perfect discrimination performance in normal hearing listeners, thereby enhancing the diagnostic value of rollover testing. Although a substantial reduction in discrimination performance was only observed for the low frequency (500 Hz) augmentation condition, this finding should ultimately lead to a more expedient method for evaluating neural degeneration

through speech discrimination testing. The relatively small standard deviations obtained across all the intensity presentation levels for the high frequency (3150 Hz) augmentation condition support its potential as a diagnostic test. Further, a disparity presentation level of 25dB appeared to provide an equal interaction between loudness distortion and the distortion created by filtered augmentation and was reasoned to be an optimum disparity level for presenting augmented speech discrimination material in a clinic population.

The prerecorded format and the use of standardized word lists make the present augmented speech test readily adaptable for most clinical protocols. However, further research is warranted before it can be broadly advocated as a viable diagnostic tool.

Implications for Further Research

Analysis of the results obtained in the present study revealed several areas of future research. Since it appears that the rollover phenomenon may be dominated by frequency distortion, a content analysis of the words missed under various augmented listening conditions would provide a clearer picture of the specific speech components contributing to the reduction in discrimination performance. Additional research should include the use of different standardized word lists under the same augmentation. Such data would allow an analysis of the test-retest reliability of augmented speech testing and possibly lead to the widespread application of this procedure in clinical settings.

The repeated measures design of the present investigation utilized a small sample of normal hearing listeners (n=6) for each intensity disparity level. While this design allowed measurement of intra-subject

variation as a function of augmentation, it provided limited analysis of inter-test reliability among subjects at the various intensity presentation levels for each augmented condition. Therefore, future research should include a larger sample of listeners for each disparity level.

Finally, the rationale for the present study indicated that an augmented discrimination test would reduce the extrinsic redundancy of speech and thus tax the central auditory pathways. Therefore, the clinical impact of this reduction in redundancy should be investigated utilizing a population of persons with confirmed retrocochlear lesions.

REFERENCES

Adam, A.J., "A Correlational Analysis of the Campbell Reconstructed
     Half Word Lists Among an Elderly Population." Unpublished
     Research, Portland State University, 1978.

American National Standards Institute, Specifications for Audiometers.
     ANSI S3.6-1969, New York: American National Standards Institute,
     Inc., 1970.

Bess, F.H. and Townsend, T.H., "Word Discrimination For Listeners
     With Flat Sensorineural Hearing Losses." JSHD, 42:232-7, 1977.

Bilger, R.C. and Wang, M.D., "Consonant Confusions in Patients With
     Sensorineural Hearing Loss." JSHR, 19:718-48, 1976.

Bocca, E., "Distorted Speech Tests." IN: Sensorineural Hearing Process-
     es and Disorders, Graham, A.B. (Ed.), Boston: Little, Brown and
     Company, 1967.

Bocca, E. and Calearo, C., "Central Hearing Processes." IN: Modern
     Developments in Audiology, Jerger, J. (Ed.), New York: Academic
     Press, 1963.

Bocca, E., Calearo, C. and Cassinari, V., "A New Method for Testing
     Hearing in Temporal Lobe Tumors." Acta Otolarygol., 44-219, 1954.

Bocca E., Calearo, C., Cassinari, V. and Migliavacca, F., "Testing
     'Cortical' Hearing in Temporal Lobe Tumors." Acta Otolaryngol.,
     45:289-304, 1955.

Bruning, J.L. and Kintz, B.L., Computational Handbook of Statistics.
     Glenview: Scott, Foresman and Company, 1977.

Campbell, R.A., "Discrimination Test Word Difficulty." JSHR, 8:13-22,
     1965.

Carhart, R., "Problems in the Measurement of Speech Discrimination."
     Arch. Otolaryngol., 82:253-60, 1965.

Castle, W.E., "Effects of Selective Narrow-Band Filtering on the
     Perception by Normal Listeners of Harvard PB-50 Word Lists."
     JASA, 36:1047, 1964.

Chari, N.C.A., Herman, G. and Danhauer, J.L., "Perception of One-Third
     Octave Band Filtered Speech." JASA, 67:576-80, 1977.

