PERFORMANCE OF NOISE-INDUCED HEARING-IMPAIRED LISTENERS ON TIME COMPRESSED CNC MONOSYLLABLES

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ABSTRACT

PERFORMANCE OF NOISE-INDUCED
HEARING-IMPAIRED LISTENERS ON TIME COMPRESSED
CNC MONOSYLLABLES

By

Sabina A. Kurdziel

The purpose of this study was to investigate the effects of time compressed CNC monosyllables, presented at various sensation levels, on the discrimination ability of persons with noise-induced sensorineural hearing impairments.

The experimental stimuli utilized were the four lists of Form B of the Northwestern University Auditory Test No. 6 (NU-6). The words of each list were time compressed by 30% through 70%, in 10% steps, in addition to a 0% control condition. Compression was accomplished with the Zemlin modification of the Fairbanks Time Compressor.

Nine males with noise-induced sensorineural hearing impairments participated in this study. Each subject was presented the six time compressed versions of the NU-6 test at four sensation levels (16, 24, 32 and 40 dB), for a total of 24 experimental conditions. The 24 combinations of time compression and sensation levels were presented randomly, and the four lists of Form B of the NU-6 counterbalanced within these randomizations. In order to accomplish the testing, it was necessary for each subject to participate in two sessions.

Results indicated that for sensorineural hearing-impaired subjects, the intelligibility of time compressed speech stimuli decreased gradually up to 60% time compression. A dramatic breakdown in intelligibility occurred at 70% time compression. Results also indicated that lower sensation levels were necessary for optimum discrimination at 0%, 30% and 40% time compression, whereas at 50% and 60% time compression, discrimination continued to improve as sensation level was increased. At 70% time compression, discrimination plateaued at 24 dB SL and remained essentially constant at 32 and 40 dB SL. Results also revealed that sensorineural subjects exhibited articulation functions essentially similar in shape, though depressed, when compared to normal hearing listeners.

There was considerable subject variability in performance among the sensorineural subjects on the time compressed CNC monosyllabic words used in this study. This finding suggested that it would be difficult to predict which sensation level would provide the maximum discrimination score for a particular subject at specific time compression ratios. Thus, if it is to be utilized clinically, it will be necessary for time compressed speech to be administered to sensorineural subjects at several sensation levels.

Based on both the present investigation and earlier studies, it appears that time compressed speech may have important clinical utility as part of a battery of central auditory tests. However, considerable further research is needed.

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By

Sabina A. Kurdziel

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Thesis Committee: _______________ Chairman

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CHAPTER I

INTRODUCTION AND REVIEW OF THE LITERATURE

One of the problems encountered in utilizing audiological tests designed for isolating site of lesion in the central auditory pathways is, that often, these tests are employed with central nervous system cases before they have been adequately standardized on normal listeners or documented with behavioral responses of individuals having peripheral lesions.

A review of the literature suggests the importance of distorted speech tests in the diagnosis of lesions in the central nervous system (Matkin and Olsen, 1971). Filtered speech was utilized by Bocca (1955), Bocca, et al. (1955), Calearo (1957) and Jerger (1964). Periodically switched speech and periodically switched noise were employed by Calearo and DiMitri (1958) and Calearo, et al. (1962). Matzker (1959) used a frequency filtering method and Katz (1962) utilized a competing message for identification of lesions in the central nervous system.

Another form of distorted speech test that has received considerable interest as a potential diagnostic tool for identification of lesions in the central auditory system is time compressed speech. A review of the literature suggests that time compressed speech may be used in the diagnosis of lesions of the central auditory pathways; however, methods of time compression utilized to date have not been clearly defined. The experimental stimuli have also varied from monosyllabic words, (Luterman, Welsh and Melrose, 1966; Sticht and Gray, 1969) to sentential material (Calearo and Lazzaroni, 1957; deQuiros, 1964; Bergman, 1971). Partly, because of these differences, it has been difficult to clinically apply time compressed speech. To obtain a clinically useful test, procedures for time compression must be well defined and clinically standardized test materials must be utilized.

Normative data on varying percentages of time compression have been obtained by Beasley, Schwimmer and Rintelmann (1972) and Beasley, Forman and Rintelmann (1972). These investigators defined the method of time compression employed and utilized a clinically standardized word list for the experimental stimuli. They emphasized the importance of obtaining data on conductive, cochlear, retrocochlear and central nervous system disorders.

Because data is needed on different populations in order to develop a clinically useful test, this study will apply the same experimental stimuli used by Beasley, Schwimmer and Rintelmann (1972) and Beasley, Forman and Rintelmann (1972) to a group of individuals with cochlear pathology. Subjects with noise-induced hearing impairments were chosen because the cochlear lesion is usually restricted to the hair cells of the Organ of Corti (Rosenberg, 1967; Davis and Silverman, 1970).

Time Compressed Speech

The importance of the time factor in speech discrimination has been emphasized by Fournier (1956). He noted that in the elderly the cortex requires increased time for identification of a message. He related this specifically to the difficulties in speech discrimination encountered by the aged. Bordley and Haskins (1955) concluded that an increased difficulty in intelligibility is evidenced in the aged, when words are presented at a high average syllabic rate. Finzi (1955) utilized various rates of accelerated speech with presbycusic subjects and attempted to determine their speech reception thresholds. He found that the speech reception threshold may rarely be reached when accelerated material is utilized as the acoustic stimuli.

Calearo and Lazzaroni (1957) conducted a study whereby aged subjects responded to "short significant senstences" recorded at several accelerated speech rates. The sentences were recorded at the rates of 140, 250 and 350 words per minute (wpm). They found a dramatic deterioration in discrimination ability with material presented at 350 wpm when elderly subjects were compared to normal hearing subjects. Under such accelerated conditions, none of the aged subjects obtained a speech reception threshold, nor did they receive higher than a 50% discrimination score. The same distorted speech stimuli was presented to subjects with lesions of the temporal lobe. It was found that poorer discrimination scores were obtained when the stimuli were presented to the contralateral ear. Although Calearo

and Lazzaroni have shown that lesions of the temporal lobe can be detected with accelerated speech, they failed to provide normative data and controlled time compression conditions.

DeQuiros (1964) utilized the same rates of accelerated speech as Calearo and Lazzaroni (1957). However, the experimental stimuli consisted of longer (10 word) sentences. The distorted speech was administered to normal and presbycusic subjects, subjects with peripheral hearing impairments and subjects with central disorders. The results of the investigation indicated that there was a marked deterioration of discrimination ability at the highest rate of speech in subjects with cochlear pathology. Results of this study also gave evidence that accelerated speech testing may provide additional information in the diagnosis of brain lesions within the temporal lobe. DeQuiros emphasized, however, that accelerated speech tests must be used in conjunction with other audiometric tests.

Bocca and Calearo (1963) reported that aged subjects experienced greater difficulty in responding to phrases spoken at an accelerated rate than younger persons. They stated that "central acoustic reaction time" was lengthened as a result of the aging process. Pestalozza and Shore (1955) also identified a "defect in cortical reaction time" in aged subjects. They found that aged subjects experienced great difficulty in interpreting speech presented at an accelerated rate.

Luterman, Welsh and Melrose (1966) utilized both an aged population and two groups of younger adults in their study. They presented their listeners with phonetically-balanced CID W-22 word lists under conditions of normal rate and 10% and 20% time compression. Time compression in this study was accomplished via an electromechanical sampling technique. Their results indicated that all subjects responded in a similar manner. The percentages of time compression utilized relative to the unaltered condition were detrimental to all three groups. However, their findings were limited in terms of the ratios of time compression utilized.

Sticht and Gray (1969), using the electromechanical sampling method, investigated speech intelligibility of time compressed phonetically-balanced (CID W-22) words for young and aged normal and sensorineural hearing-impaired subjects. They used a control condition of 0%, and experimental conditions of 36%, 46% and 59% time compression. They found that discrimination of time compressed words was not affected differentially by the nature of the subject's hearing ability. Results did indicate, however, that discrimination ability of the aged listeners was affected more than that of the younger listeners under time compression, and that this difference increased as the percentage of time compression was increased. Sticht and Gray, however, did not use a large enough population (28 subjects) to establish normative data and obtain clinically usable articulation functions. They also utilized a limited number of time compression conditions.

Bergman (1971) tested the hearing for speech of adults in each age decade from 20 - 89 years under several difficult listening con-

ditions. Results of his study indicated that the understanding of speech under conditions of distortion, time alteration and competing signals showed dramatic deterioration, even though conventional audiometric configurations revealed relatively normal hearing for pure tones. Bergman suggested that this deterioration is somehow related to a decrease in time-related processing abilities.

In a carefully controlled study by Beasley, Schwimmer and Rintelmann (1972), 96 normal-hearing young adults were administered six different percentages of time compression (0%, 30%, 40%, 50%, 60% and 70%) at four different sensation levels (8, 16, 24 and 32 dB). The experimental stimuli used in this study were the four lists of Form B of Northwestern University Auditory Test No. 6 (NU-6) (Tillman and Carhart, 1966).

The NU-6 word lists were chosen as the experimental stimuli for this study because they have been standardized with both normal and pathological listeners. Tillman and Carhart (1966) administered these tests to three groups of subjects: normal hearing persons, those with conductive impairments and those with sensorineural hearing losses. Articulation curves were plotted as a function of sensation level. The inter- and intra-list reliability was found to be good. Further, the slope of the articulation function was found to vary according to the status of the auditory system; that is 5.6% per dB for the normal hearing and conductive populations and 3% per dB for persons with sensorineural hearing impairments.

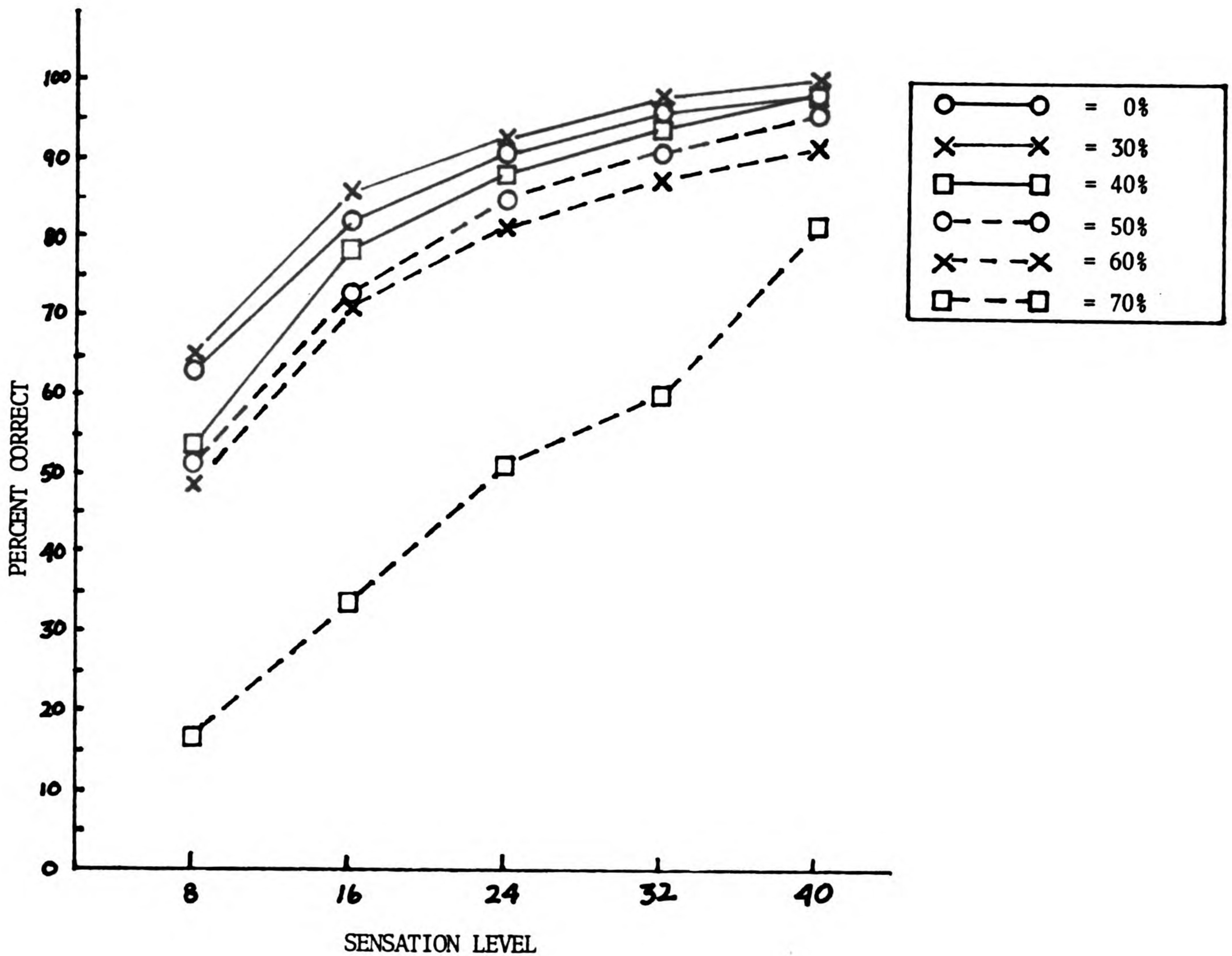
Beasley, Schwimmer and Rintelmann (1972) recorded the four word

lists of NU-6 and taped them according to the method advocated by Rintelmann and Jetty (1968). The experimental tapes were then temporally processed using the Fairbanks electromechanical time compression apparatus (Fairbanks, Everritt and Jaeger, 1954) as modified by Zemlin (1971). Each list was time compressed by 30%, 40%, 50%, 60% and 70%. A control condition of 0% time compression was also utilized. The subjects were divided into six groups corresponding to the six ratios of time compression. Each subject was then presented with the four lists at a specific percentage of time compression at each of the four sensation levels.

Results indicated that as the percentage of time compression increases, intelligibility decreases. The decrease in intelligibility is gradual over the conditions of 30% - 60%; however, it was found that at 70% a dramatic breakdown in intelligibility of time compressed speech occurred (Figure 1). Results also indicated that the intelligibility is affected by sensation level. It was found that discrimination ability at each condition of time compression increased as sensation level increased.

A study by Beasley, Forman and Rintelmann (1972) utilized the same experimental stimuli as the Beasley, Schwimmer and Rintelmann (1972) study, to determine the responses of 16 normal-hearing young adults to the six conditions of time compression at a 40 dB sensation level. Results were similar to those obtained in the Beasley, Schwimmer and Rintelmann (1972) study, which utilized lower sensation levels; that is, intelligibility decreased as time compression increased, with

Figure 1. Average articulation scores for six conditions of time compression plotted by sensation level; 8-32 dB SL (Beasley, Schwimmer and Rintelmann, 1972) and 40 dB SL (Beasley, Forman and Rintelmann (1972).


PERCENT CORRECT
0
10
20
30
40
50
60
70
80
90
100
8
16
24
32
40
SENSATION LEVEL
= 0%
= 30%
= 40%
= 50%
= 60%
= 70%

a dramatic breakdown in intelligibility occurring at 70% time compression (Figure 1).

As stated earlier, if a diagnostic measure is to become clinically useful, data must be obtained on normal-hearing young adults by applying controlled time compression procedures to a clinically standardized speech discrimination test. The studies by Beasley, Schwimmer and Rintelmann (1972) and Beasley, Forman and Rintelmann (1972) have accomplished this. These authors have stressed that other clinical populations should be examined. There is a need to collect similar data on individuals with cochlear and retrocochlear lesions, as well as persons with central nervous system disorders. The present investigation will focus on individuals having cochlear lesions.

Sensorineural Hearing Disorders

An understanding of sensorineural hearing loss is important in order to examine distorted speech tests in relation to clinical application. Thus, a review of sensorineural hearing loss and its parameters is presented below.

Davis and Silverman (1970) stated that the term sensorineural hearing loss implies an abnormality of the sense organ, the auditory nerve or both. They further stated that dysacusis or "faulty hearing" may be due to malfunction of the sense organ, or it may be due to abnormal function of the brain. A pure sensorineural hearing impairment exists when the outer and middle ear are functioning properly. Sound is conducted to the inner ear, but it cannot be perceived or analyzed correctly. The typical sensorineural loss is characterized by better hearing for the lower frequencies than for the high frequencies.

Sensorineural hearing loss has a multitude of causes (Rosenberg, 1967). Shambaugh (1967) lists twenty common types of sensorineural losses, including congenital deafness, endolymphatic hydrops, acoustic neurinoma, presbycusis and noise exposure.

Shambaugh also stated that certain types of sensorineural losses can be of central origin. For example, multiple sclerosis can sometimes produce a sensorineural type hearing impairment. This is thought to be due to the interruption of the auditory pathways within the brain stem. Shambaugh emphasized, however, that diseases of the central nervous system are usually not accompanied by a loss of hearing.

The most common cause of sensorineural hearing impairment is presbycusis. Sensory processes tend to deteriorate with age. The deterioration begins at approximately age 30 and becomes increasingly noticeable with each decade. Presbycusis usually reaches the state of a handicap in a person between the ages of 60 and 70 (Rosenberg, 1967).

In presbycusis the higher frequencies are affected first. The audiogram displays a bilaterally symmetrical sloping hearing impairment. The air and bone conduction thresholds are interweaving, with normal or nearly normal hearing at the lower frequencies. Discrimination is difficult for the presbycusic because of the loss of high frequency consonant sounds.

Some cases of presbycusis are accompanied by phonemic regression (disproportionate loss of the ability to understand speech). As a result of the aging process, a degeneration of the central nervous system, including the higher auditory pathways, occurs (Shambaugh, 1967).

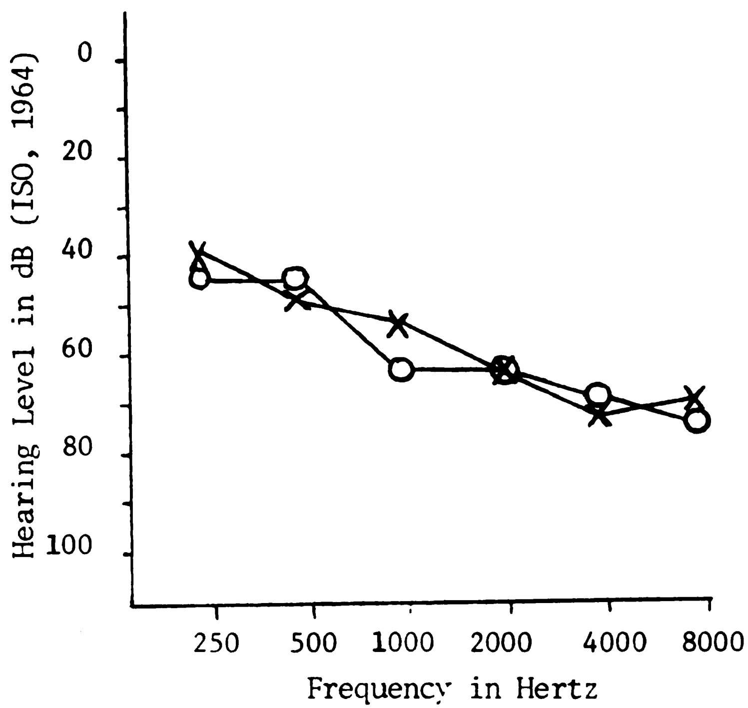
Another common cause of sensorineural hearing loss is excessive noise exposure. Many industrial noises are of sufficient magnitude to produce permanent damage to the nerve fibers in the cochlea (Rosenberg, 1967). People working in excessive noise (drop forges, metal working plants, jet aircraft) can have damage to the hair cells to such an extent as to produce a socially handicapping, permanent loss of hearing. The audiometric configuration of a noise-induced hearing impairment shows a sloping air and bone conduction curve, reaching its deepest point at 3000 or 4000 Hz. There may be some slight recovery at higher frequencies. In some cases the loss continues to deepen and widen after noise exposure has ceased (Shambaugh, 1967). People with noise-induced hearing impairments do not experience phonemic regression, since according to Rosenberg (1967), only the hair cells of the cochlea are typically involved.

Lindberg (1971) investigated permanent threshold shifts of 71 drop forge workers. He reported that after about 10 - 15 years of exposure to impulse noise in a drop forge hammer shop, the typical audiometric configuration displays either a steeply sloping audiometric configuration or a gradual sloping configuration (Figure 2a and 2b).

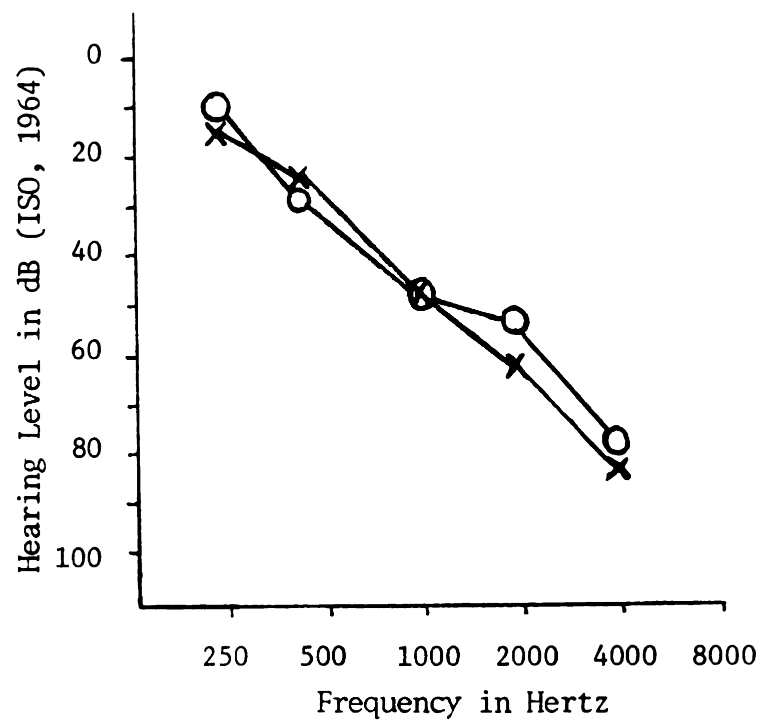
The discrimination ability of persons with sensorineural hearing impairments is lowered in comparison to normal hearing persons or those with conductive losses. Carhart (1946) stated that there is a relationship between the hearing loss for pure tones and speech discrim-

Figure 2. Typical audiometric configurations of noise-induced hearing losses resulting from 10-15 years exposure to drop forge noise (Lindberg, 1971).

2a


Hearing Level in dB (ISO, 1964)
0
20
40
60
80
100
250
500
1000
2000
4000
8000
Frequency in Hertz

2b


Hearing Level in dB (ISO, 1964)
0
20
40
60
80
100
250
500
1000
2000
4000
8000
Frequency in Hertz

ination. The frequency range important for understanding speech is approximately 250 - 4000 Hz. If a person has normal hearing within this range, his discrimination score will be approximately 90% - 100%. However, if pure tone thresholds in this range become poorer, discrimination will also become poorer. Various researchers have noted that the speech discrimination score is in good relation to the pure tone configuration and audiometric reduction (Pestalozza and Shore, 1955; Thompson and Hoel, 1962; Gollesberg and Plath, 1967).