Danhauer, J.L., Chari, N.C.A. and Herman, G., "Normal-Hearing Subjects' Perception of Speech Through One-Third Octave Bands." JAR, 17:275-81, 1977.

Dirks, D.D., Kamm, C., Bower, D. and Betsworth, A., "Use of Performance-Intensity Function For Diagnosis." JSHD, 42:408-15, 1977.

Durrant, J.D. and Lovrinic, J.H., Bases of Hearing Science. Baltimore: The Williams and Wilkins Company, 1977.

French, N.R. and Steinberg, J.C., "Factors Governing the Intelligibility of Speech Sounds." JASA, 19:90-119, 1947.

Freund, J.E., Modern Elementary Statistics. Englewood Cliffs: Prentice-Hall, Inc., 1973.

Gang, R.P., "The Effects of Age on the Diagnostic Utility of the Rollover Phenomenon." JSHD, 41:63-9, 1976.

Geffner, D. and Donovan, N., "Intelligibility Function of Normal and Sensorineural Loss Subjects on the W-22 Lists." JAR, 14:82-7, 1974.

Goetzinger, C.P., "Word Discrimination Testing." IN: Handbook of Clinical Audiology, Katz, J. (Ed.), Baltimore: The Williams and Wilkins Company, 1978.

Hirsh, I.J., Reynolds, E.G. and Joseph, M., "Intelligibility of Different Speech Materials." JASA, 26:530-8, 1954.

Hodgson, W.R., "Audiological Report of a Patient with Left Hemispherectomy." JSHD, 32:39-45, 1967.

Jacobs, S.W. and Francone, C.A., Structure and Function in Man. Philadelphia: W.B. Saunders Company, 1970.

Jerger, J., "Audiological Manifestations of Lesions in the Auditory Nervous System." Laryngoscope, 4:417-25, 1960.

_____, "Auditory Tests for Disorders of the Central Auditory Mechanism." IN: Neurological Aspects of Auditory and Vestibular Disorders. Fields, W.S. and Alford, B.R. (Eds.), Springfield: Charles C. Thomas, Publisher, 1964.

_____, "Diagnostic Audiometry." IN: Modern Developments in Audiology, Jerger, J. (Ed.), New York: Academic Press, 1973.

Jerger, J., Harford, E., Clemis, J. and Alford, B., "The Acoustic Reflex in Eighth Nerve Disorders." Arch. Otolaryngol., 99:409-13, 1974.

Jerger, J. and Hayes, D., "Diagnostic Speech Audiometry." Arch. Otolaryngol., 103:216-22, 1977.

Jerger, J. and Jerger, S., "Audiological Comparison of Cochlear and Eighth Nerve Disorders." Ann. Otol. Rhinol. Laryngol., 83:275-85, 1974a.

_____, "Auditory Findings in Brain Stem Disorders." Arch. Otolaryngol., 99:342-50, 1974b.

_____, "Comment on 'The Effects of Age on the Diagnostic Utility of the Rollover Phenomenon." JSHD, 41:556-7, 1976a.

_____, "Diagnostic Significance of PB Word Functions." Arch. Otolaryngol., 93:573-80, 1971.

_____, "Estimating Speech Threshold From PI-PB Function." Arch. Otolaryngol., 102:487-96, 1976b.

_____, "Extra and Intra-Apial Brain Stem Disorders." Audiology, 14:93-117, 1975.

_____, "Progression of Auditory Symptoms in a Patient With Acoustic Neurinoma." Ann. Otol. Rhinol. Laryngol., 77:230-42, 1968.

_____, "Psychoacoustic Comparison of Cochlear and VIII Nerve Disorders." JSHR, 10, 659-88, 1967.

Jerger, J., Jerger, S., Ainsworth, J. and Caram P., "Recovery of Auditory Function After Surgical Removal of Cerebellar Tumor." JSHD, 31:377-82, 1966.

Kirikae, E., Sato, T. and Shitara, T., "A Study of Hearing in Advanced Age." Laryngoscope, 74:205-20, 1964.

Korsan-Bengtsen, M., "Distorted Speech Audiometry." Acta Otolaryngol., Suppl. 310, 1973.