Summary and Statement of the Problem

Theoretical and diagnostic implications of time compressed speech with reference to central auditory disorders have been discussed (Beasley, Schwimmer and Rintelmann, 1972; Bocca and Calearo, 1963; Calearo and Lazzaroni, 1957; deQuiros, 1964 and Sticht and Gray, 1969). Studies which have investigated the potential of time compressed speech as a diagnostic tool have failed to provide normative data (Calearo and Lazzaroni, 1957; Bocca and Calearo, 1963; deQuiros, 1964; Sticht and Gray, 1969). Other studies have also utilized limited ratios of time compression (Sticht and Gray, 1969; Luterman, Welsh and Melrose, 1966). Sticht and Gray and Luterman, *et al.* also utilized the CID W-22 speech discrimination test as the experimental stimuli. As stated by Carhart (1965), the W-22 word lists may not be effective in a differential diagnosis as the word lists are too easy.

Beasley, Schwimmer and Rintelmann (1972) and Beasley, Forman and Rintelmann (1972) have obtained normative data using a time compressed version of the Northwestern University Auditory Test No. 6. Results of their studies indicate possible clinical application of this particular test; however, further research is needed to examine the effects of time compressed monosyllabic CNC words on the discrimination ability of subjects with conductive, cochlear, retrocochlear and central nervous system disorders. It is the purpose of this study to investigate the effects of time compression on the discrimination ability of persons with cochlear pathology. Subjects with noise-induced hearing loss were selected because, unlike presbycusis, the site of lesion is restricted to hair cell damage within the Organ of Corti (Rosenberg, 1967; Shambaugh, 1967).

The specific purpose of this study is to examine the effects of varying percentages of time compression on monosyllabic word intelligibility as a function of sensation level upon subjects with bilaterally symmetrical noise-induced hearing impairments. Thus, the following questions will be investigated:

1) Will different percentages of time compression (30% - 70% in 10% steps) result in differential intelligibility scores among persons with a noise-induced sensorineural hearing impairment? Further, how will the results compare to the data on normal hearing persons?
2) Will the intelligibility scores at the varying percentages of time compression interact with sensation level in this population? Also, will the results be comparable to data on normal hearing listeners?
3) Will specific subjects show differences in response ability on this task?

CHAPTER II

EXPERIMENTAL PROCEDURES

In this study nine subjects with bilaterally symmetrical noise-induced hearing impairments received the Northwestern University Auditory Test No. 6 at six percentages of time compression at four sensation levels for a total of 24 word lists per subject.

Subjects

Nine subjects with an age range of 28 years 2 months to 53 years 3 months and a mean age of 44 years 9 months were utilized. The subjects were employed at one of the drop forges in the Lansing area. Each subject was initially contacted by letter (Appendix A), and given a detailed questionnaire concerning his history of noise exposure (Appendix B). All subjects were then required to take a bilateral pure-tone air- and bone-conduction test at octave intervals from 250 through 8000 Hz to insure a bilaterally symmetrical noise-induced sensorineural hearing impairment. Subjects with a conductive component of 15 dB or more for the speech frequencies (500, 1000 and 2000 Hz) and pure tone averages of 30 dB or better and 70 dB or poorer were excluded from the study.

A tape recorded version of the CID W-1 spondee word list was administered bilaterally to obtain speech reception thresholds. The ear with the best speech reception threshold, within the experimental limits of the design, was then selected as the test ear.

The median audiogram and individual audiograms of each subject are in Appendix C.

Equipment

To obtain pure tone audiometric data, a Maico audiometer, (Model MA 24), was used to drive TDH-39 transducers mounted in MX 41/AR cushions. A Grason Stadler speech audiometer (Model 162) was coupled with a tape recorder (Ampex 602-2) to drive the TDH-39 transducers mounted in MX 41/AR cushions to present the CID W-1 spondee word lists and the experimental stimuli.

Calibration of the equipment took place before, during and after the experiment. No important systematic changes were noted in the output of the equipment during the course of this investigation. Calibration procedures are presented in Appendix D.

Test Environment

The subjects performed their listening tasks in a sound-treated booth (pre-fabricated double-walled 1200 series IAC test chamber) which contained earphones and an intercom. The overall level of the ambient noise in the test chamber measured 48 dB SPL on the C Scale of the Brüel and Kjaer Sound Level Meter (2204S). Measuring the noise with octave band filters, the most intense component was found to be the 31.5 and 63 Hz bands, which had levels of 44 and 31 dB SPL respectively. The level of the noise in the 125 and 250 Hz octave band was

20 and 17 dB SPL respectively. The levels of the octave bands from 500 through 8000 Hz were below 10 dB SPL. These levels were sufficiently low so as not to interfere with the subject's listening task.

The experimenter and the test equipment were in an adjacent single-walled IAC control room. All equipment utilized was located in the Audiology and Speech Sciences Building at Michigan State University.

Experimental Stimuli

The experimental stimuli utilized in this study were the four lists of Form B of Northwestern University Auditory Test No. 6 (Tillman and Carhart, 1966). Each list is composed of 50 monosyllabic CNC words. The words have been phonemically balanced as recommended by Lehiste and Peterson (1962). The four word lists were recorded locally at normal conversational speech and effort level by a trained white male talker who spoke General American English under controlled recording procedures. These lists were found to be essentially equivalent and to demonstrate good inter- and intra-test reliability (Rintelmann and Jetty, 1968).

As explained by Beasley, Schwimmer and Rintelmann (1972), copies of each tape were temporally processed using the Fairbanks electromechanical time compression apparatus (Fairbanks, Everritt and Jaeger, 1954), as modified by Zemlin (1971). Each list was time compressed by 30%, 40%, 50%, 60% and 70% in addition to a 0% time compressed condition, resulting in 24 experimental tapes.

Presentation Procedures

Each subject was seen twice with each experimental session lasting two hours. During the first session each subject was given a conventional pure-tone air- and bone-conduction test bilaterally. The CID W-1 spondee word list was then administered monaurally under earphones to both ears, to obtain speech reception thresholds (SRT), and to determine the test ear. The ear with the best SRT within the limits of the experimental design was designated as the test ear.

Prior to the presentation of the experimental stimuli, the subject received a set of instructions (Appendix E) and a set of answer forms for writing his responses to the monosyllabic word lists (Appendix F). Each subject was then presented with the four lists of Form B of the NU-6 (Appendix G), at four Sensation Levels: 16, 24, 32 and 40 dB at each percentage of time compression: 0%, 30%, 40%, 50%, 60% and 70%. For each subject each time-compressed condition was presented four times, that is, once at each sensation level, for a total of 24 conditions within two test sessions. Half of the word lists (12) were presented during the first test session and the other half were presented about one week later, during the second session. In no case did more than eight days elapse between the first and second test session for any subject. The time compression conditions and the sensation levels were randomized and the lists were counterbalanced to the randomizations (Appendix H).

Analysis

The experimenter hand-scored the data and converted them to percent correct scores. The subject's scores were individually plotted at each sensation level over the varying percentages of time compression. Mean percentage scores were also determined for each percentage of time compression.

CHAPTER III

RESULTS

The results of this study generally support the thesis that as the ratio of time compression increases, intelligibility decreases among subjects with noise-induced sensorineural hearing impairments. The data are presented as mean values and, in some instances, standard deviations are shown. Also, individual data are displayed and discussed in relation to the means. Further, one subject (No. 9), due to his unusual response characteristics, is discussed individually.

Results are reported in Table I and Appendix I and are shown in Figures 3 through 24.

Time Compression and Intelligibility

Mean results for eight subjects show that different percentages of time compression result in differential intelligibility scores for noise-induced sensorineural hearing-impaired individuals. Table I and Figures 3 through 7 indicate that intelligibility decreased as the ratio of time compression increased.

Table I and Figure 3 show that there is a gradual decrease in intelligibility from 0% through 60% time compression and that at 70% time compression a dramatic breakdown in intelligibility occurs at all sensation levels. However, no trends in amount of reduction in per-

Table I. Percent correct speech discrimination (means and standard deviations) as a function of time compression and sensation level (N=8).

		16 dB	24 dB	32 dB	40 dB
0%	$\bar{x}$	63.75	68.50	72.50	66.50
	SD	14.64	9.37	13.97	10.70
30%	$\bar{x}$	57.00	66.25	63.00	60.00
	SD	13.40	13.33	14.93	15.97
40%	$\bar{x}$	48.25	47.50	56.50	55.75
	SD	14.60	16.38	21.00	16.95
50%	$\bar{x}$	43.75	47.50	56.75	58.50
	SD	20.04	15.03	19.30	17.23
60%	$\bar{x}$	31.50	38.25	43.25	44.00
	SD	12.44	15.87	17.33	20.23
70%	$\bar{x}$	3.50	8.75	8.75	9.25
	SD	4.87	9.50	8.55	9.68

centage scores between time compression conditions is evident. Figure 3 also shows that at 40%, 50% and 60% time compression, subjects performed clearly better at the higher sensation levels (32 and 40 dB).

Figures 4 through 7 demonstrate the performance of the subjects over each ratio of time compression with each figure showing only one sensation level. At all sensation levels except 16 dB, a plateauing effect between 40% and 50% time compression occurs. There is even a slight improvement at 50% time compression at 40 dB SL. However, at 16 dB SL, the reduction in intelligibility was consistent as a function of increase in compression.

Figures 4 through 7 also demonstrate the wide range in scores obtained at each condition of time compression and sensation level. The spread of scores around the mean, as exhibited by the standard deviations, is relatively large at all conditions of time compression.

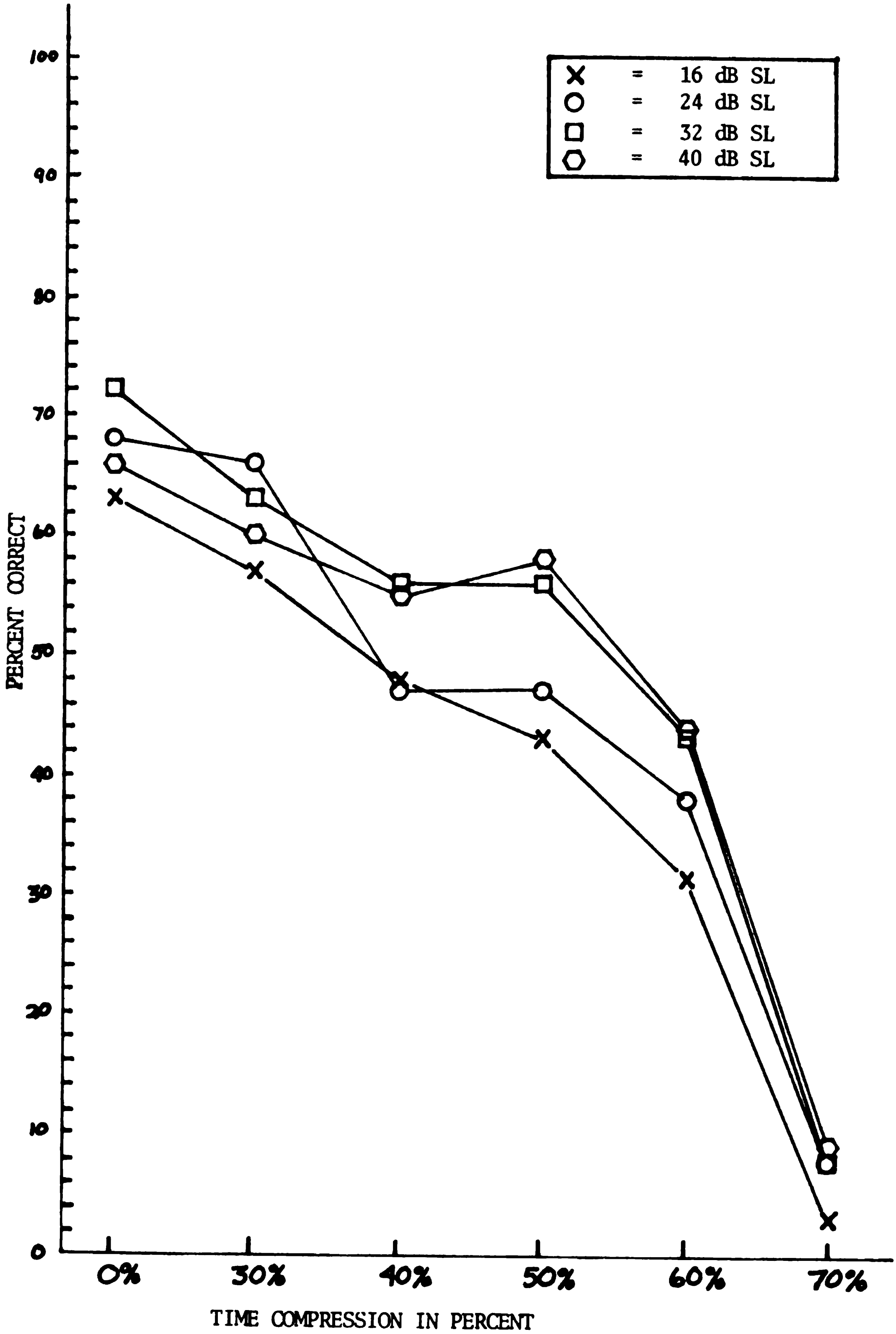
Figure 8 displays the average articulation scores for all sensation levels, plotted by time compression. This illustrates the similarities in slopes of functions between normal-hearing individuals as gathered by Beasley, Schwimmer and Rintelmann (1972) and Beasley, Forman and Rintelmann (1972), and sensorineural hearing-impaired individuals. A reduction in intelligibility in the sensorineural group can be noted over all conditions of time compression in comparison to the normal-hearing group. Except for a slight plateau at 40% to 50% time compression in the sensorineural group, the parallelism to normals evident in the slope of the function is quite remarkable.

Figure 8 also illustrates that in the normal hearing population, 0% and 30% time compression scores were almost identical. The normals then consistently dropped at 40%, 50% and 60% time compression. In the sensorineural group, a small deterioration in discrimination immediately begins at 30% time compression. They then continue to drop with a plateau occurring at 40% - 50% time compression. Both groups showed a dramatic breakdown in intelligibility at 70% compression.

Recognizing that given individuals often deviate considerably from group means, it was felt important to display the results of each subject. The performance of each subject is therefore shown in Figures 9 through 12. Each figure displays the individual performance of each subject over each time compression condition, with every figure showing only one sensation level. Considerable variability in performance both among and within subjects is evident at each sensation level.

Each subject exhibited basically two types of response curves over the six conditions of time compression. Figures 13a through 17a illustrate that Subjects 1 through 5 display gradually decreasing scores at 0%, 30%, 40% and 50% compression, with a definite drop in performance at 60% time compression. A dramatic breakdown in intelligibility then occurs at 70% time compression. Figures 18a through 20a show that Subjects 6 through 8 demonstrated gradually decreasing scores from 0% through 60% time compression, with again a dramatic breakdown in intelligibility occurring at 70% time compression.

Figure 3. Speech discrimination in percent as a function of time compression at 16, 24, 32 and 40 dB SL.



X = 16 dB SL
O = 24 dB SL
□ = 32 dB SL
⬡ = 40 dB SL
PERCENT CORRECT
100
90
80
70
60
50
40
30
20
10
0
0%
30%
40%
50%
60%
70%
TIME COMPRESSION IN PERCENT

Figure 4. Speech discrimination in percent (mean and ± one standard deviation) as a function of time compression at 16 dB sensation level.

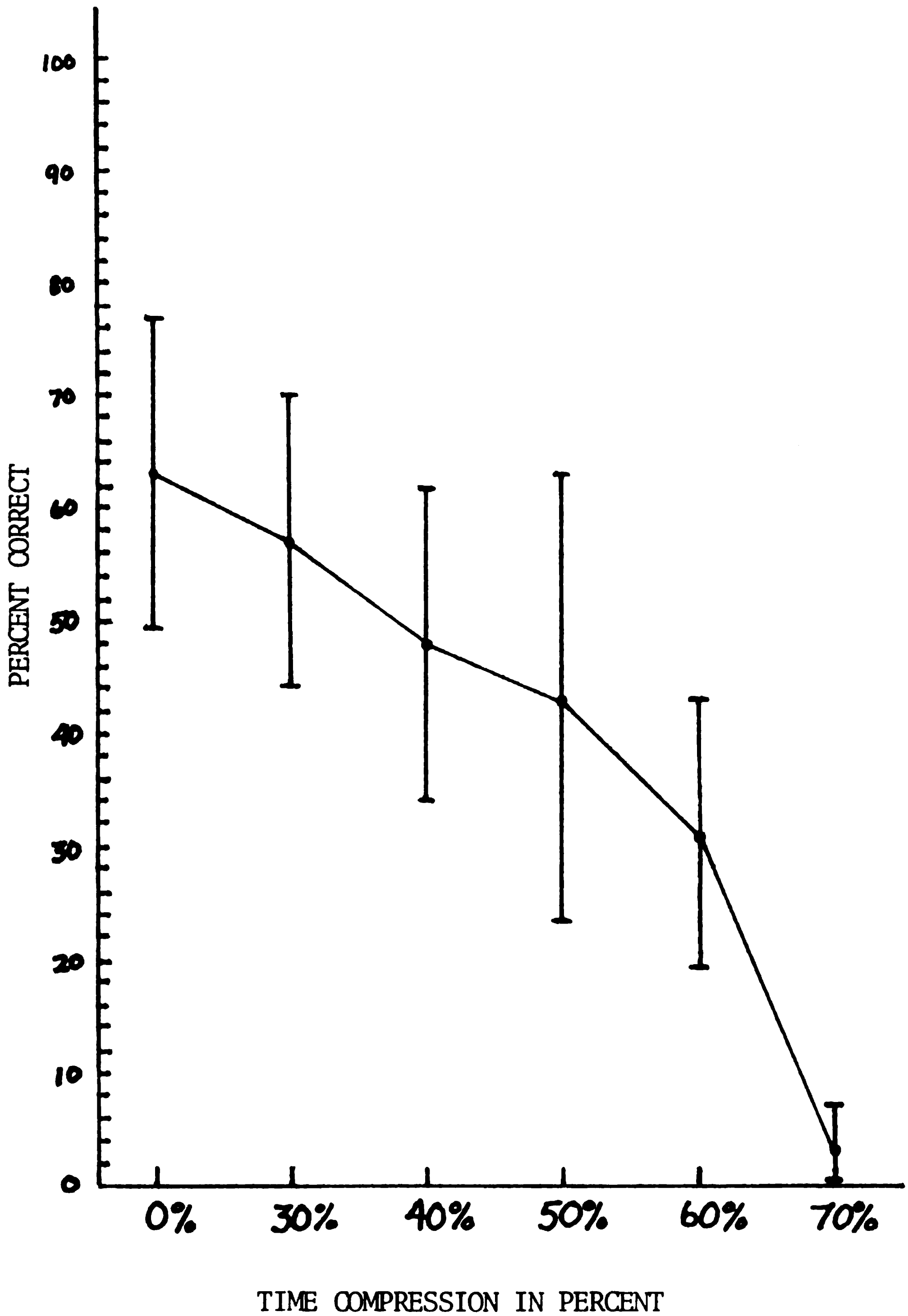

100
90
80
70
60
50
40
30
20
10
0
PERCENT CORRECT
0%
30%
40%
50%
60%
70%
TIME COMPRESSION IN PERCENT

Figure 5. Speech discrimination in percent (mean and ± one standard deviation) as a function of time compression at 24 dB sensation level.

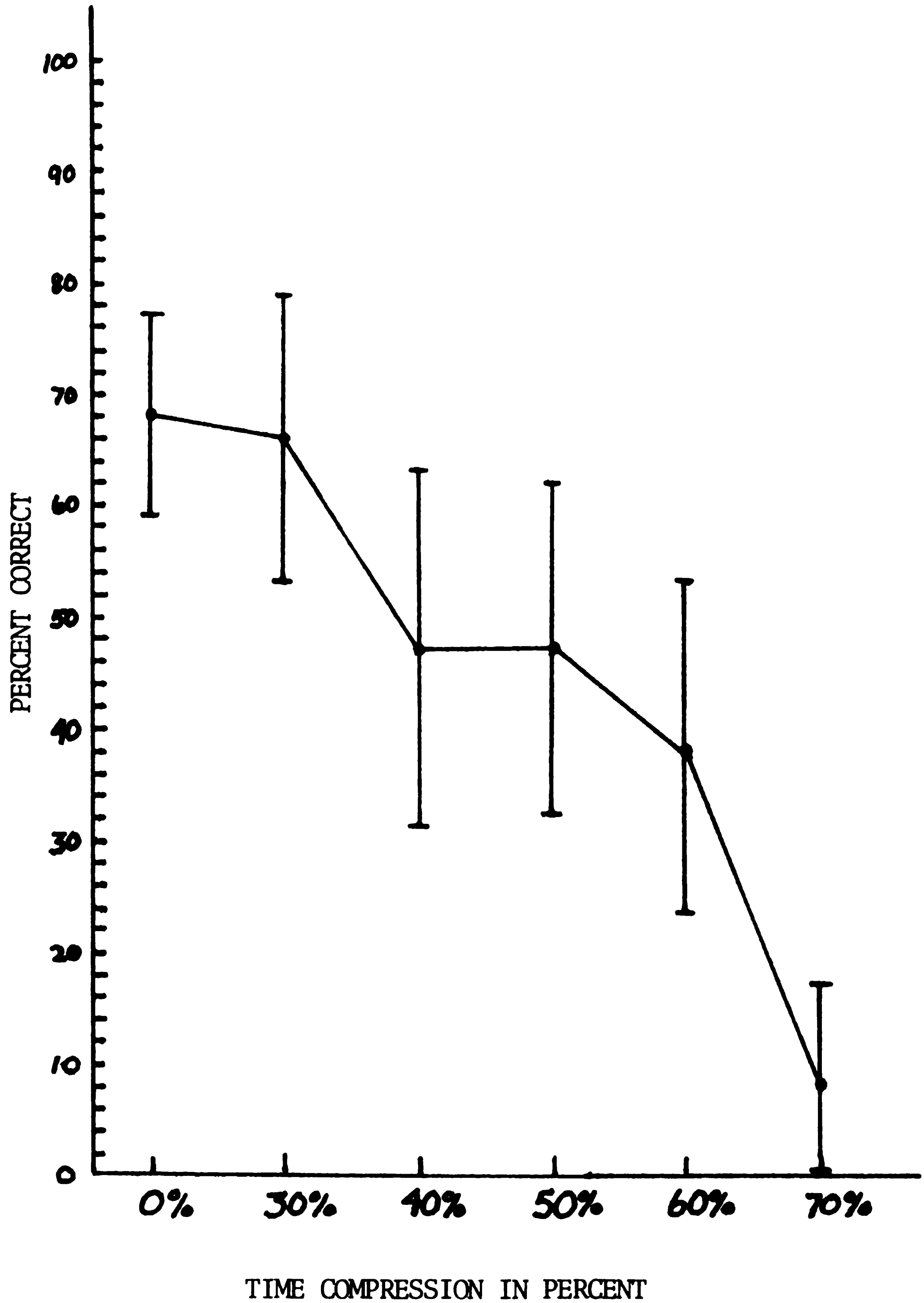

100
90
80
70
60
50
40
30
20
10
0
PERCENT CORRECT
0%
30%
40%
50%
60%
70%
TIME COMPRESSION IN PERCENT

Figure 6. Speech discrimination in percent (mean and ± one standard deviation) as a function of time compression at 32 dB sensation level.

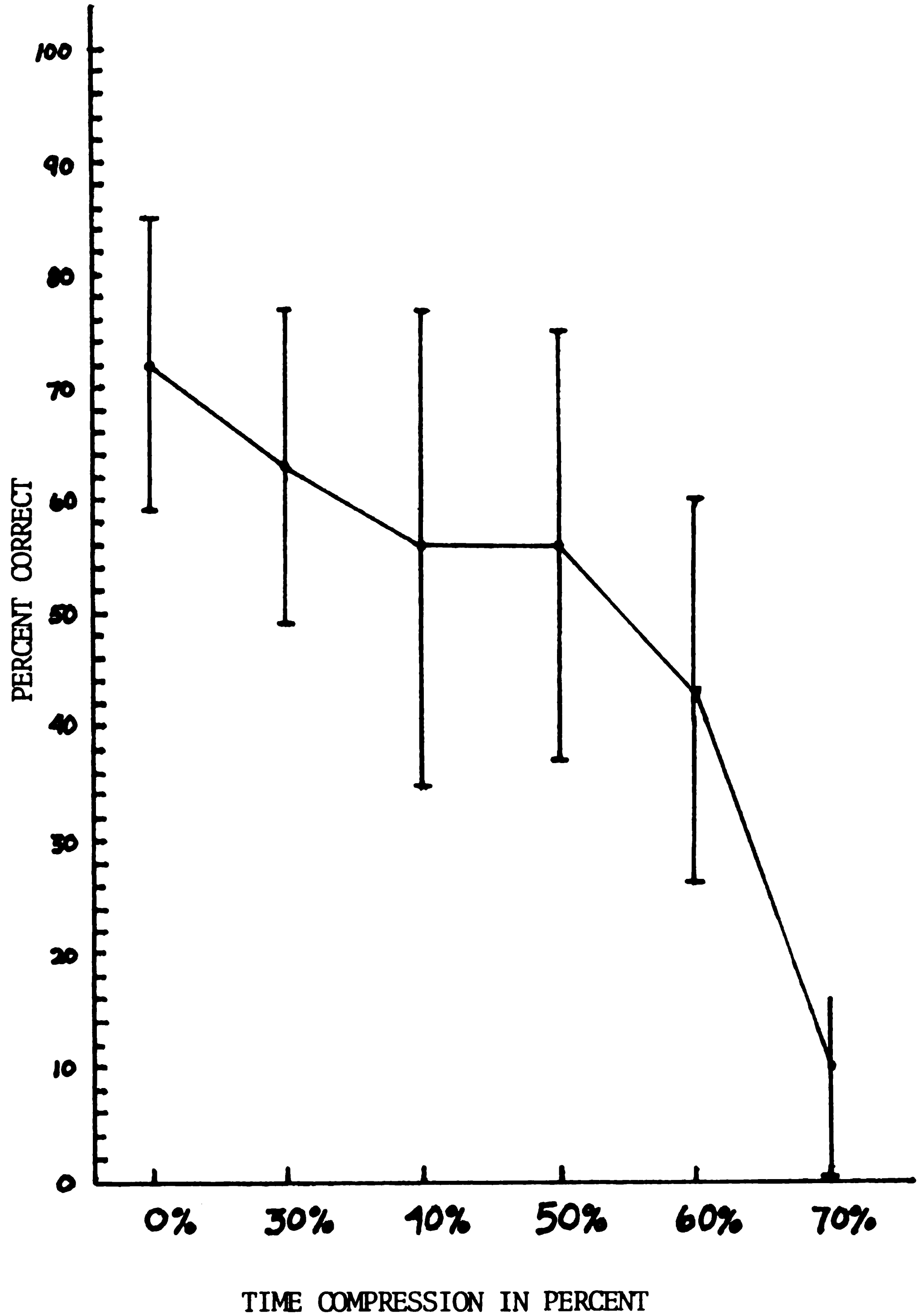

100
90
80
70
60
50
40
30
20
10
0
PERCENT CORRECT
0%
30%
40%
50%
60%
70%
TIME COMPRESSION IN PERCENT

Figure 7. Speech discrimination in percent (mean and ± one standard deviation) as a function of time compression at 40 dB sensation level.

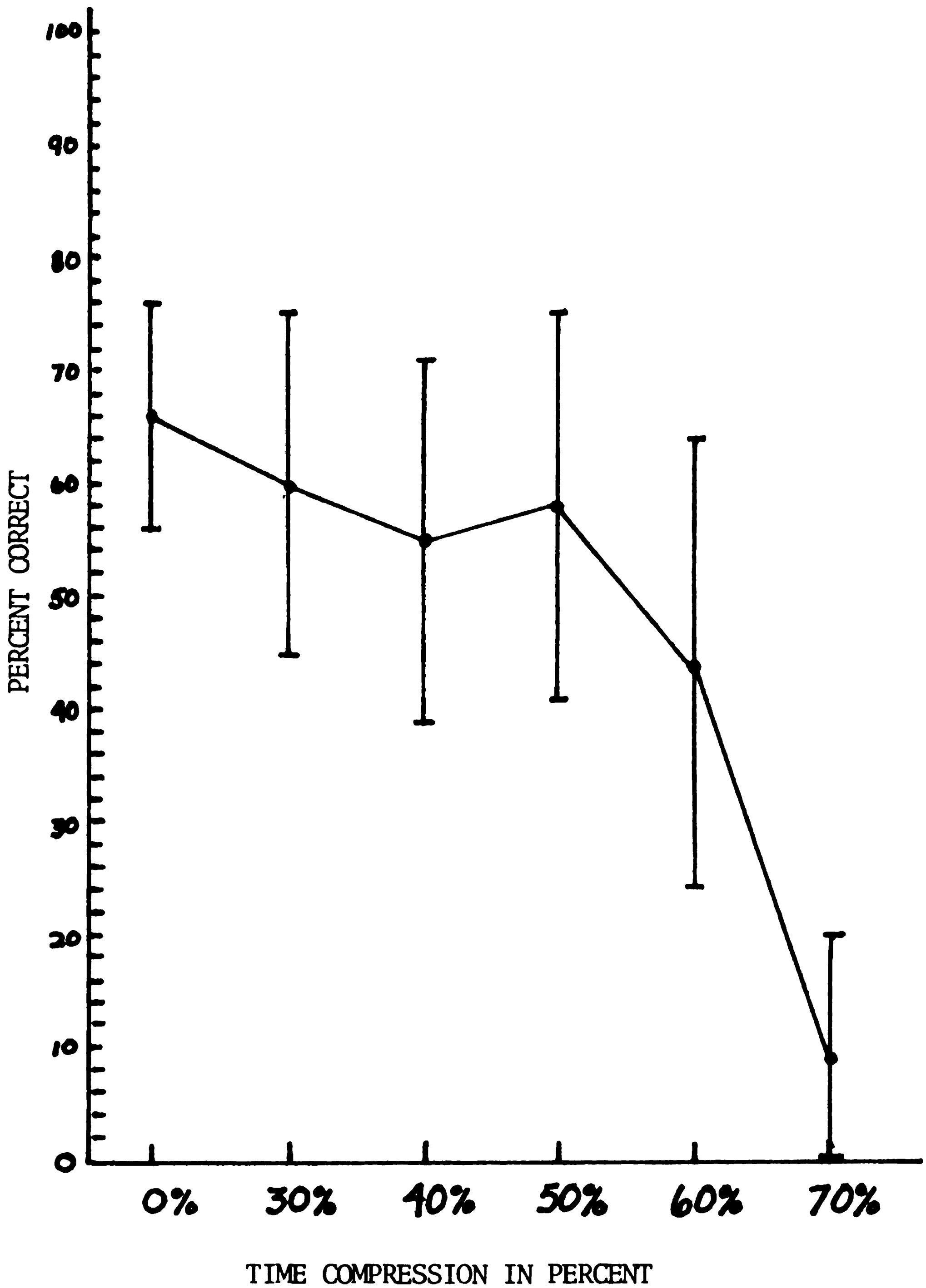

100
90
80
70
60
50
40
30
20
10
0
PERCENT CORRECT
0%
30%
40%
50%
60%
70%
TIME COMPRESSION IN PERCENT

Figure 8. Average articulation scores collapsed over sensation level, plotted by time compression conditions, illustrating similarities in slopes of functions between normal-hearing (Beasley, Schwimmer and Rintelmann, 1972; Beasley, Forman and Rintelmann, 1972) and sensorineural groups.

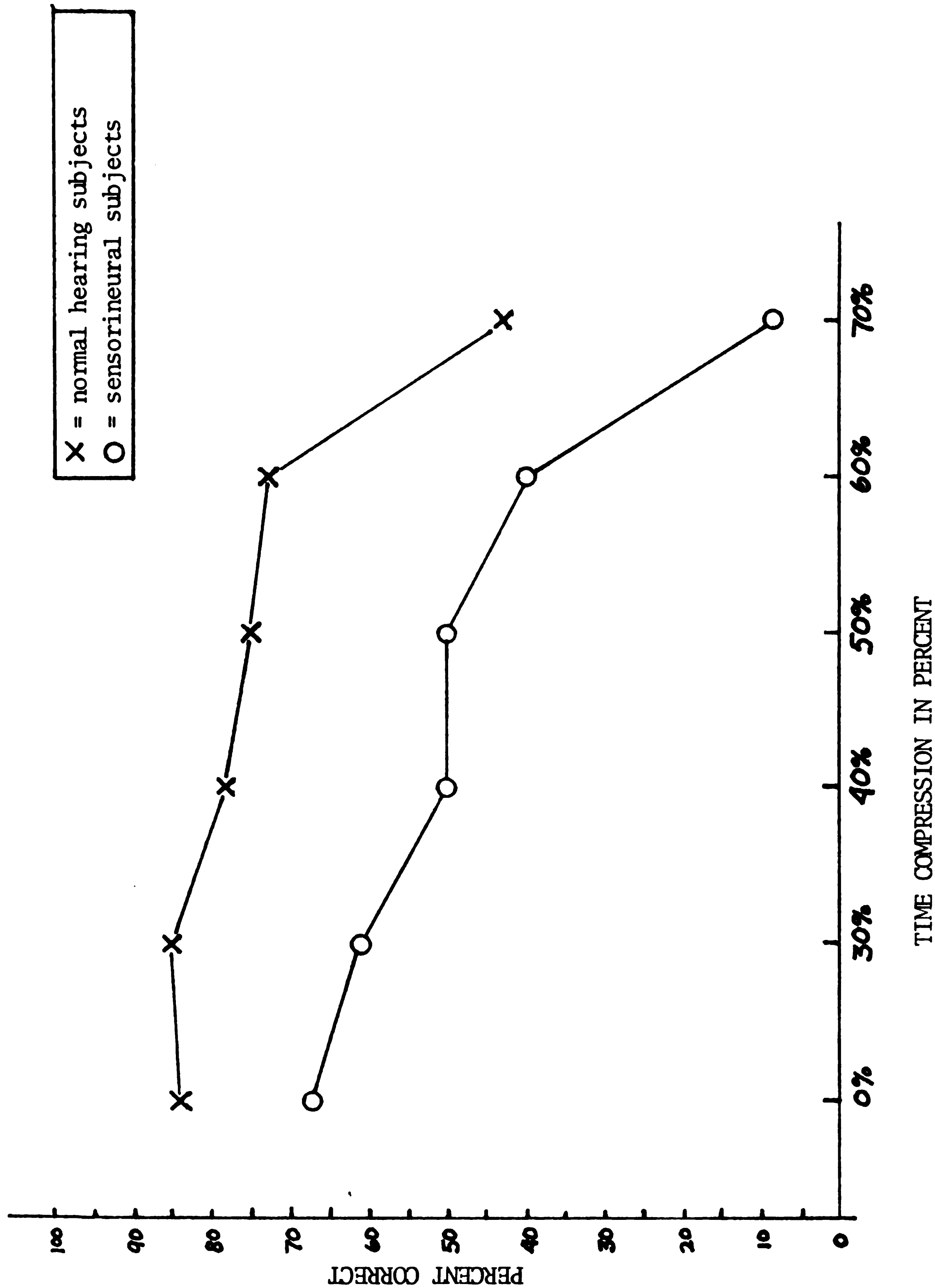

X = normal hearing subjects
O = sensorineural subjects
PERCENT CORRECT
100
90
80
70
60
50
40
30
20
10
0
0%
30%
40%
50%
60%
70%
TIME COMPRESSION IN PERCENT

Figure 9. Individual subject performance in percent, as a function of time compression at 16 dB sensation level.

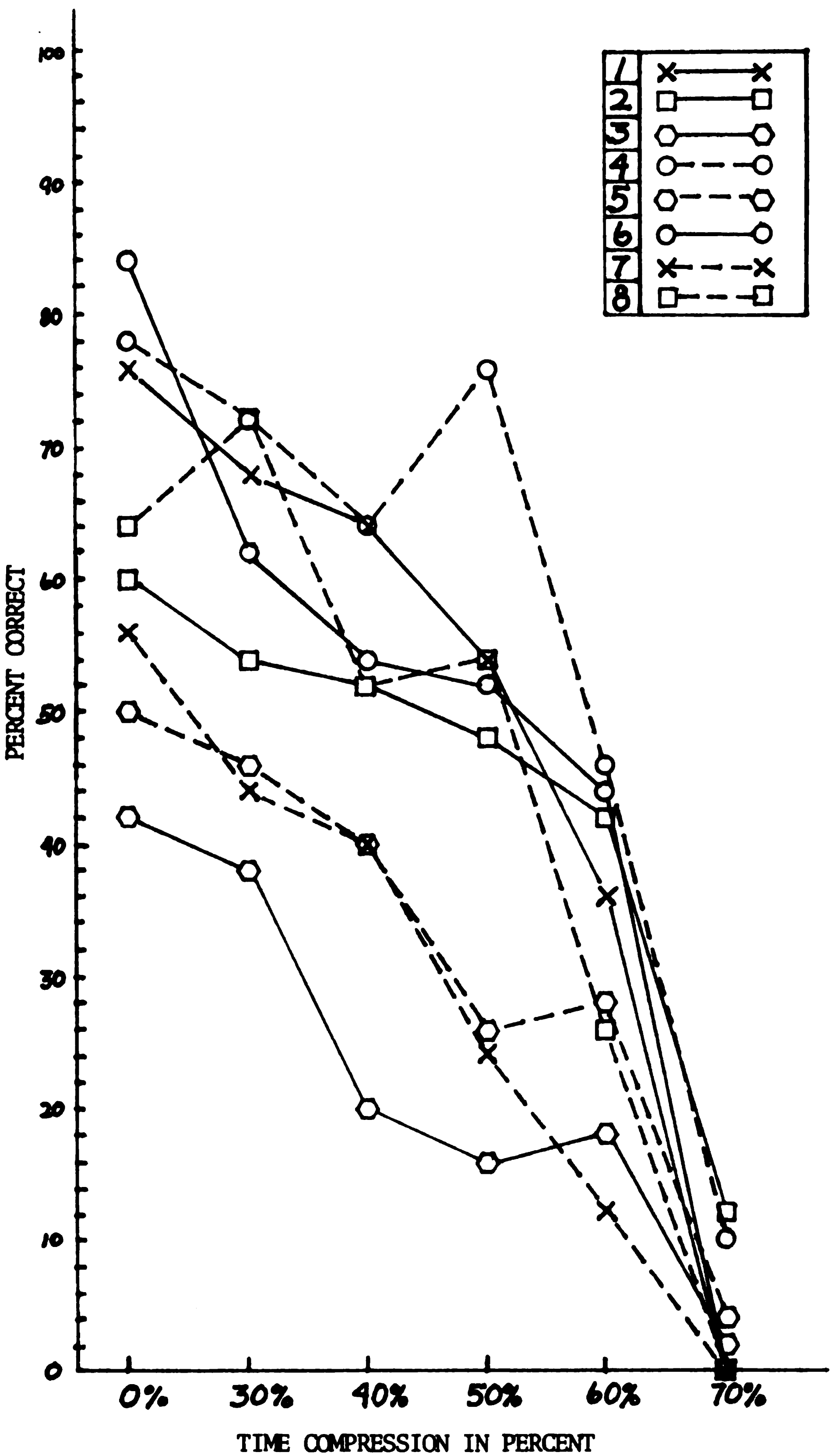
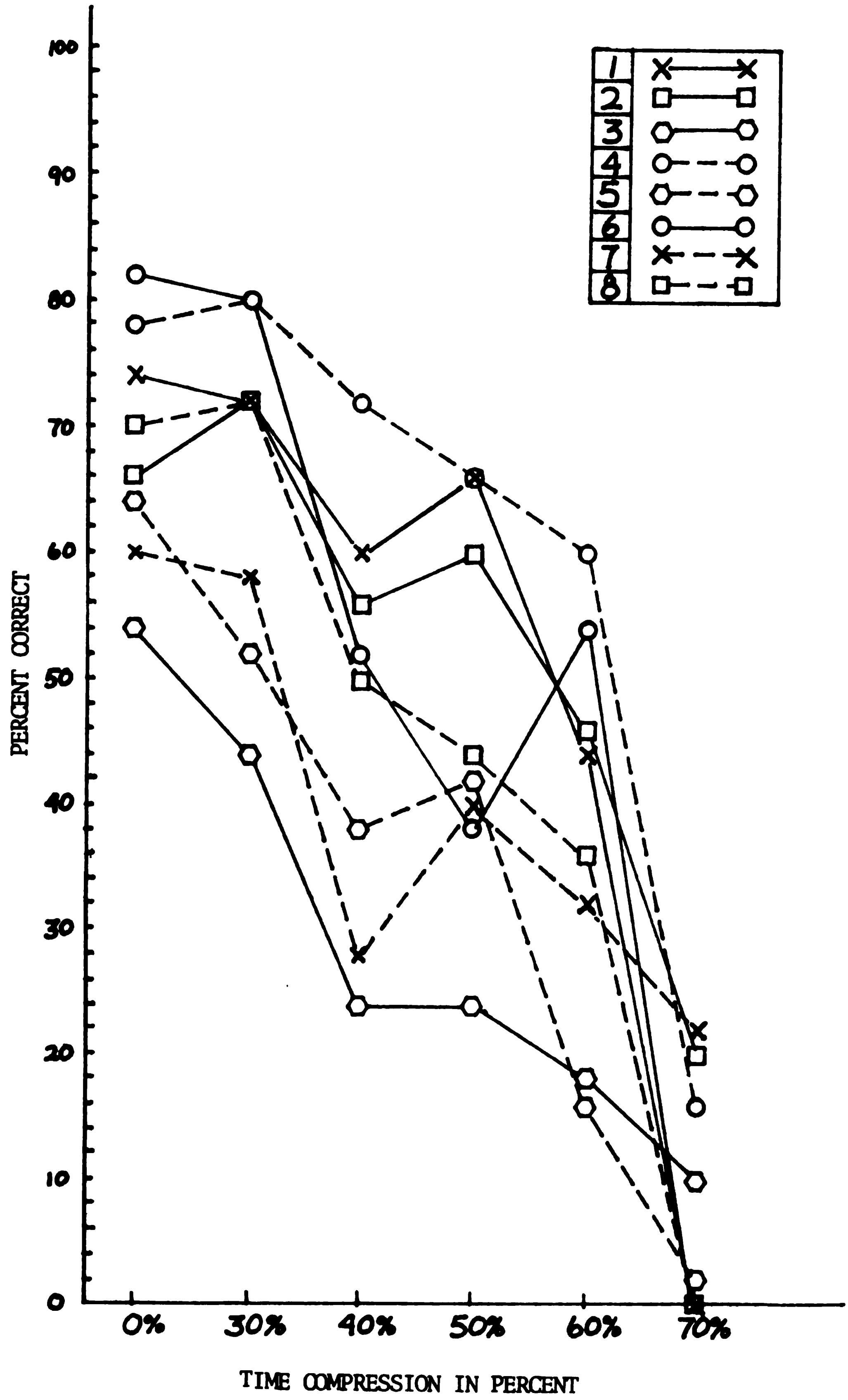

100
90
80
70
60
50
40
30
20
10
0
PERCENT CORRECT
1
2
3
4
5
6
7
8
0%
30%
40%
50%
60%
70%
TIME COMPRESSION IN PERCENT

Figure 10. Individual subject performance in percent, as a function of time compression at 24 dB sensation level.



100
90
80
70
60
50
40
30
20
10
0
PERCENT CORRECT
0%
30%
40%
50%
60%
70%
TIME COMPRESSION IN PERCENT
1
2
3
4
5
6
7
8

Figure 11. Individual subject performance in percent, as a function of time compression at 32 dB sensation level.