Kryter, K.D., "Methods for the Calculation and Use of the Articulation Index." JASA, 34:1689-97, 1962a.

_____, "Speech Bandwidth Compression Through Spectrum Selection." JASA, 32:547-56, 1960.

_____, "Validation of the Articulation Index." JASA, 34:1698-1702, 1962b.

LaCroix, P.G. and Harris, J.D., "Effects of High-Frequency Cue Reduction on the Comprehension of Distorted Speech." JSHD, 44:236-46, 1979.

Liden, G., "Distorted Speech and Binaural Speech Resynthesis Tests." Acta Otolaryngol., 58:32-48, 1964.

Liden, G., "Undistorted Speech Audiometry." IN: Sensorineural Hearing Processes and Disorders, Graham, A.B. (Ed.), Boston: Little, Brown and Company, 1967.

Lundborg, T., Rosenhamer, J., Murray, T. and Zwetnow, N., "Information Abundance of Speech and Distorted Speech Testing in Topical Diagnosis Within the C.N.S." Scand. Aud., 4:9-16, 1975.

Maurer, J.F., Hicks, A. and Bowen, N.M., "A Test for Speech Discrimination Function Utilizing Frequency Specific Auditory Augmentation." Unpublished Research, Grant #90-050-5801, Portland State University, 1981.

Orchik, D.J., Krygier, K.M. and Cutts, B.P., "A Comparison of the NU-6 and W-22 Speech Discrimination Tests for Assessing Sensorineural Hearing Loss." JSHD, 44:522-7, 1979.

Owens, E., "Intelligibility of Words Varying in Familiarity." JSHR, 4:113-29, 1961.

Palva, A., "Filtered Speech Audiometry." Acta Otolaryngol., Suppl. 210, 1965.

Pollack, I., "Effects of High Pass and Low Pass Filtering on the Intelligibility of Speech in Noise." JASA, 20:259-66, 1948.

Sanders, D.A. and Goodrich, S.J., "The Relative Contribution of Visual and Auditory Components of Speech to Speech Intelligibility as a Function of Three Conditions of Frequency Distortion." JSHR, 14:154-9, 1971.

Schuknecht, H., Pathology of the Ear. Cambridge: Harvard University Press, 1974.

Schultz, M.C. and Streepy, C.S., "The Speech Discrimination Function in Loudness Recruiting Ears." Laryngoscope, 127:2114-27, 1967.

Sher, A.E. and Owens, E., "Consonant Confusions Associated with Hearing Loss Above 2000 Hz." JSHR, 17, 669, 81, 1974.

Shirinian, M. and Arnst, D.J., "PI-PB Rollover in a Group of Aged Listeners." Ear and Hearing, 1:50-3, 1980.

Skinner, M.W., "Speech Intelligibility in Noise-Induced Hearing Loss: Effects of High Frequency Compensation." JASA, 67:306-17, 1980.

Snow, J.B., Rintelmann, W.F., Miller, J.M. and Konkle, D.F., "Central Auditory Imperception." Laryngoscope, 87:1450-71, 1977.

Stevens, J.H., "Monosyllabic Speech Tests." IN: Handbook of Clinical Audiology, Katz, J. (Ed.), Baltimore: The Williams and Wilkins Company, 1978.

Tillman, T.W. and Olsen, W.O., "Speech Audiometry." IN: Modern Developments in Audiology, Jerger, J. (Ed.), New York: Academic Press, 1973.

Wang, M.D., Reed, C.M. and Bilger, R.C., "Comparison of the Effects of Filtering and Sensorineural Hearing Loss on Patterns of Consonant Confusions." JSHR, 21:5-36, 1978.

Wegel, R.L. and Lane, C.E., "The Auditory Masking of One Pure Tone by Another and Its Probable Relation to the Dynamics of the Inner Ear." Phys. Rev., 23:266-85, 1924.

Welsh, O.L., Luterman, D.M. and Bell, B., "The Effects of Aging on Responses to Filtered Speech." J. of Gerontology, 24:189-92, 1969.

Willeford, J., "The Geriatric Patient." IN: Rose, D. (Ed.), Audiological Assessment, Englewood Cliffs: Prentice-Hall, 1971.