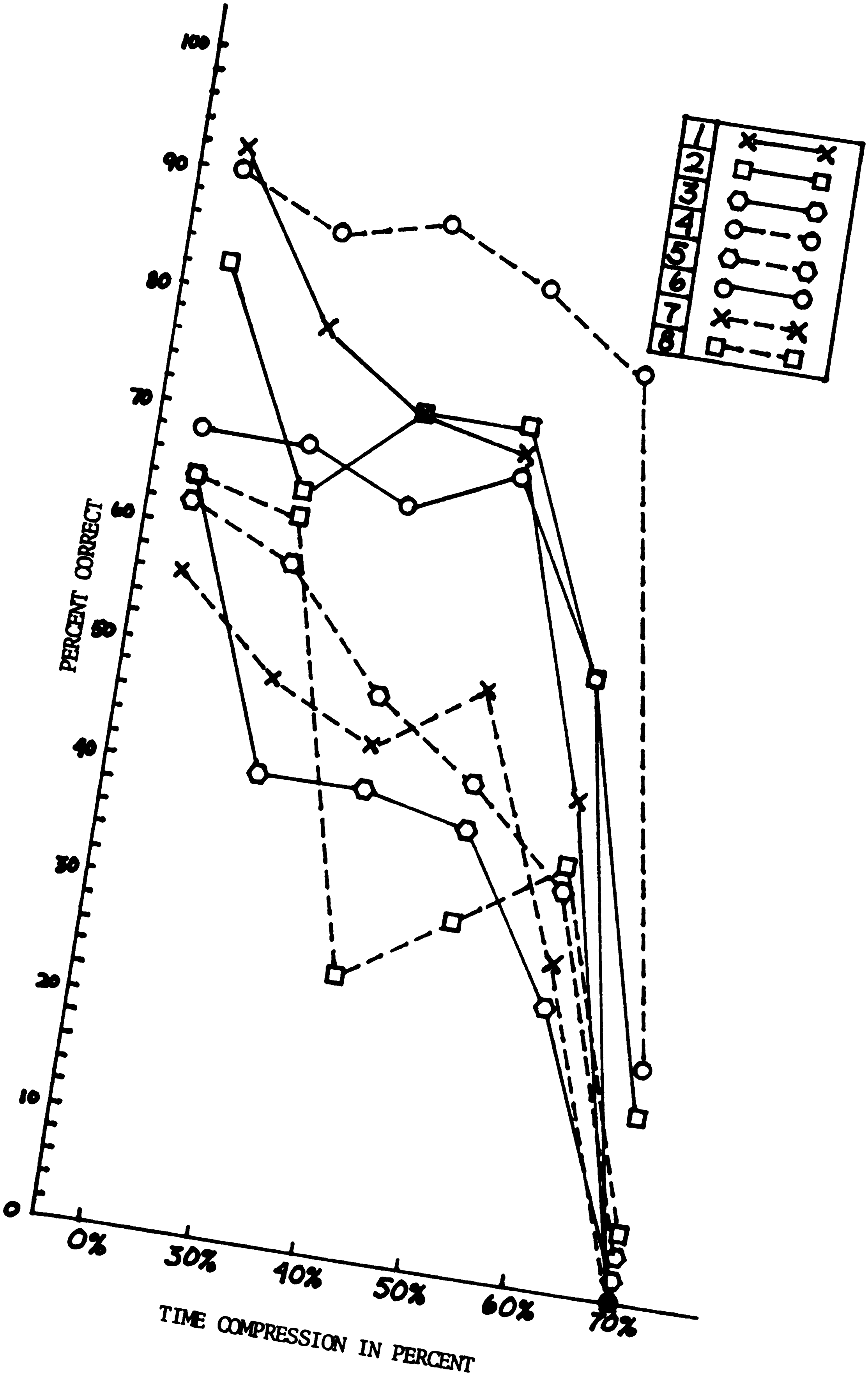
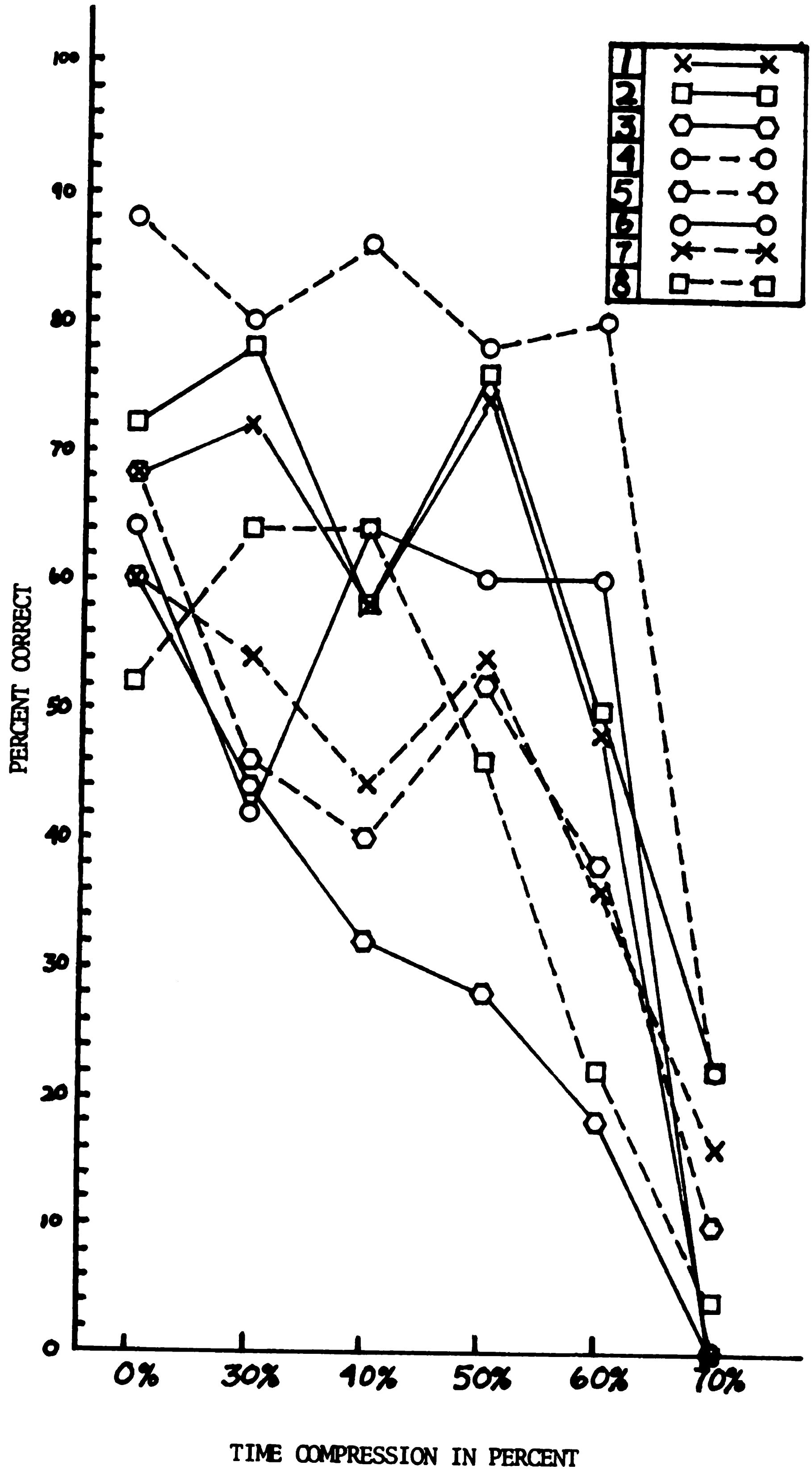

100
90
80
70
60
50
40
30
20
10
0
PERCENT CORRECT
0%
30%
40%
50%
60%
70%
TIME COMPRESSION IN PERCENT
1
2
3
4
5
6
7
8

Figure 12. Individual subject performance in percent, as a function of time compression at 40 dB sensation level.


PERCENT CORRECT
0
10
20
30
40
50
60
70
80
90
100
0%
30%
40%
50%
60%
70%
1
2
3
4
5
6
7
8
TIME COMPRESSION IN PERCENT

Time Compression and Sensation Level

Table I and Figure 21 illustrate that at 0% time compression the highest mean percent correct score was obtained at 32 dB SL, followed by 24, 40 and 16 dB SL respectively. At 30% time compression the best discrimination was achieved at 24 dB SL, followed by 32, 40 and 16 dB respectively. At 40% time compression PB Max was reached at 32 dB SL, however, this was the only ratio of time compression that did not illustrate an increase in intelligibility from 16 to 24 dB SL. Thus, scores obtained at 0%, 30% and 40% time compression indicate that PB Max occurs prior to the highest sensation level of 40 dB.

Beginning at 50% time compression, intelligibility improved at each successive higher sensation level. This is particularly evident at 50% and 60% time compression. At 70% time compression the greatest increase in intelligibility occurs between 16 and 24 dB SL, with no significant change beyond 24 dB SL.

Figure 22 compares the Beasley, Schwimmer and Rintelmann (1972) and Beasley, Forman and Rintelmann (1972) data on normal-hearing subjects to the data obtained in this study on sensorineural hearing-impaired subjects. Results of the normal-hearing group indicates that intelligibility of time compressed CNC monosyllables is significantly affected by sensation level. These investigators found that increased discrimination ability was demonstrated at each time compression condition as sensation level was increased; thus, maximum intelligibility for normal listeners was attained at 40 dB SL over all conditions of time compression.

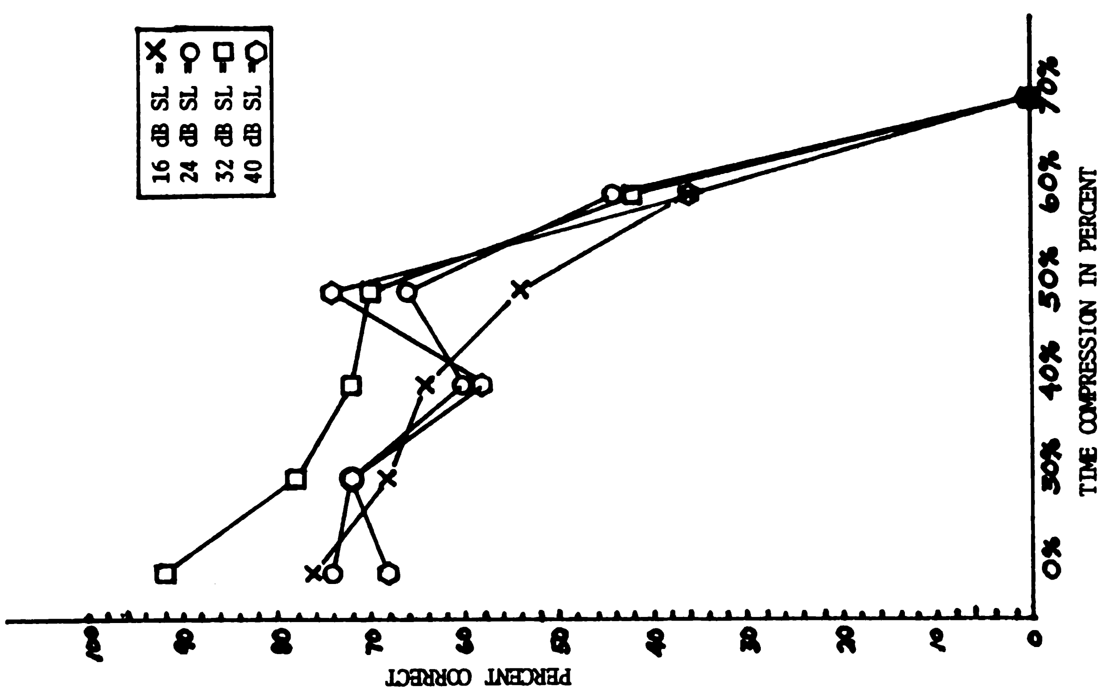
When the data of the present study are collapsed across time compression conditions, there appears to be little improvement in discrimination at sensation levels higher than 24 dB. However, this is somewhat misleading because, as reported above, at different ratios of time compression, maximum discrimination ability is shown at different sensation levels.

Figures 13b through 20b illustrate the articulation functions for each subject. Subject 1 showed an increase in intelligibility as sensation level was increased for only the 50% ratio of time compression. At all other compression ratios intelligibility decreased at the highest sensation level. Subject 3 reached PB Max at 32 dB SL for each time compression condition except 30% and 70% time compression where maximum discrimination was reached at 24 dB SL. Subject 4 achieved his best discrimination score at 32 dB SL for 0%, 30%, 40% and 50% time compression with a slight reduction in scores at 40 dB SL. For this subject, at 60% and 70% time compression, intelligibility increased as sensation level was increased and his highest scores were obtained at 40 dB SL. Subject 2 and Subjects 5 through 8 show somewhat erratic articulation functions throughout each ratio of time compression.

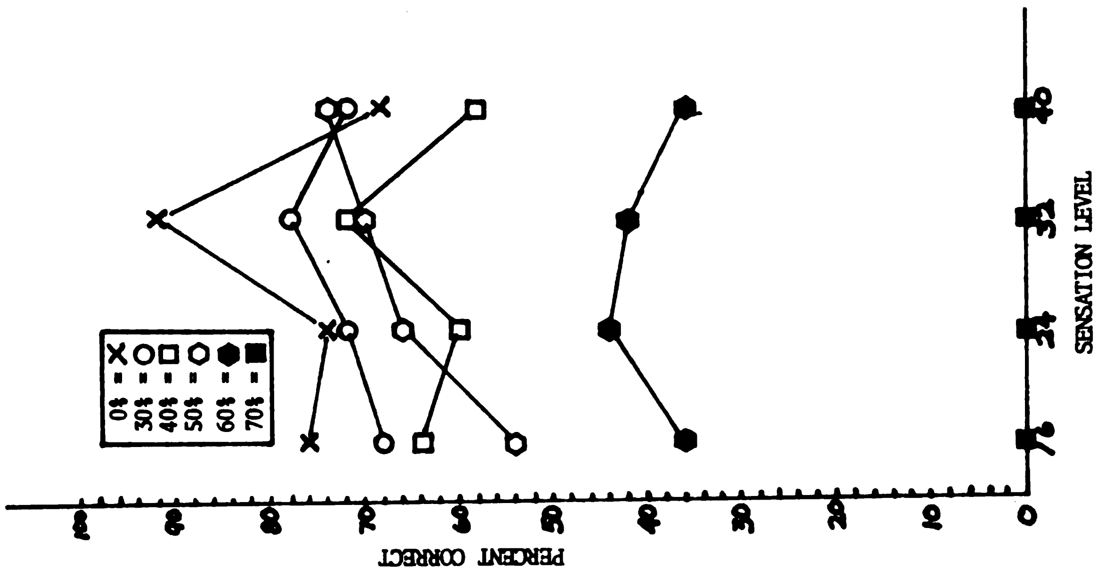
The variability described above for a given subject under varying conditions of time compression suggest the necessity for generating articulation functions with time compressed speech rather than testing at a single sensation level and hoping to reach PB Max.

Figure 13a. Speech discrimination in percent, as a function of time compression, at all sensation levels for Subject 1.

Figure 13b. Speech discrimination in percent, as a function of sensation level for, for six conditions of time compression for Subject 1.


16 dB SL
24 dB SL
32 dB SL
40 dB SL
PERCENT CORRECT
TIME COMPRESSION IN PERCENT
0%
30%
40%
50%
60%
70%

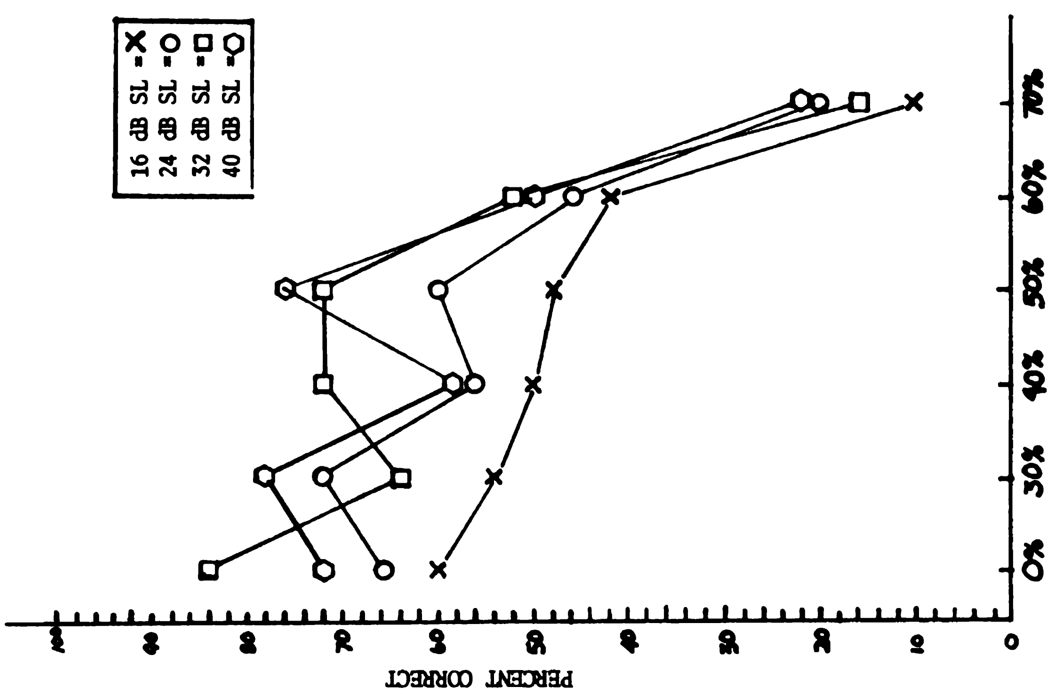
13a


0%
30%
40%
50%
60%
70%
PERCENT CORRECT
SENSATION LEVEL

13b

Figure 14a. Speech discrimination in percent, as a function of time compression, at all sensation levels for Subject 2.

Figure 14b. Speech discrimination in percent, as a function of sensation level, for six conditions of time compression for Subject 2.


PERCENT CORRECT
0
10
20
30
40
50
60
70
80
90
100
0%
30%
40%
50%
60%
70%
TIME COMPRESSION IN PERCENT
16 dB SL = X
24 dB SL = O
32 dB SL = □
40 dB SL = ⬡
14a

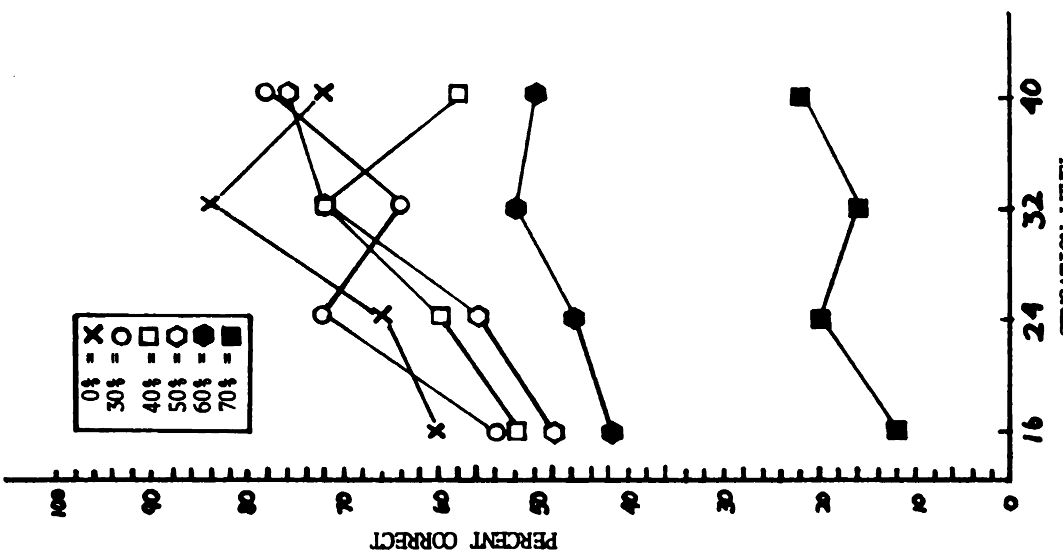
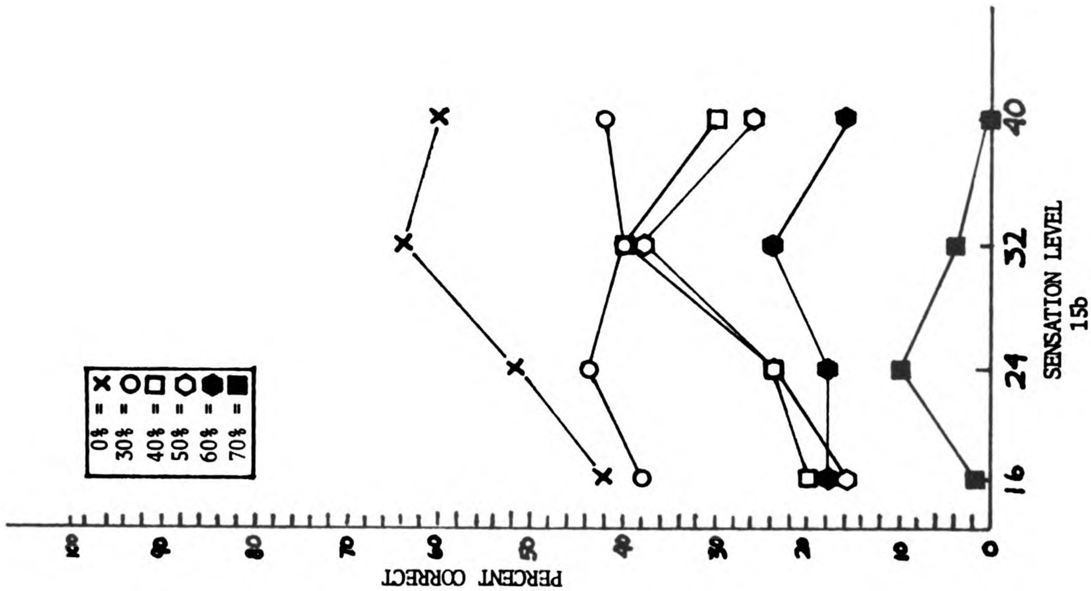

PERCENT CORRECT
0
10
20
30
40
50
60
70
80
90
100
16
24
32
40
SENSATION LEVEL
0% = X
30% = O
40% = □
50% = ⬡
60% = ⬢
70% = ■
14b

Figure 15a. Speech discrimination in percent, as a function of time compression, at all sensation levels for Subject 3.

Figure 15b. Speech discrimination in percent, as a function of sensation level, for six conditions of time compression for Subject 3.


PERCENT CORRECT
0% =
30% =
40% =
50% =
60% =
70% =
16
24
32
40
SENSATION LEVEL
15b

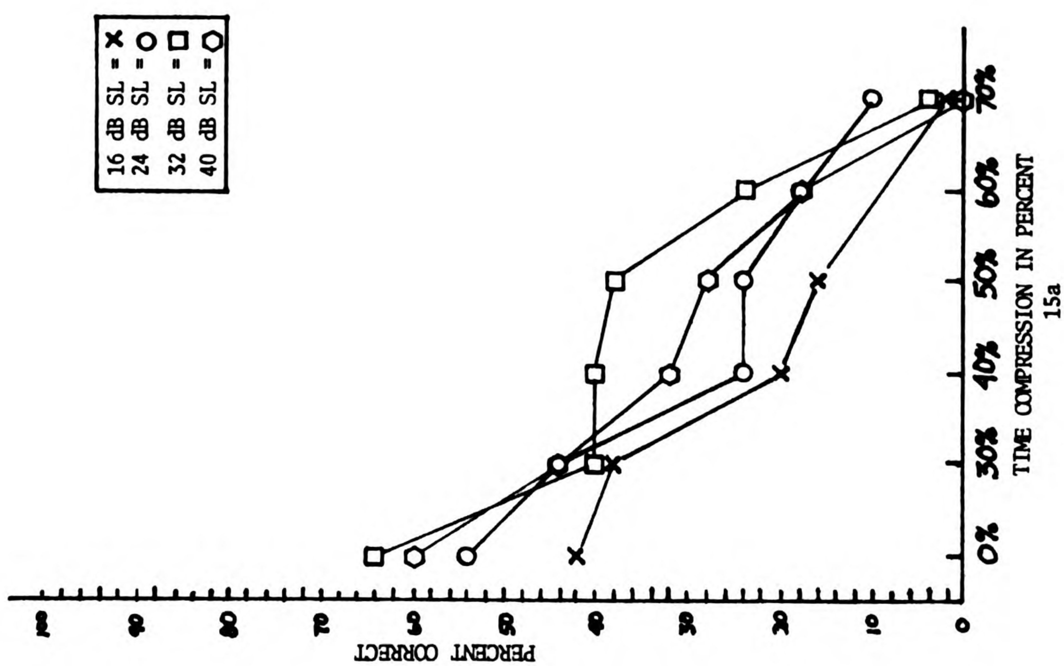

PERCENT CORRECT
16 dB SL =
24 dB SL =
32 dB SL =
40 dB SL =
0%
30%
40%
50%
60%
70%
TIME COMPRESSION IN PERCENT
15a

Figure 16a. Speech discrimination in percent, as a function of time compression, at all sensation levels for Subject 4.

Figure 16b. Speech discrimination in percent, as a function of sensation level, for six conditions of time compression for Subject 4.

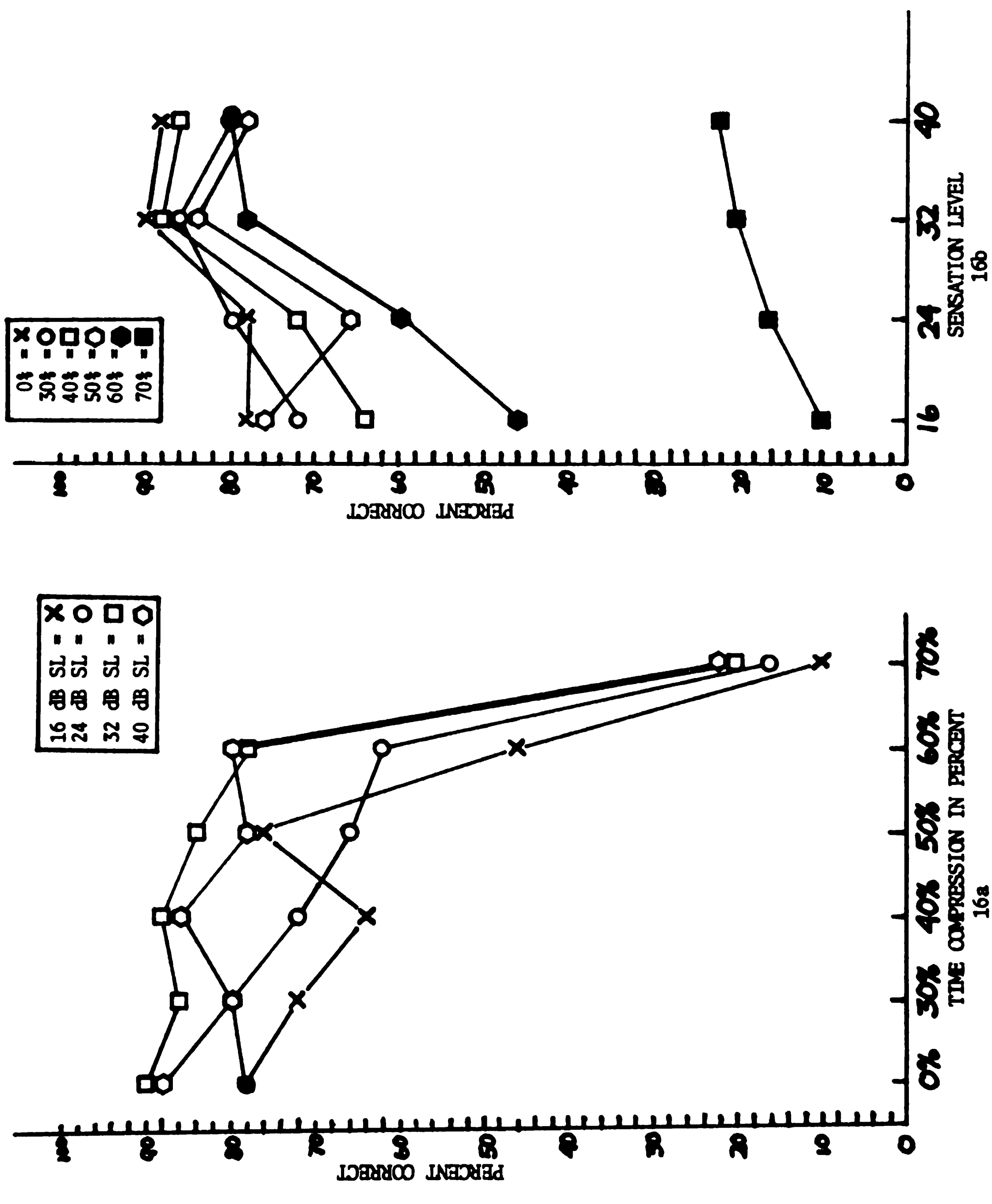
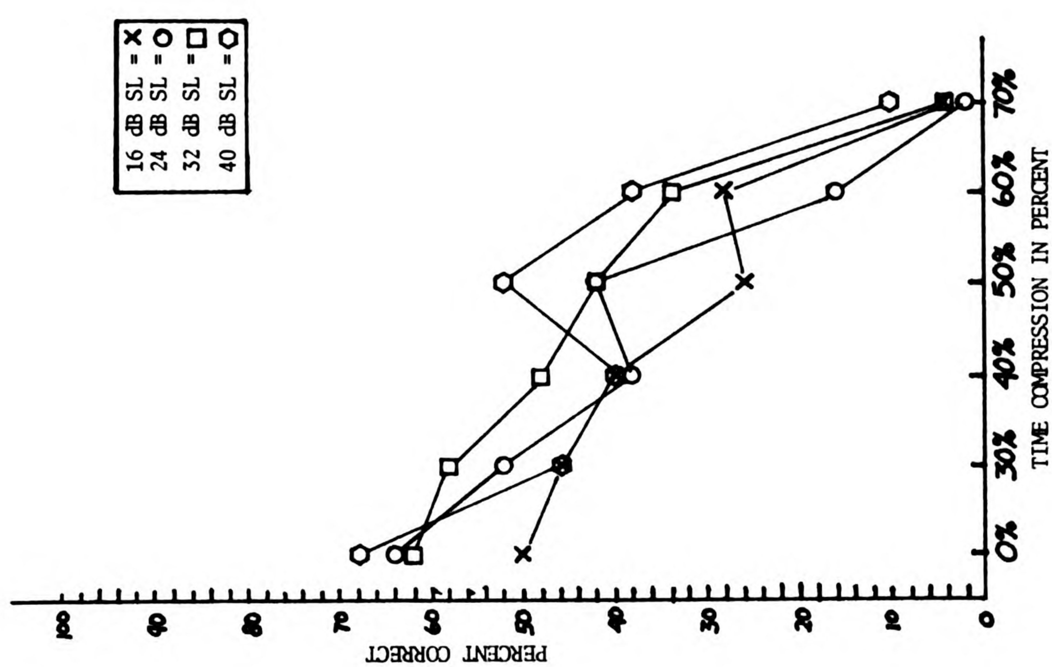
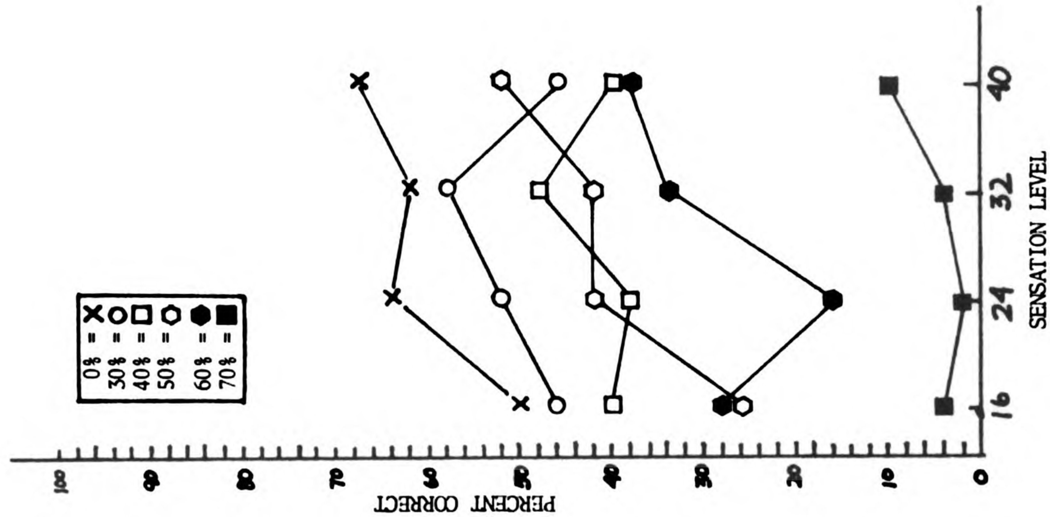

PERCENT CORRECT
0% 30% 40% 50% 60% 70%
TIME COMPRESSION IN PERCENT
16a
16 dB SL =
24 dB SL =
32 dB SL =
40 dB SL =
16 24 32 40
SENSATION LEVEL
16b
0% =
30% =
40% =
50% =
60% =
70% =

Figure 17a. Speech discrimination in percent, as a function of time compression, at all sensation levels for Subject 5.

Figure 17b. Speech discrimination in percent, as a function of sensation level, for six conditions of time compression for Subject 5.


16 dB SL = ×
24 dB SL = ○
32 dB SL = □
40 dB SL = ⬡
PERCENT CORRECT
0
10
20
30
40
50
60
70
80
90
100
0%
30%
40%
50%
60%
70%
TIME COMPRESSION IN PERCENT

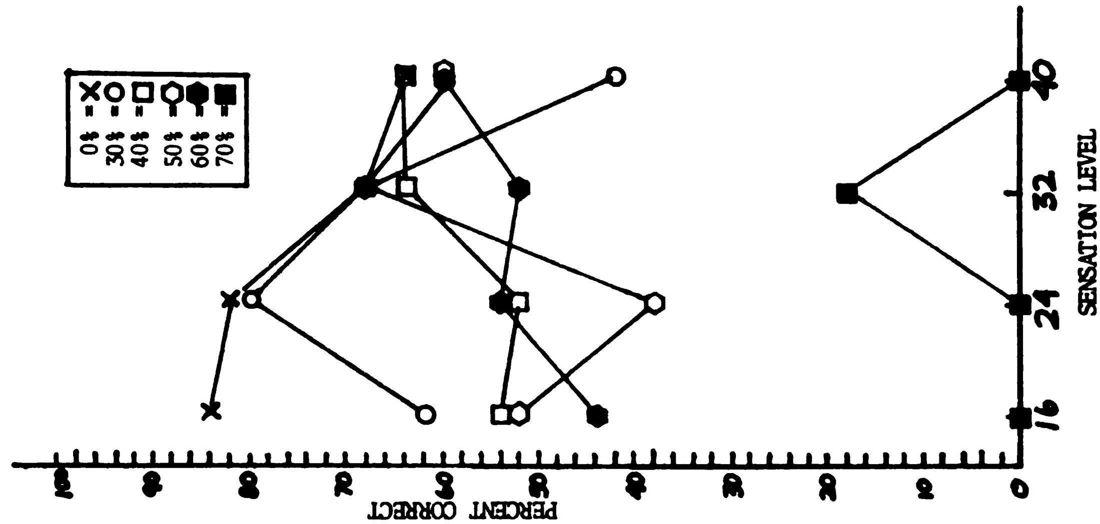
17a


0% = ×
30% = ○
40% = □
50% = ⬡
60% = ⬢
70% = ■
PERCENT CORRECT
0
10
20
30
40
50
60
70
80
90
100
16
24
32
40
SENSATION LEVEL

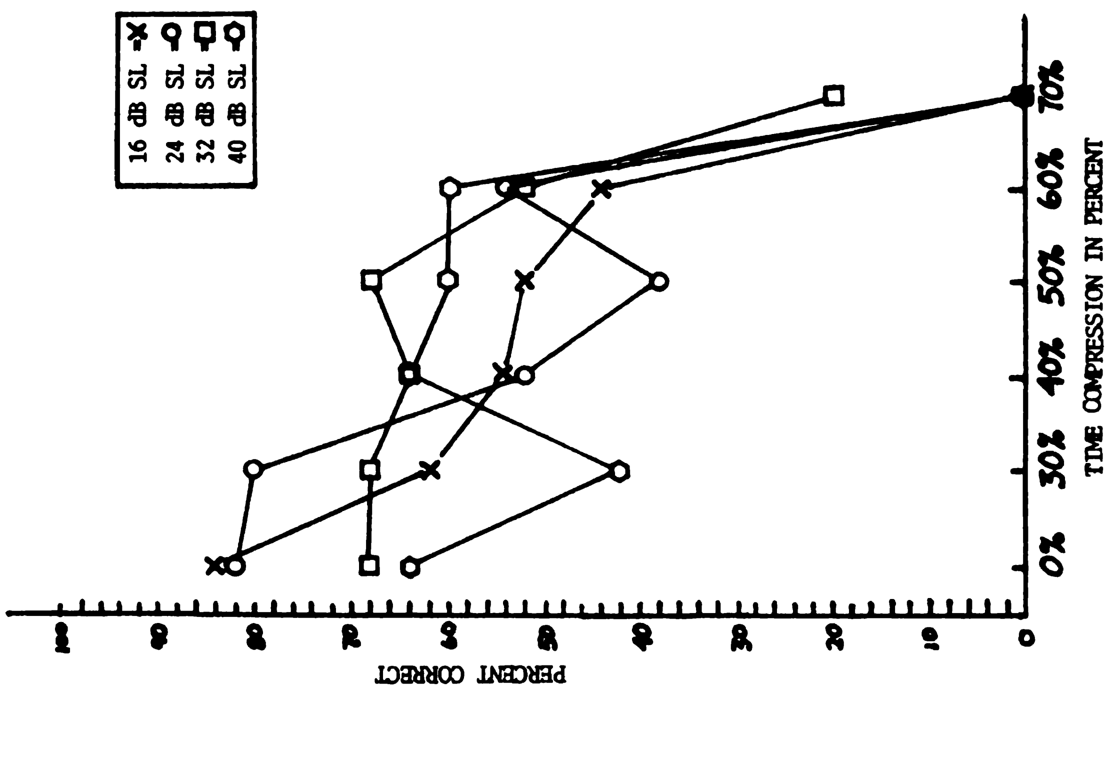
17b

Figure 18a. Speech discrimination in percent, as a function of time compression, at all sensation levels for Subject 6.

Figure 18b. Speech discrimination in percent, as a function of sensation level, for six conditions of time compression for Subject 6.


0%
30%
40%
50%
60%
70%
PERCENT CORRECT
0
10
20
30
40
50
60
70
80
90
100
16
24
32
40
SENSATION LEVEL

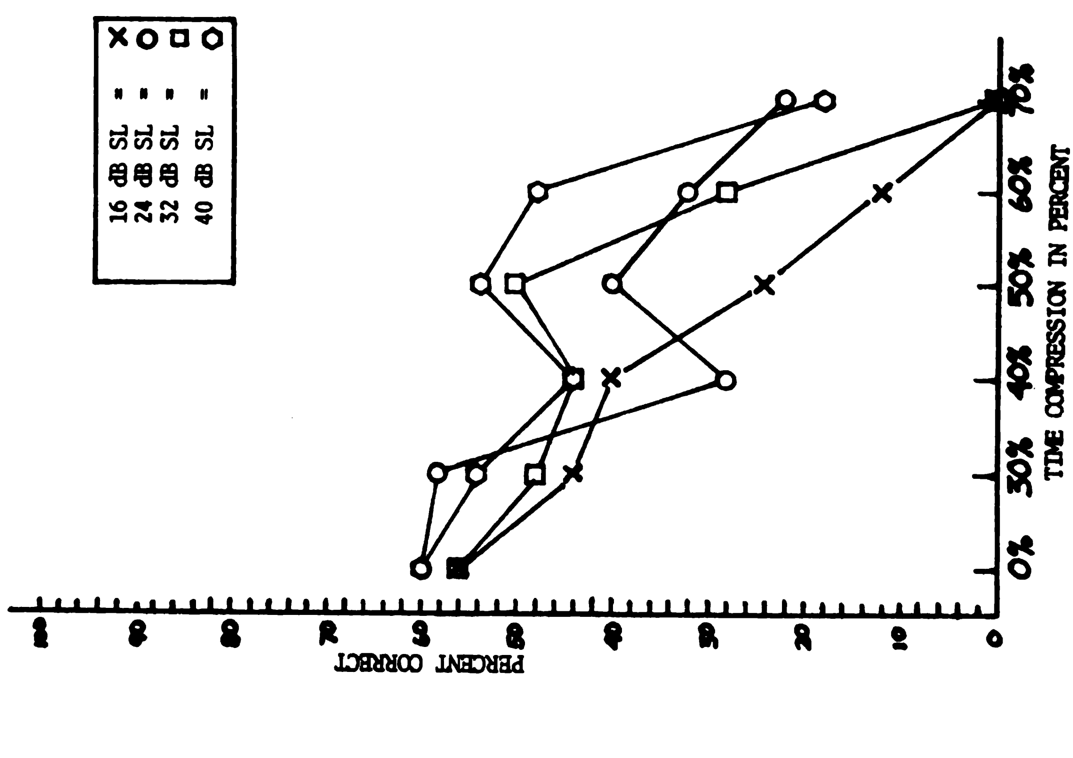
18b


16 dB SL
24 dB SL
32 dB SL
40 dB SL
PERCENT CORRECT
0
10
20
30
40
50
60
70
80
90
100
0%
30%
40%
50%
60%
70%
TIME COMPRESSION IN PERCENT

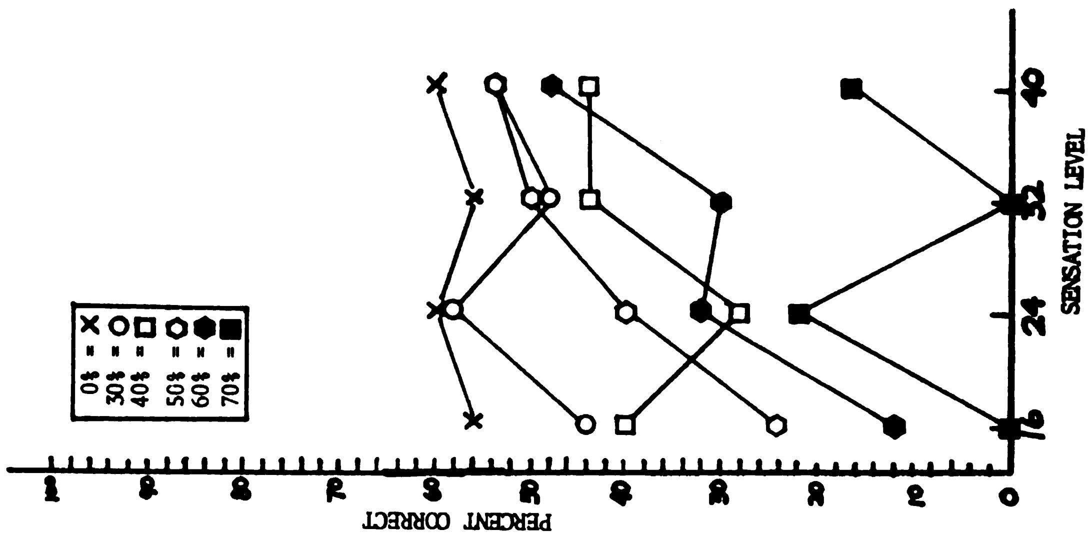
18a

Figure 19a. Speech discrimination in percent, as a function of time compression, at all sensation levels for Subject 7.

Figure 19b. Speech discrimination in percent, as a function of sensation level, for six conditions of time compression for Subject 7.


PERCENT CORRECT
0
10
20
30
40
50
60
70
80
90
100
0%
30%
40%
50%
60%
70%
TIME COMPRESSION IN PERCENT
16 dB SL =
24 dB SL =
32 dB SL =
40 dB SL =

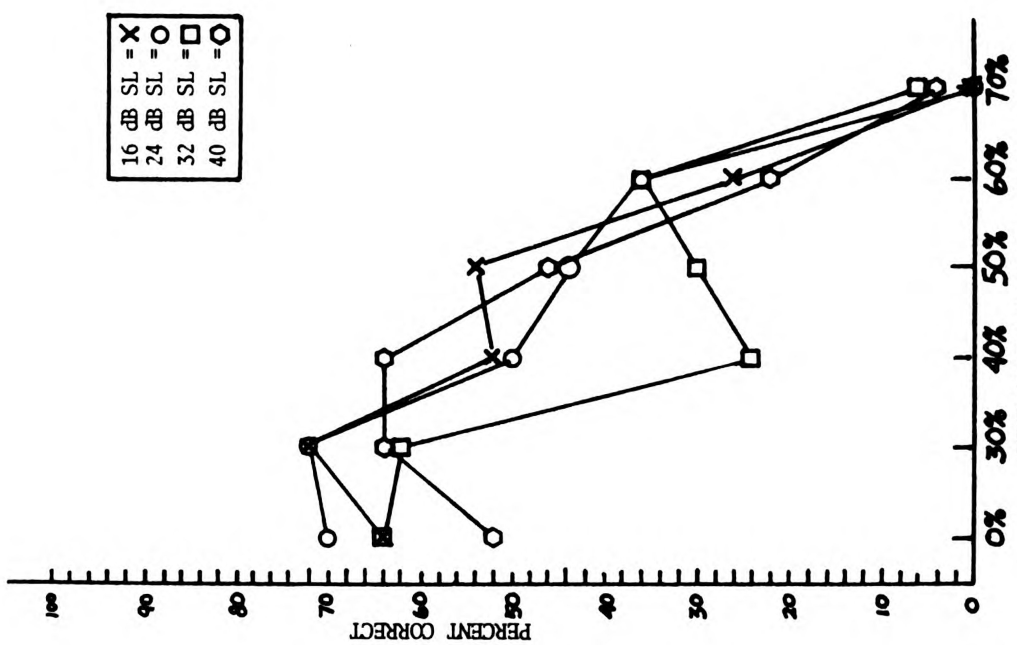
19a


PERCENT CORRECT
0
10
20
30
40
50
60
70
80
90
100
16
24
32
40
SENSATION LEVEL
0% =
30% =
40% =
50% =
60% =
70% =

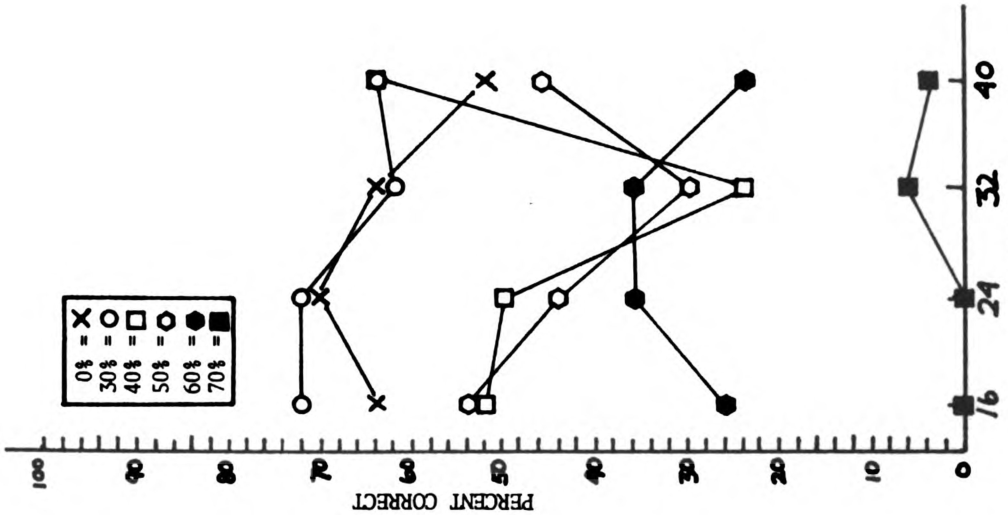
19b

Figure 20a. Speech discrimination in percent, as a function of time compression, at all sensation levels for Subject 8.

Figure 20b. Speech discrimination in percent, as a function of sensation level, for six conditions of time compression, for Subject 8.


PERCENT CORRECT
100
90
80
70
60
50
40
30
20
10
0
0%
30%
40%
50%
60%
70%
TIME COMPRESSION IN PERCENT
16 dB SL =
24 dB SL =
32 dB SL =
40 dB SL =

20a


PERCENT CORRECT
100
90
80
70
60
50
40
30
20
10
0
16
24
32
40
SENSATION LEVEL
0% =
30% =
40% =
50% =
60% =
70% =

20b

Figure 21. Discrimination in percent as a function of sensation level at six conditions of time compression, (N=8).

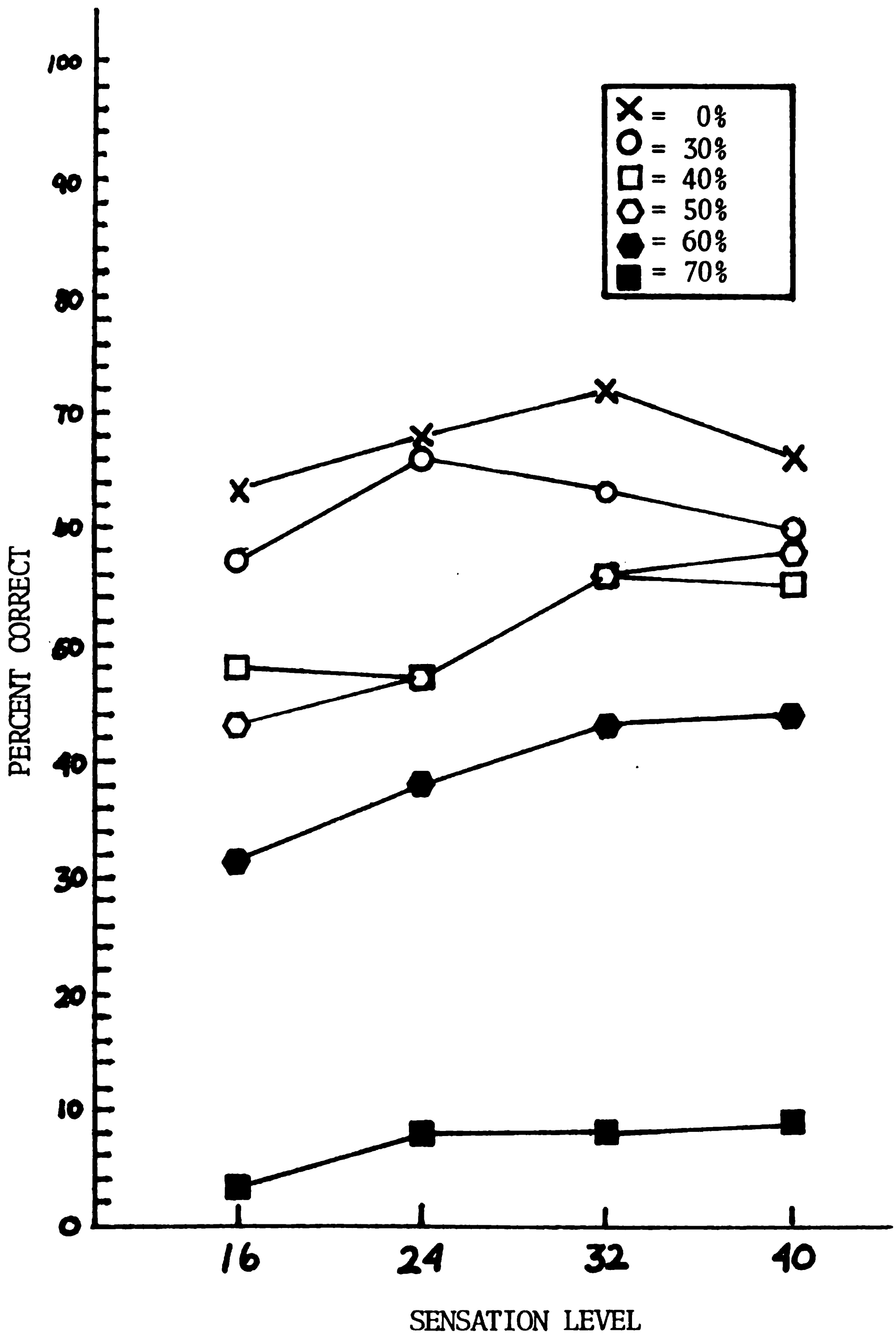
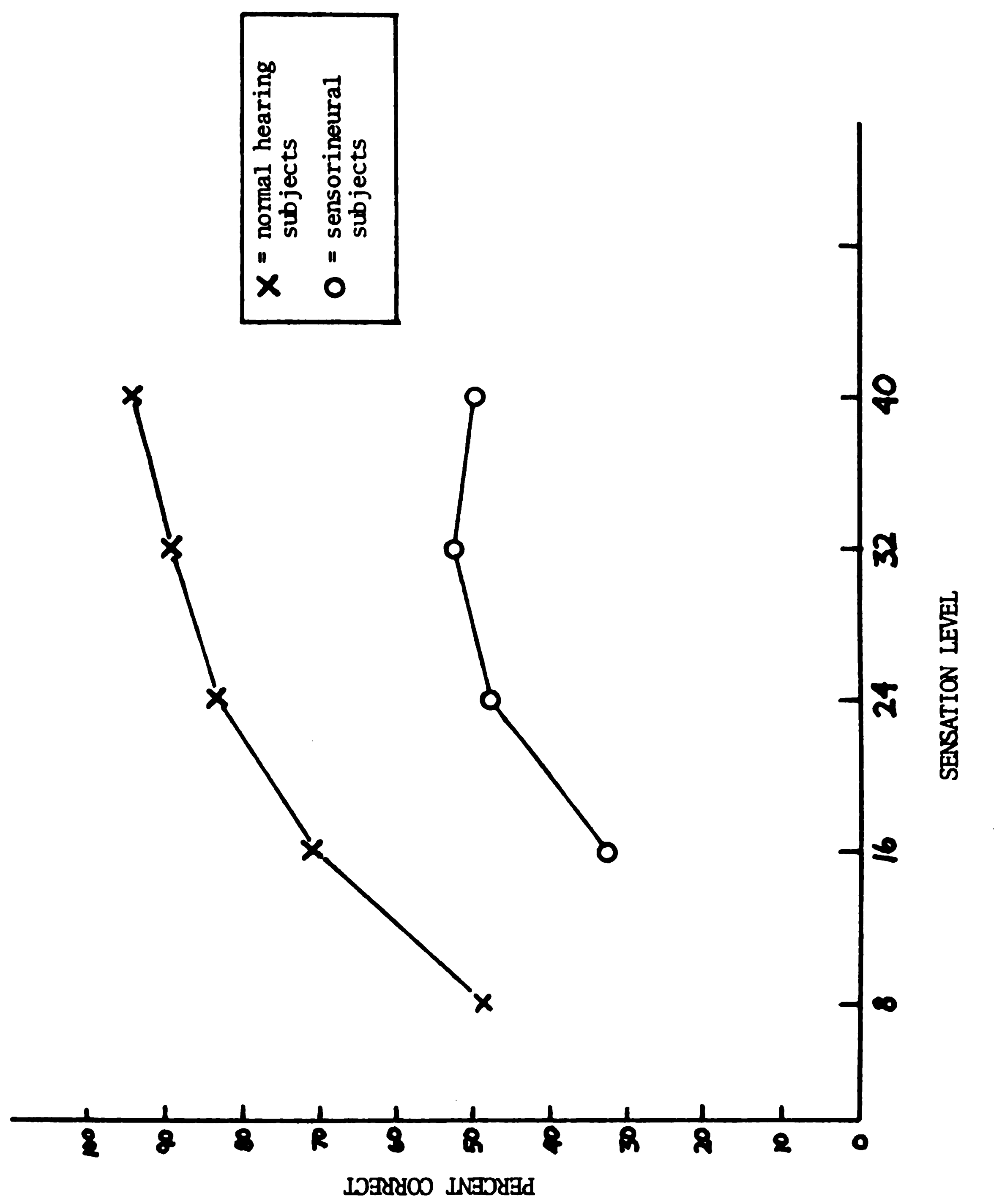

X = 0%
O = 30%
□ = 40%
⬡ = 50%
⬢ = 60%
■ = 70%
100
90
80
70
60
50
40
30
20
10
0
PERCENT CORRECT
16
24
32
40
SENSATION LEVEL

Figure 22. Average articulation scores collapsed over time compression, plotted by sensation level, illustrating the performance of normal-hearing (Beasley, Schwimmer and Rintelmann, 1972; Beasley, Forman and Rintelmann, 1972) and sensorineural groups.


X = normal hearing subjects
O = sensorineural subjects
PERCENT CORRECT
0
10
20
30
40
50
60
70
80
90
100
8
16
24
32
40
SENSATION LEVEL

An Unusual Case

Subject 9's results were atypical in comparison to the other 8 subjects; therefore, he was not included in the group means. Instead his responses are described separately. Figure 23 shows his pure tone audiogram and Figure 24a and 24b depict the time compression results for this subject. His audiogram is typical of the group and, therefore, cannot account for his unusual response characteristics.

At 0%, 30% and 40% time compression his speech discrimination scores are in agreement with the other subjects. He shows relatively flat articulation functions at these ratios of time compression, with his best score at 0% time compression at 24 dB SL. Beginning with 40% time compression, however, the articulation functions become slightly erratic and at 50% through 70% time compression, better discrimination scores were obtained at the lowest sensation level of 16 dB. At 50% time compression the best scores were obtained at 16 and 40 dB SL, followed by 32 and 24 dB SL respectively. At 60% and 70% time compression his best scores were again at 16 dB SL, followed by 24, 32 and 40 dB SL respectively. Specifically, this subject reached PB Max at 16 dB SL at the higher ratios of time compression. This is illustrated in Figure 24b. Because of this unusual response pattern, Subject 9 was retested at 30%, 60% and 70% time compression at 16 and 40 dB SL. The results of the retest were in good agreement with those of the test. Therefore it was concluded that his responses were reliable.

Figure 24a depicts that as the ratio of time compression is increased, intelligibility decreases. Even though results are atypical, related to sensation level, a gradual reduction in intelligibility occurs from 0% through 60% time compression with a definite breakdown in intelligibility at 70% time compression. Thus, the way in which this subject is unusual is that his best performance at high time compression conditions occurs at low sensation levels. A possible explanation for this unusual behavior is given in the Discussion section.

Figure 23a. Speech discrimination in percent, as a function of time compression, at all sensation levels for Subject 9.

Figure 23b. Speech discrimination in percent, as a function of sensation level, for six conditions of time compression for Subject 9.

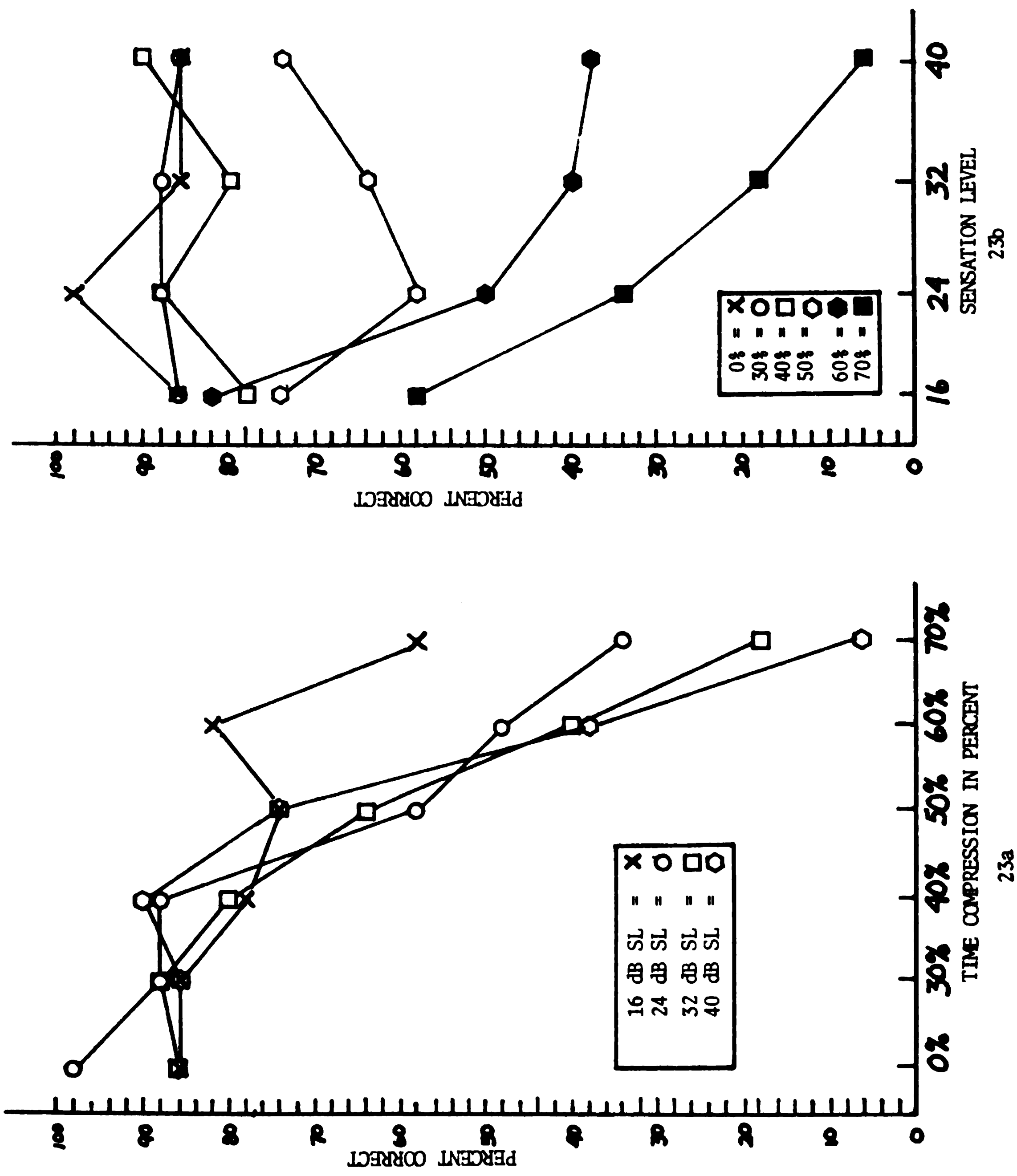
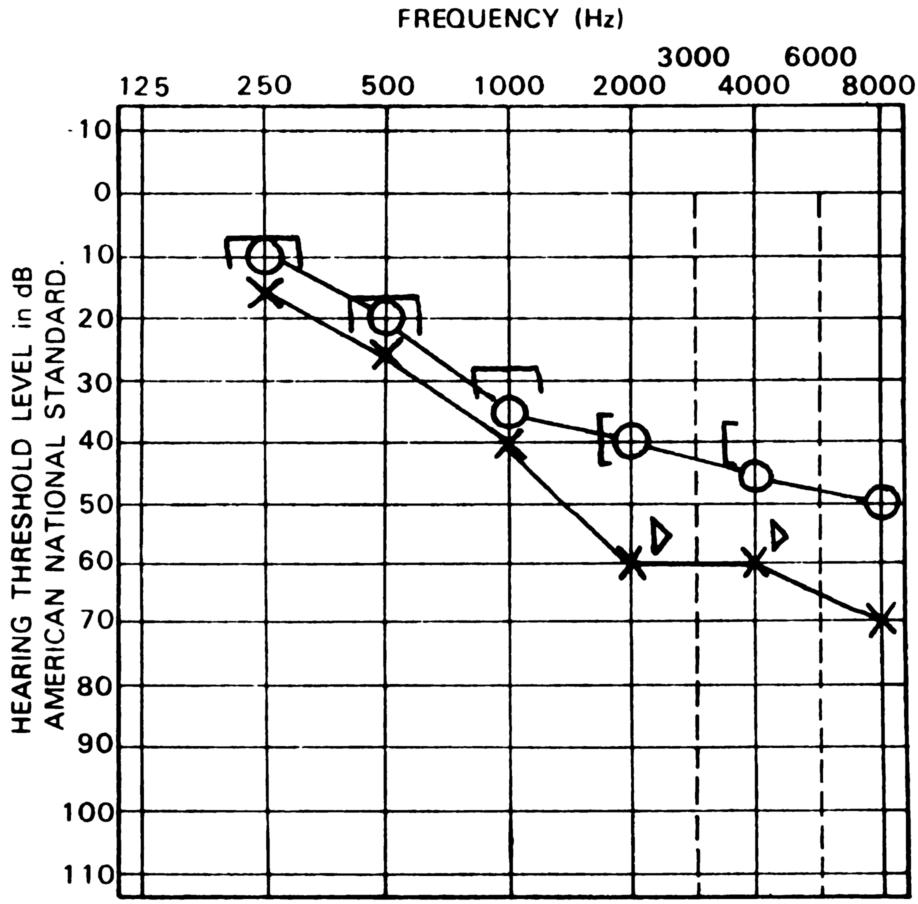

PERCENT CORRECT
SENSATION LEVEL
23b
0% =
30% =
40% =
50% =
60% =
70% =
PERCENT CORRECT
TIME COMPRESSION IN PERCENT
23a
16 dB SL =
24 dB SL =
32 dB SL =
40 dB SL =

Figure 24. Pure tone audiogram of Subject 9.

Subject 9
Age: 29

Ear Under Test: Right



Better Cochlea: ⌐¬

500, 1000 and 2000 Hz Average:	Right Ear	32 dB
	Left Ear	42 dB
Speech Reception Threshold:	Right Ear	38 dB
	Left Ear	40 dB

CHAPTER IV

DISCUSSION

Time Compression and Intelligibility

Results of this study are similar to the results obtained by Beasley, Schwimmer and Rintelmann (1972) and Beasley, Forman and Rintelmann (1972), in that, intelligibility decreases as the ratio of time compression is increased. This decrease is gradual over the conditions of time compression until 70% time compression where a dramatic breakdown in intelligibility occurs.

Although the decrease in intelligibility is gradual over all conditions of time compression, for individual subjects with sensorineural hearing loss, it is not as "clean cut" as the data obtained on a normal hearing population. Persons with sensorineural hearing impairments, with the pathology localized in the cochlea, characteristically demonstrate decreased ability to discriminate speech stimuli (Yantis, _et al._, 1966). Discrimination also varies considerably from person to person, whereas, in persons with normal hearing, discrimination is usually close to 100% (Carhart, 1965). The amount of reduction over each percentage of time compression will also depend upon the type and extent of the auditory lesion. This accounts for the large standard deviations noted over all the conditions of time compression utilized in this study.

It is difficult to make direct comparisons between this study and other studies using sensorineural subjects because of differences in the speech discrimination test material (e.g. CID W-22 versus NU-6), in time compression conditions, methods of time compression and extent and nature of sensorineural hearing loss. It can be noted, however, that in previous studies, at the higher rates of accelerated speech, a marked deterioration in intelligibility was found both in cochlear pathology (deQuiros, 1964) and in aged adults (Calearo and Lazzaroni, 1957; Bergman, 1971). This latter group of subjects, aged adults, represents not only cochlear damage isolated to hair cells, but also neural degeneration in the central as well as the peripheral auditory system (Schuknecht, 1959). Thus, one would expect that time compressed speech discrimination should be markedly reduced in presbycusic subjects. It is hypothesized that, in the aged, a dramatic "breakdown" in speech discrimination with CNC monosyllables would occur at 50% or 60% instead of 70% as it does in both normals and sensorineural hearing-impaired subjects. This hypothesis, of course, awaits investigation with a carefully standardized time compression test such as the one employed in the present study.

Time Compression and Sensation Level

Results of this study demonstrated that at 0%, 30% and 40% time compression, a maximum discrimination score was reached prior to the highest sensation level (40 dB); whereas, at 50%, 60% and 70% compression, intelligibility continued to improve slightly as sensation level was increased to 40 dB SL. Beasley, Schwimmer and Rintelmann (1972) and Beasley, Forman and Rintelmann (1972) found sensation level to be a significant factor in intelligibility at all time compression conditions in a normal hearing population. They found that each time sensation level was increased, intelligibility improved. Thus, sensorineural subjects did not benefit as much as normals at 0%, 30% and 40% time compression when they were given the same speech discrimination task (NU-6).

Among sensorineural subjects, the range of sensation levels that are capable of yielding the highest discrimination score (PB Max) is often quite restricted, and levels above these intensities can produce a reduction in discrimination scores rather than maintaining a "plateau" as is seen in a normal-hearing listener or one with a conductive hearing impairment (Huizing and Reyntjes, 1952).

Individuals with cochlear pathology demonstrate a greatly restricted dynamic range. Some hearing-impaired populations with restricted dynamic ranges, such as noise-induced hearing loss cases, also experience recruitment, or an abnormally rapid increase in the loudness function. When PB words are presented to these persons, at varying intensity levels, the articulation curve generated does not resemble that of a normal hearing population. When the optimum listening level is passed, a rapid fall of articulation score is found. At higher sensation levels the discrimination score decreases (Huizing and Reyntjes, 1952).

Clemis and Carver (1967) in a study on individuals with Meniere's disease, found that best discrimination scores were obtained at 32 dB SL instead of the highest sensation level of 40 dB. The articulation functions generated in their study are slow rising, until 32 dB SL; the functions then "roll over" or become worse at 40 dB SL, suggesting only a narrow range of maximum discrimination ability. They suggested that PB Max be established by plotting an entire articulation function for these hearing-impaired individuals, so that discrimination scores can be compared.

One subject (9) in the present study, dramatically illustrates this phenomenon at 60% and 70% time compression. At these ratios his highest speech discrimination score was obtained at the lowest sensation level. Percent correct scores then decreased consistently as sensation level was increased. Although tests for recruitment were not administered, it can be hypothesized that this subject had a restricted dynamic range. His optimum intensity level was low as illustrated by his performance at these high ratios (60% and 70%) of time compression. It may be speculated that this individual's articulation function shows a very steep rise with a plateau at about 16 dB SL and then a rapid "roll over" function so that at higher sensation levels where most individuals perform maximally, this subject demonstrated poorer discrimination performance.

Unfortunately, effects of sensation level on the intelligibility of time compressed speech in earlier studies with sensorineural subjects (Luterman, <u>et al.</u>, 1966; Sticht and Gray, 1969) cannot be compared to the present findings. Luterman, et al. and Sticht and Gray utilized only a 40 dB sensation level over all conditions of time compression. In cochlear pathology, a restricted dynamic range and recruitment may be present, thus optimum intensity may be lower than 40 dB SL for these subjects. Therefore, the above studies may not illustrate the optimum discrimination score at each condition of time compression employed.

Implications for Further Research

Since information on time compressed CNC monosyllables has been obtained on normal hearing and sensorineural subjects, research should be extended to the effects of time compressed CNC words on the discrimination ability of subjects with conductive, retrocochlear and central auditory system disorders. These investigations would further assess the clinical significance of time compressed speech in the differential diagnosis of central auditory lesions. Investigations of this nature would also permit the best combinations of time compression and sensation level that would be diagnostically usable.

The time compressed monosyllables should also be presented to a group of presbycusic adults. Although presbycusis produces a sensorineural hearing impairment, some central involvement may be present (Shambaugh, 1967). Because of this, differences in scores over all ratios of time compression may be seen in comparison to the data obtained on subjects with only cochlear pathology.

Time compressed monosyllables should also be compared with other distorted speech signals that have been previously developed for the identification of central auditory lesions. Bocca and Calearo (1963) have noted that frequency distortion is useful in the identification of lesions above the 3rd neuron. Time distorted speech stimuli have been more useful in diagnosing involvement from the superior olivary nuclei to the auditory radiations (Carhart, 1969). Calearo and Lazzaroni (1957) and deQuiros (1964) have also found that distorted speech can aid in the identification of damage in the higher auditory pathways and also of lesions at or above the 3rd neuron. Thus, it appears that time compressed speech may have important clinical utility as part of a battery of central auditory tests. Considerable further research is needed.

CHAPTER V

SUMMARY AND CONCLUSIONS

Since lesions in the brain stem and the auditory cortex elude conventional audiometric techniques, more sophisticated tests must be developed (willeford, 1969). Distorted speech tests, particularly time compressed speech material, have been investigated as potential diagnostic tools to aid in the positive identification of these lesions.

Beasley, Schwimmer and Rintelmann (1972) and Beasley, Forman and Rintelmann (1972) have discussed the clinical significance of time compressed CNC monosyllabic words, and have provided normative data using standard clinical procedures. The results of this study provide additional information relative to the intelligibility of time compressed speech. Specifically, results have been obtained on persons with noise-induced sensorineural hearing impairments. These findings have been compared to results on normal hearing adults under the same conditions of time compression.

It was found that for sensorineural hearing loss subjects, the intelligibility of time compressed speech stimuli decreases gradually up to the 60% time compression condition, with a dramatic breakdown in intelligibility at 70% time compression. This finding is in agreement with the studies conducted by Beasley, Schwimmer and Rintelmann (1972) and Beasley, Forman and Rintelmann (1972) on normal-hearing young adults.

It was also found that sensation level has an effect on intelligibility of time compressed speech. Lower sensation levels were required to reach optimal discrimination scores at 0%, 30% and 40% than at 50%, 60% and 70% time compression. At 30% time compression PB Max was reached at 24 dB SL, at 0% and 40% the best discrimination was found at 32 dB SL, whereas at 50%, 60% and 70% discrimination slightly improved continuously up to 40 dB SL. Thus, it appears that the greater the time compression the higher the intensity required for optimum discrimination.

Finally, sensorineural hearing-impaired subjects show time compressed articulation functions essentially parallel to normals but with reduced speech discrimination scores at all sensation levels. It should be cautioned, however, that there is considerable subject variability in performance among sensorineural subjects on time compressed CNCs, so that, it is difficult to predict which sensation level will attain "PB Max" for a given subject at any particular percentage of time compression. Therefore, time compressed speech should be administered to sensorineural subjects at several sensation levels.

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APPENDIX A

INITIAL LETTER SENT TO SUBJECTS

MICHIGAN STATE UNIVERSITY

Department of Audiology and Speech

November, 1971

Dear

The Michigan State University Speech and Hearing Clinic is presently conducting a research study. One essential step in doing so is to learn more about hearing problems. For this reason I am writing to you now. To explain: We are carrying out a specific research project for the purpose of perfecting better hearing tests. In the long run, the knowledge we gain from these tests will lead to a more adequate evaluation and treatment of hearing problems. At the moment, we have a new set of tests ready. The next step is to validate these tests on people with hearing patterns such as yours. It is for this reason that we hope you will wish to assist us.

In a few days one of our staff members will telephone you to see about arranging an appointment which will be convenient for you. The details can be discussed at that time. I am writing to you today so that you will know about the plan in advance. Your cooperation will assist us in carrying forward an important project.

Sincerely,

William F. Rintelmann, Ph.D.
Professor,
Audiology

WFR:sk

APPENDIX B

HISTORY OF NOISE EXPOSURE

HISTORY OF NOISE EXPOSURE

Subject #:________ Date:______________

Name:_____________________________________ Birthdate:____________

Address:__________________________ Age:________ Sex:___________

City: ___________________________ State: ______________________

Phone:___________________________ Social Security Number: ________
Work Home

Place of Employment:____

Number of years at present job: ________________________________

Specific job: ____

Type of noise exposure: _____ Intermittent _____ Steady

How many days per week are you exposed to noise? _______________

How many hours per day are you exposed to noise? _______________

Describe the noise(s):

Previous place of employment: ____________________________________

Number of years at previous job: ________________________________

Specific job: ____

Type of noise exposure: _____ Intermittent _____ Steady

How many days per week were you exposed to noise? _______________

How many hours per day were you exposed to noise? _______________

Describe the noise(s):

How many years have you been exposed to noise? __________________

Do you wear ear protection? ______________________________________

If yes, what type? ____

How long do you wear them per day? _______________________________

How long have you worn ear protectors? ___________________________

If you don't wear ear protection, why not? ______________________________

Hearing Conservation Program

Last audiometric evaluation: ____

Status of hearing at that time: ____

Recommendations given by Hearing Conservation Program:

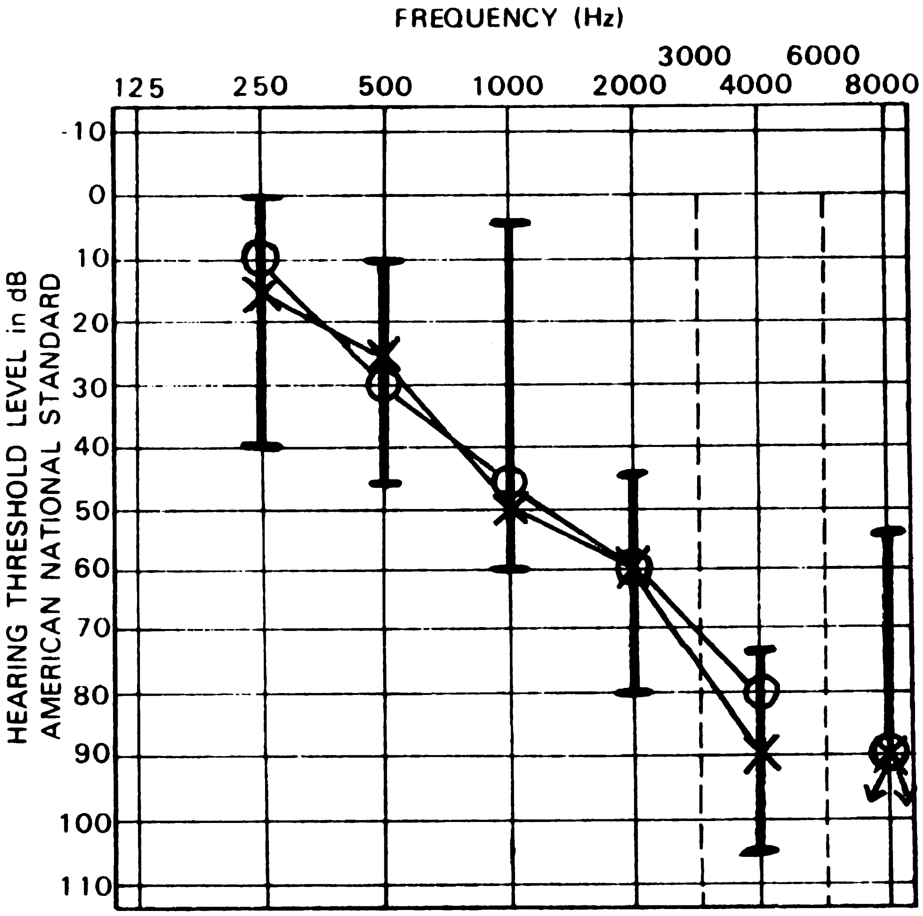
APPENDIX C

MEDIAN AUDIOGRAM

AND

INDIVIDUAL AUDIOGRAMS

MEDIAN AUDIOGRAM OF 8 SUBJECTS

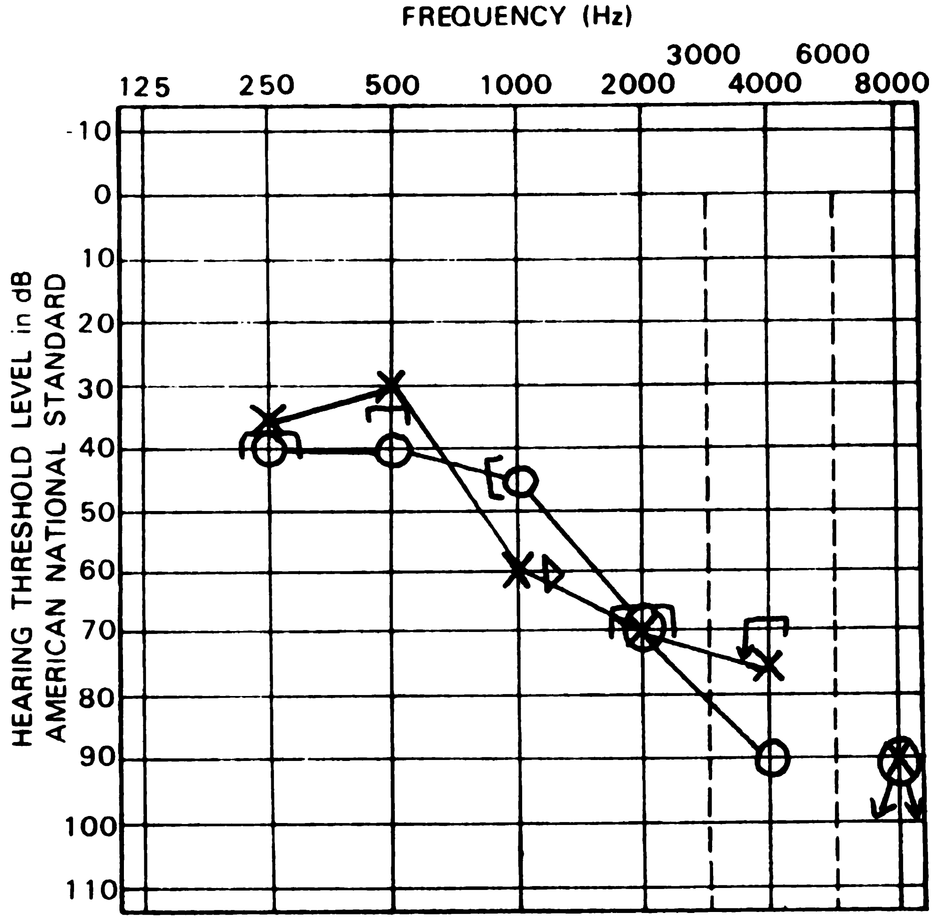


500, 1000 and 2000 Hz Average: Right Ear 45 dB
Left Ear 45 dB

Range of Thresholds at Each Frequency: I

Subject 1
Age: 51

Ear Under Test: Right

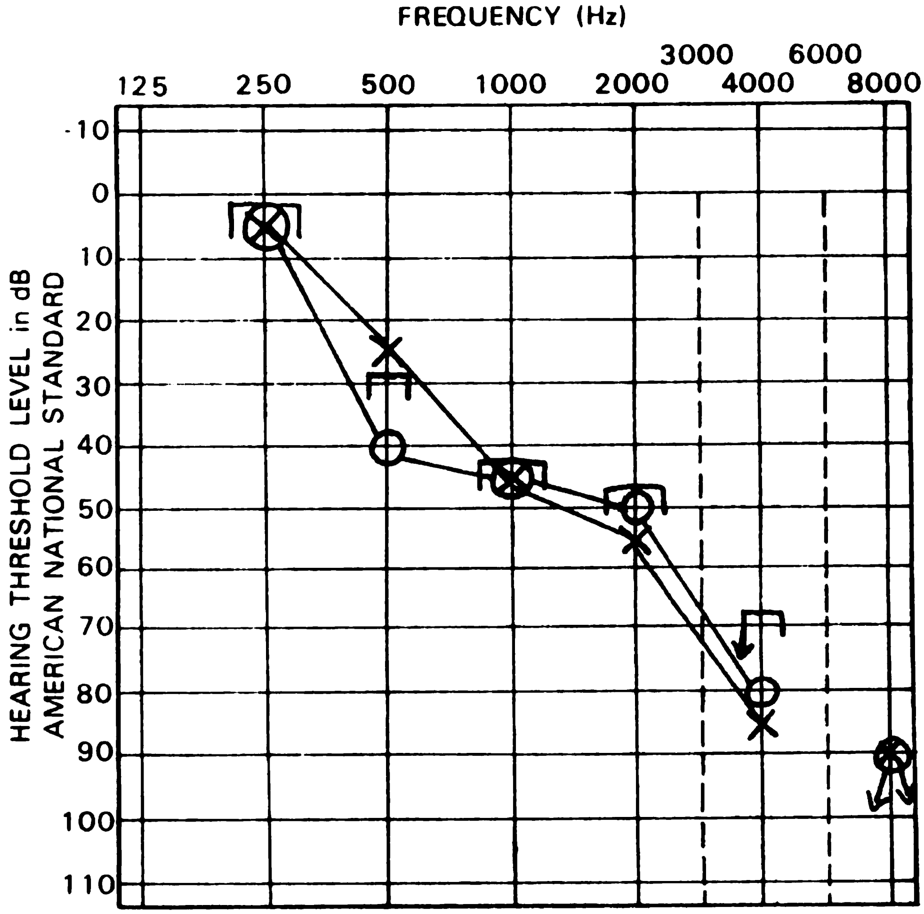


Better Cochlea: ⊓

500, 1000 and 2000 Hz Average:	Right Ear	52 dB
	Left Ear	55 dB
Speech Reception Threshold:	Right Ear	46 dB
	Left Ear	55 dB

Subject 2
Age: 34

Ear Under Test: Left

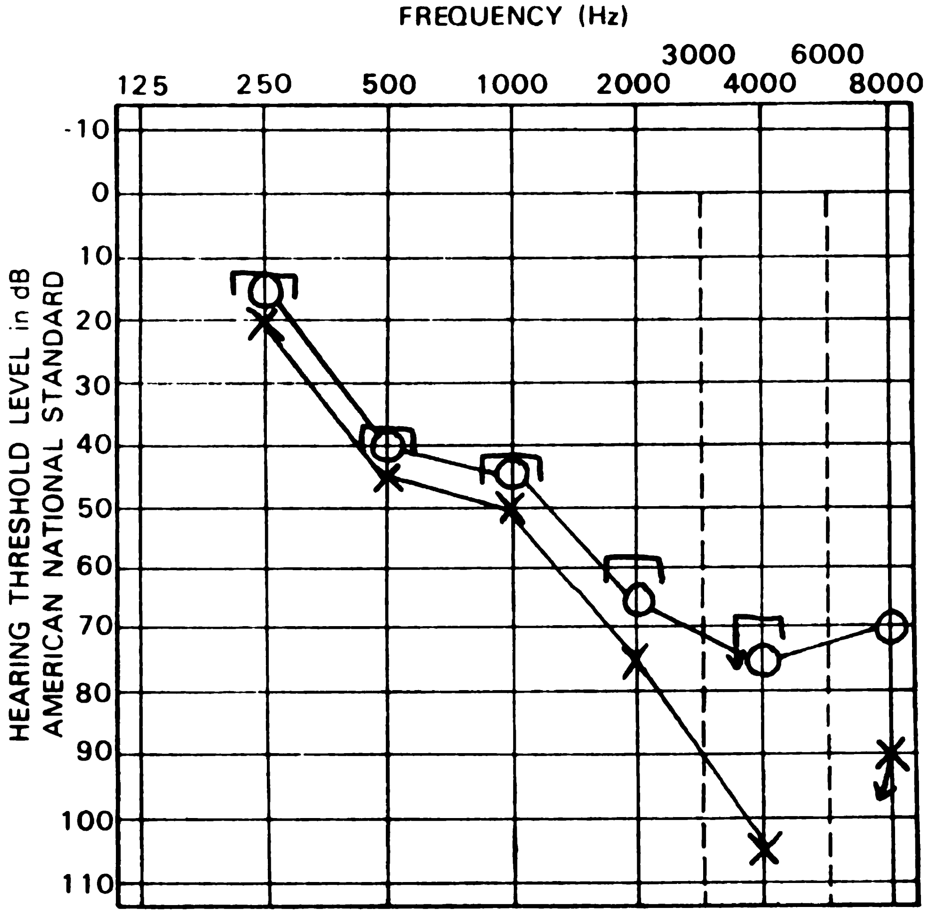


Better Cochlea: ⊓

500, 1000 and 2000 Hz Average:	Right Ear	45 dB
	Left Ear	41 dB
Speech Reception Threshold:	Right Ear	44 dB
	Left Ear	43 dB

Subject 3
Age: 54

Ear Under Test: Right

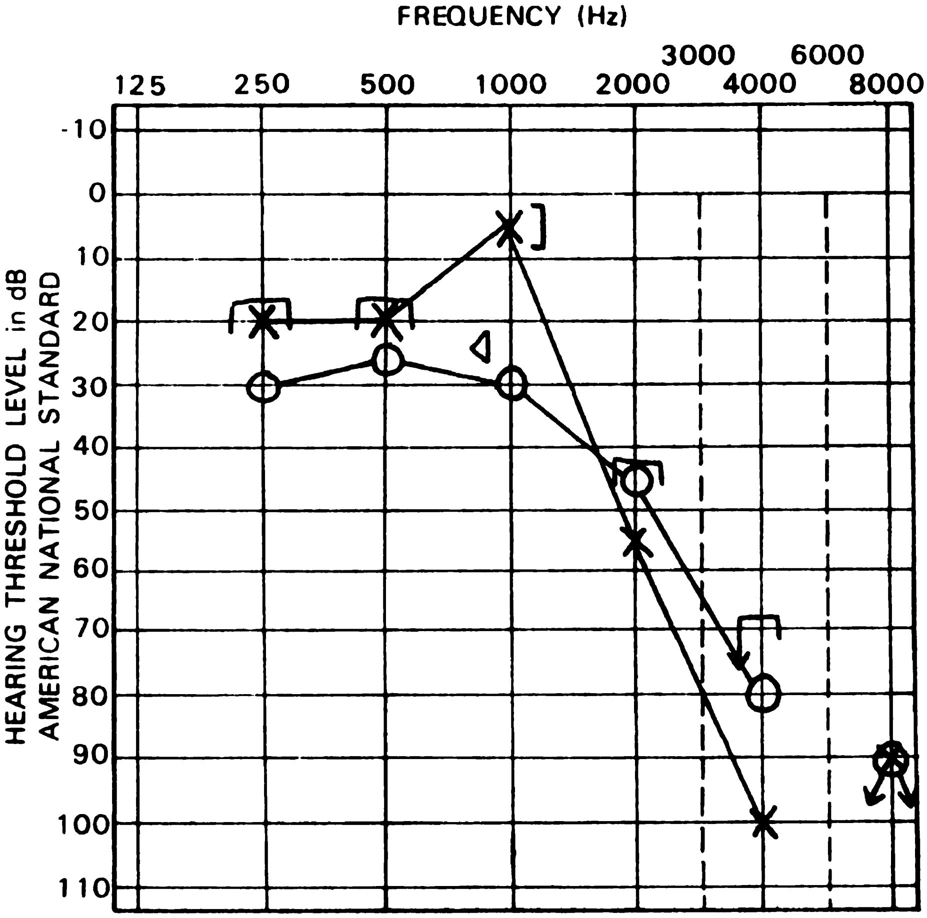


Better Cochlea: ⊓

500 and 1000 Hz Average:	Right Ear	42 dB
	Left Ear	47 dB
Speech Reception Threshold:	Right Ear	46 dB
	Left Ear	50 dB

Subject 4
Age: 47

Ear Under Test: Right



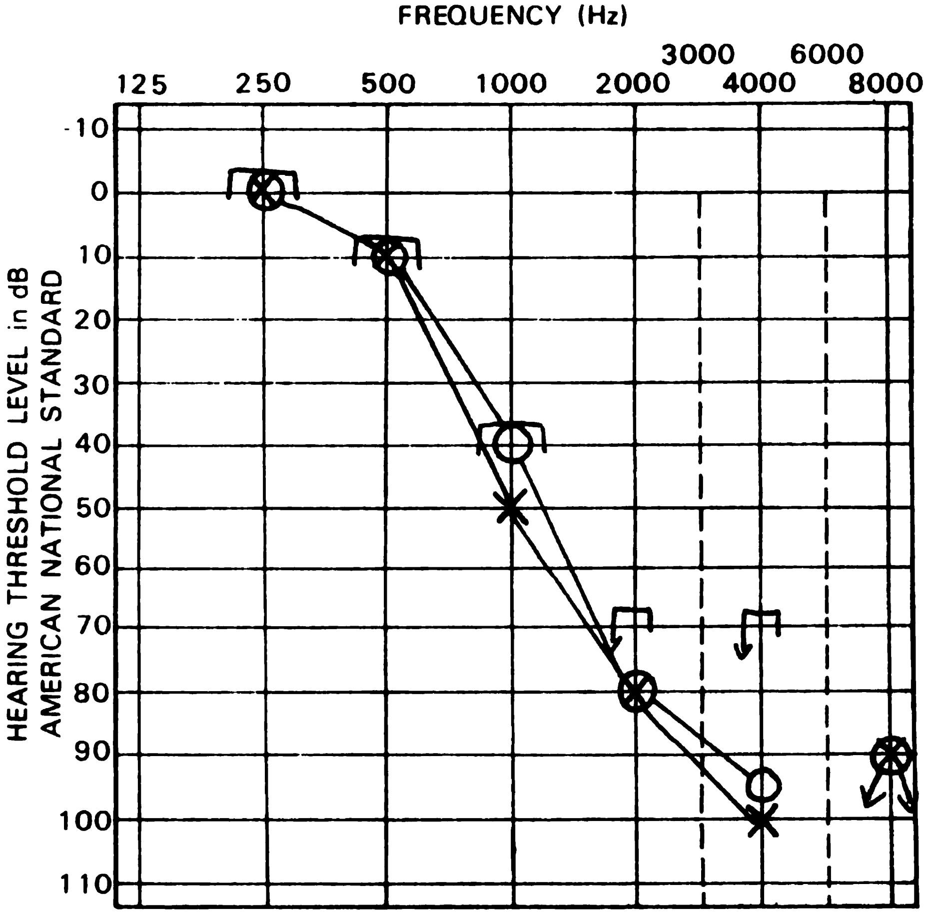
Better Cochlea: ⊓

500, 1000 and 2000 Hz Average: Right Ear 33 dB
Left Ear 26 dB

Speech Reception Threshold: Right Ear 32 dB
Left Ear 20 dB

Subject 5
Age: 45

Ear Under Test: Left

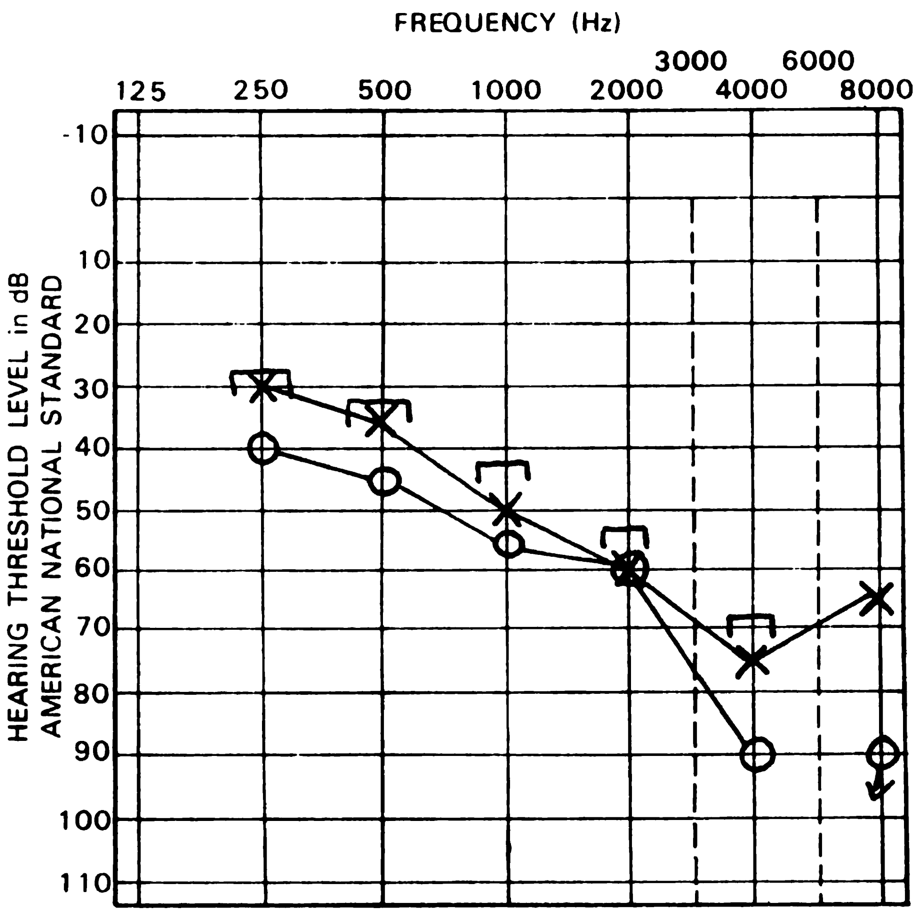


Better Cochlea: ⊓

500, 1000 and 2000 Hz Average:	Right Ear	43 dB
	Left Ear	46 dB
Speech Reception Threshold:	Right Ear	36 dB
	Left Ear	34 dB

Subject 6
Age: 54

Ear Under Test: Left

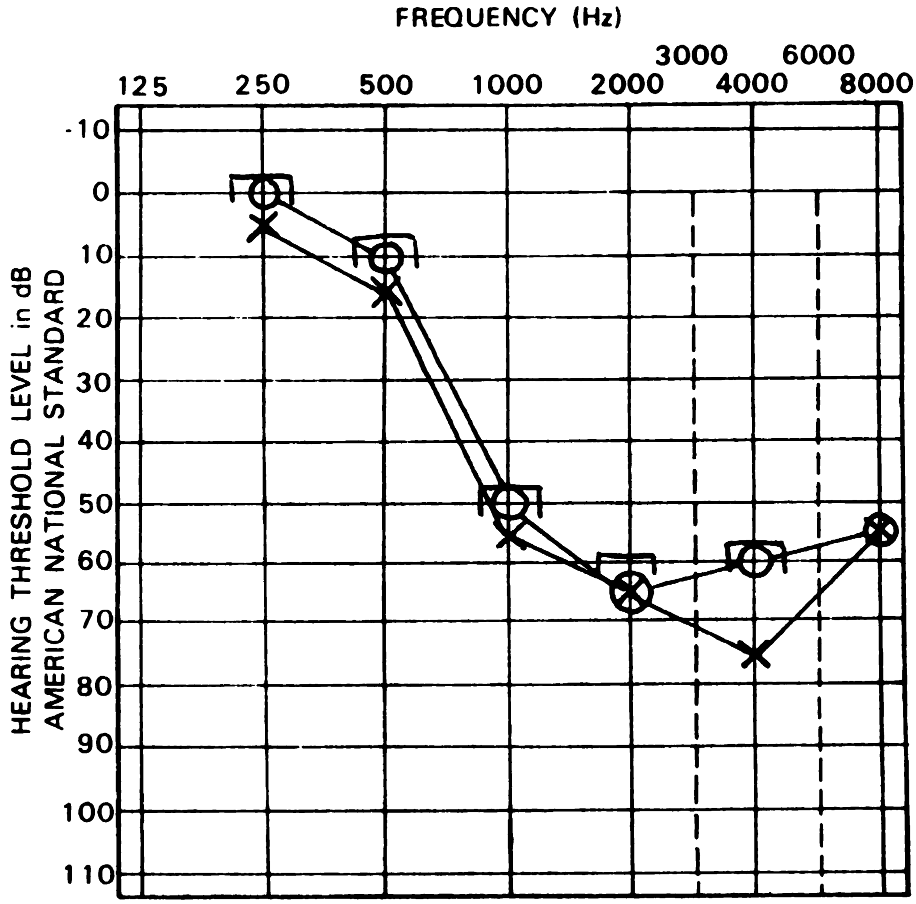


Better Cochlea: ⌐¬

500, 1000 and 2000 Hz Average:	Right Ear	53 dB
	Left Ear	48 dB
Speech Reception Threshold:	Right Ear	52 dB
	Left Ear	46 dB

Subject 7
Age: 45

Ear Under Test: Right



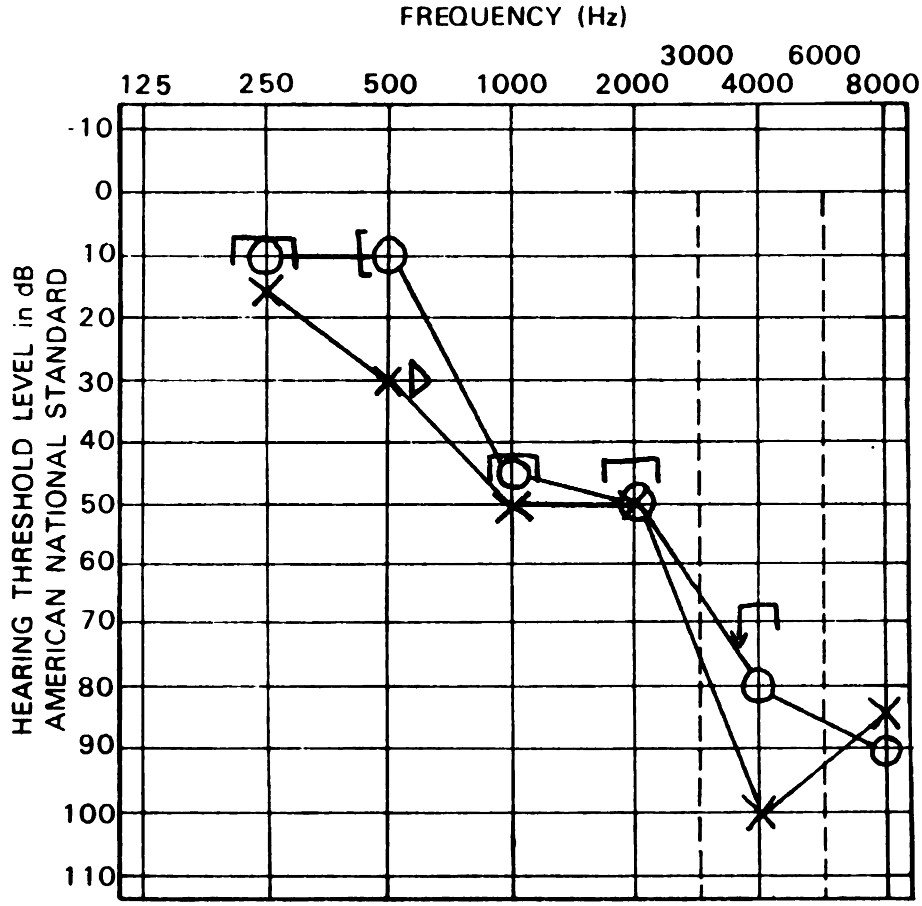
Better Cochlea: ⌐¬

500, 1000 and 2000 Hz Average: Right Ear 41 dB
Left Ear 45 dB

Speech Reception Threshold: Right Ear 44 dB
Left Ear 44 dB

Subject 8
Age: 47

Ear Under Test: Right



Better Cochlea: ⊓

500 and 1000 Hz Average:	Right Ear	47 dB
500, 1000 and 2000 Hz Average:	Left Ear	43 dB
Speech Reception Threshold:	Right Ear	42 dB
	Left Ear	44 dB

APPENDIX D

CALIBRATION OF EQUIPMENT

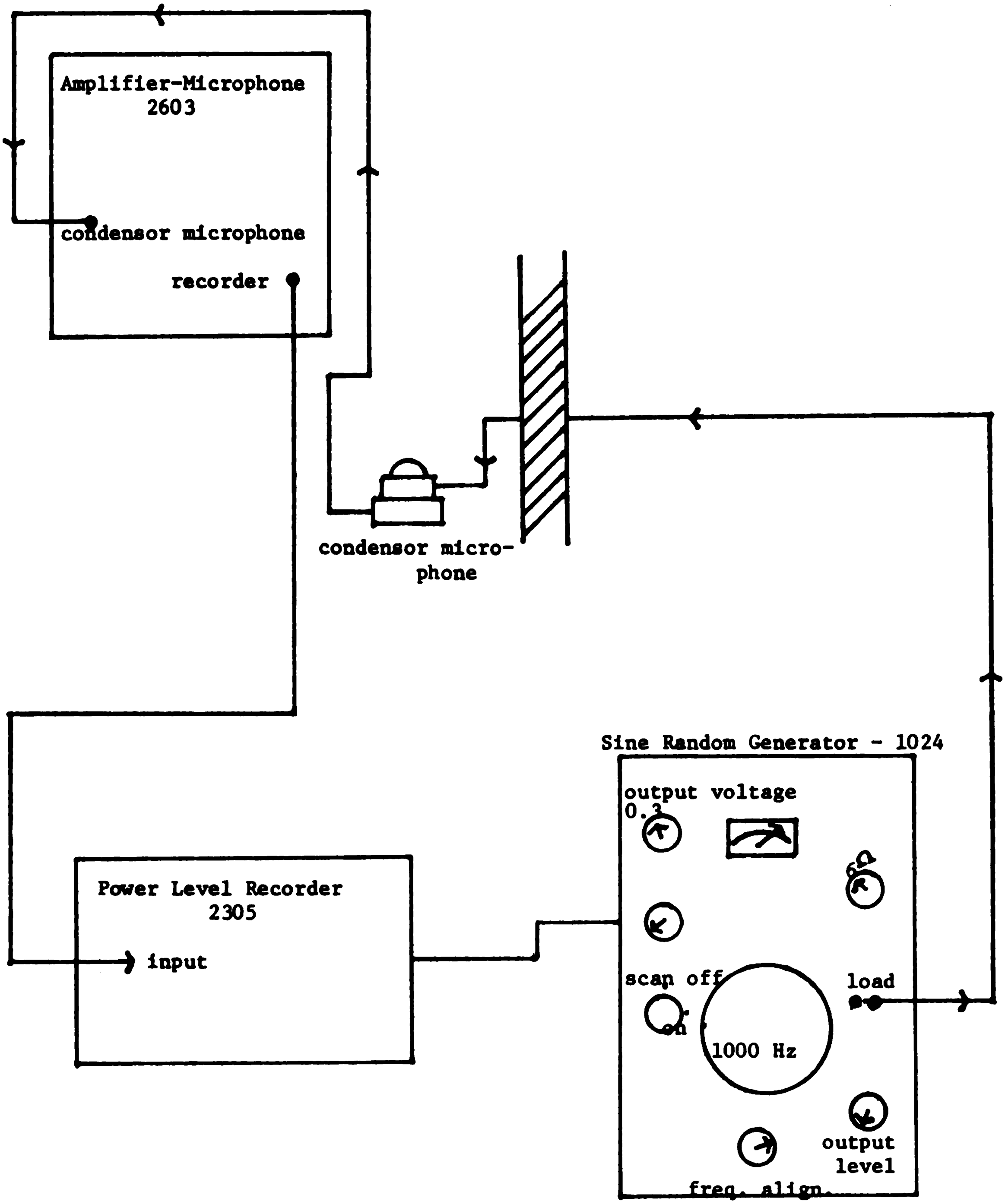
Before beginning the experiment the total system was calibrated to determine the setting and adjustments required to produce the desired signals. Throughout the investigation the equipment was monitored carefully during each experimental session, and the apparatus was calibrated periodically to assure appropriate performance. The method of monitoring and calibrating and the results of the measurements are described next.

1. Calibration of the Tape Recorder: The tape recorder heads and contacts were cleaned twice a week.
2. Acoustic Output of the Grason Stadler 162 Speech Audiometer: Acoustic output of the speech audiometer was measured before and after each test session. These measurements were accomplished with the aid of the Brüel and Kjaer Sound Level Meter (2204S). The TDH-39 earphone was connected to the 6cc coupler of the artificial ear and this in turn was coupled to the sound level meter. The output of the audiometer was checked at a 60 dB attenuator setting. Speech spectrum noise was fed into each earphone respectively. This system, under earphones was calibrated to 20 dB SPL re 0.0002 microbar. Measurements at the end of each two hour session were within 1 dB of those attained prior to the session.
3. Attenuator Linearity: The linearity of the grey attenuator was checked acoustically with the aid of the sound level meter described previously. No error in attenuation greater than 0.6 dB for any 2 dB step was found.

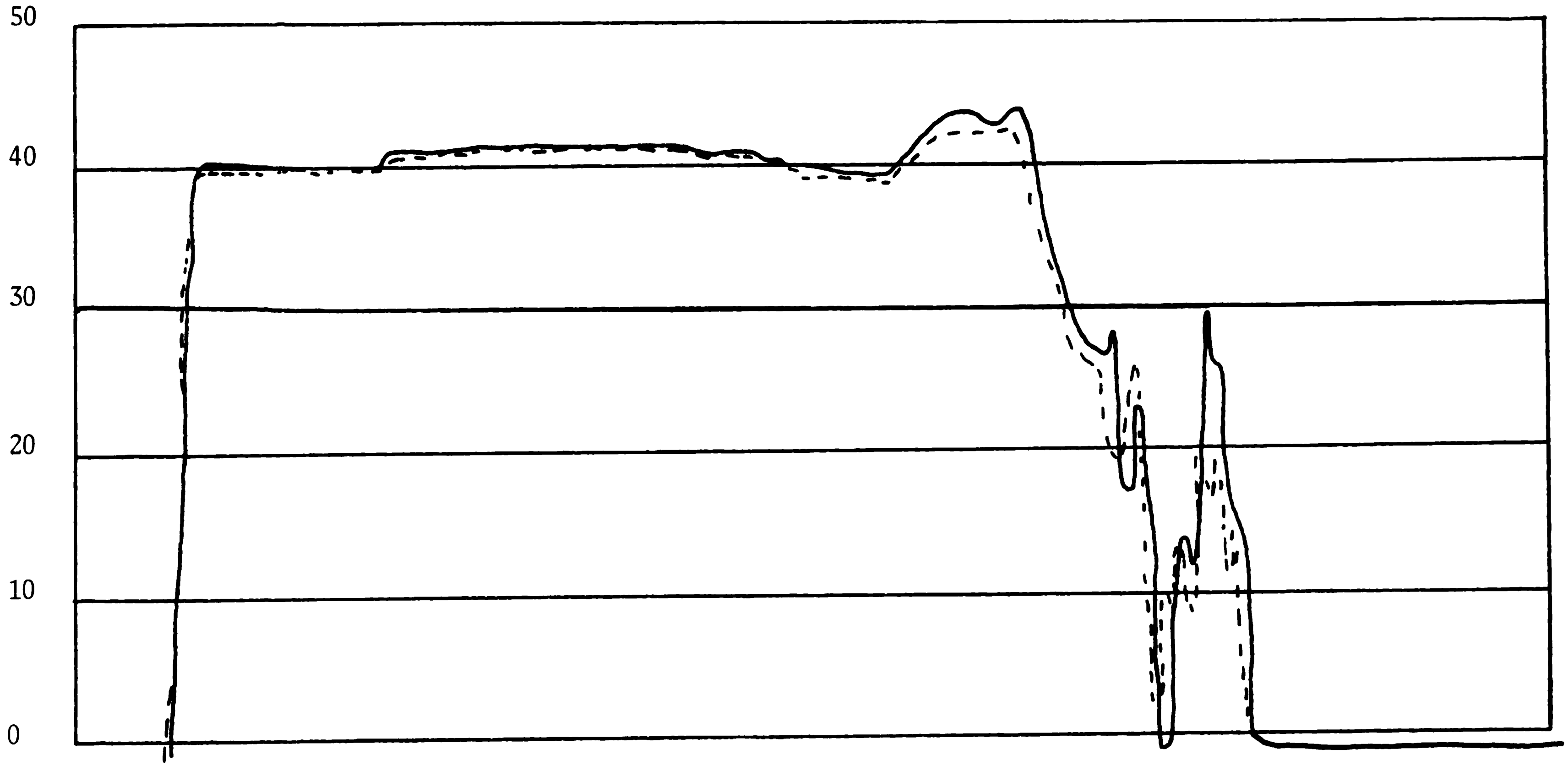
4. Harmonic Distortion: The acoustical measurements were made at the beginning and end of the total experiment with the aid of the Brüel and Kjaer Sine-Random Generator (1024) and the Frequency Analyzer (2107). The intensity of the 2nd and 3rd harmonic was 55 dB less than that of the fundamental frequency of 1000 Hz at 73 dB SPL. These values were within limits set by ANSI standards.
5. Earphone Frequency Response: A graphic record of the frequency response characteristics of the earphones was obtained before and after the total experiment to note any changes in acoustic output. These curves were obtained with the aid of the Bruel and Kjaer Sine Random Generator (1024) connected to the 6cc coupler of the artificial ear which was coupled with the Amplifier Microphone (2603), which was in turn coupled with the Power Level Recorder (2305). No change was noted when these curves were compared.

Summary

Periodic measurements demonstrated that the experimental apparatus had maintained control of the stimulus within acceptable limits over the 2 hours of a single test session and throughout the entire investigation.



Equipment utilized to determine frequency response of the TDH-39 earphones.



Frequency response of the TDH-39 earphones; baseline 76.5 dB SPL, .16 input voltage.
------ right earphone ——— left earphone

APPENDIX E

INSTRUCTIONS GIVEN TO LISTENERS

You will now hear a tape recording of lists of words, each composed of fifty monosyllabic words. Each word is preceded by a carrier phrase, "You will say". Your task will be to write down the word immediately following the carrier phrase in the appropriate space provided on the answer sheet. For example, if you hear, "You will say dog", you would be expected to write the word "dog". There will be an ample amount of time provided immediately after each word presentation for you to write down your response.

The lists will be presented to you at different intensity levels, although all of the fifty words on the same list will be equally loud. Some of the lists may sound extremely soft, so it is of extreme importance that you pay careful attention to the listening task. In addition, it may seem that the words are spoken on this tape in an unusually rapid manner, so again, pay close attention to what you hear and respond to the best of your ability. If you are uncertain of a response item you are encouraged to guess. When you have completed an entire word list, there will be approximately 2 minutes before the items from the next list will be presented. Are there any questions?

APPENDIX F

ANSWER FORM USED BY LISTENERS

No. ____________________ Form ____________________

Name ____________________ Sex ____________________

Age ______ yrs. __________ mos. Date ____________________

1 ______________

2 ______________

3 ______________

4 ______________

5 ______________

6 ______________

7 ______________

8 ______________

9 ______________

10 ______________

11 ______________

12 ______________

13 ______________

14 ______________

15 ______________

16 ______________

17 ______________

18 ______________

19 ______________

20 ______________

21 ______________

22 ______________

23 ______________

24 ______________

25 ______________

26 ______________

27 ______________

28 ______________

29 ______________

30 ______________

31 ______________

32 ______________

33 ______________

34 ______________

35 ______________

36 ______________

37 ______________

38 ______________

39 ______________

40 ______________

41 ______________

42 ______________

43 ______________

44 ______________

45 ______________

46 ______________

47 ______________

48 ______________

49 ______________

50 ______________

APPENDIX G

4 LISTS OF FORM B NU AUDITORY TEST NO. 6

NORTHWESTERN UNIVERSITY AUDITORY TEST NO. 6, FORM B

LIST I	LIST II	LIST III	LIST IV
burn	live	sheep	rose
lot	voice	cause	dog
sub	ton	rat	time
home	learn	bar	such
dime	match	mouse	have
which	chair	talk	mob
keen	deep	hire	bone
yes	pike	search	sail
boat	room	luck	rough
sure	read	cab	dip
hurl	calm	rush	join
door	book	five	check
kite	dab	team	wheat
sell	loaf	pearl	thumb
nag	goal	soup	near
take	shack	half	lease
fall	far	chat	yearn
week	witch	road	kick
death	rot	pole	get
love	pick	phone	lose
tough	fail	life	kill
gap	said	pain	fit
moon	wag	base	judge
choice	haze	mop	should
king	white	mess	pass
size	hush	germ	back
pool	dead	thin	hall
vine	pad	name	bath
chalk	mill	ditch	tire
laud	merge	tell	peg
goose	juice	cool	perch
shout	keg	seize	chain
fat	gin	dodge	make
puff	nice	youth	long
jar	numb	hit	wash
reach	chief	late	food
rag	gaze	jug	mood
mode	young	wire	neat
tip	keep	walk	tape
page	tool	date	ripe
raid	soap	when	hole
raise	hate	ring	gas
bean	turn	check	came
hash	rain	note	vote
limb	shawl	gun	lean
third	bought	beg	red
jail	thought	void	doll
knock	bite	shall	shirt
whip	lore	lid	sour
met	south	good	wife

APPENDIX H

ORDER OF PRESENTATION OF NU AUDITORY TEST NO. 6

Subject 1

	TC	SL	LIST
1.	40	24	I
2.	0	40	II
3.	70	40	III
4.	40	32	IV
5.	30	16	II
6.	50	24	III
7.	60	16	IV
8.	70	24	I
9.	70	16	III
10.	60	24	IV
11.	50	16	I
12.	60	32	II
13.	30	24	IV
14.	40	16	I
15.	40	40	II
16.	30	40	III
17.	60	40	I
18.	70	32	II
19.	50	40	III
20.	0	24	IV
21.	50	32	II
22.	30	32	III
23.	0	16	IV
24.	0	32	I

Subject 2

	TC	SL	LIST
1.	40	24	I
2.	50	16	II
3.	40	40	III
4.	40	16	IV
5.	70	24	II
6.	30	32	III
7.	70	40	IV
8.	0	24	I
9.	30	16	III
10.	50	40	IV
11.	70	32	I
12.	0	40	II
13.	40	32	IV
14.	60	32	I
15.	0	32	II
16.	60	16	III
17.	0	32	I
18.	70	16	II
19.	60	24	III
20.	30	24	IV
21.	60	40	II
22.	50	24	III
23.	30	40	IV
24.	50	32	I

Subject 3

	TC	SL	LIST
1.	30	16	I
2.	40	40	II
3.	70	40	III
4.	60	24	IV
5.	40	16	II
6.	40	24	III
7.	60	32	IV
8.	30	32	I
9.	40	32	III
10.	50	16	IV
11.	0	24	I
12.	70	32	II
13.	0	32	IV
14.	70	16	I
15.	50	40	II
16.	0	40	III
17.	60	40	I
18.	70	24	II
19.	30	40	III
20.	50	24	IV
21.	60	16	II
22.	30	24	III
23.	0	16	IV
24.	50	32	I

Subject 4

	TC	SL	LIST
1.	30	40	I
2.	70	40	II
3.	70	16	III
4.	0	24	IV
5.	60	24	II
6.	70	32	III
7.	0	32	IV
8.	30	32	I
9.	40	32	III
10.	50	16	IV
11.	50	40	I
12.	40	24	II
13.	40	16	IV
14.	60	16	I
15.	30	16	II
16.	40	40	III
17.	0	16	I
18.	50	24	II
19.	0	40	III
20.	60	32	IV
21.	60	40	II
22.	50	32	III
23.	30	24	IV
24.	70	24	I

Subject 5

	TC	SL	LIST
1.	40	32	I
2.	0	24	II
3.	30	40	III
4.	30	24	IV
5.	40	24	II
6.	50	40	III
7.	60	32	IV
8.	50	16	I
9.	60	40	III
10.	0	16	IV
11.	70	40	I
12.	60	24	II
13.	60	16	IV
14.	30	32	I
15.	50	32	II
16.	30	16	III
17.	40	16	I
18.	0	40	II
19.	40	40	III
20.	70	24	IV
21.	50	24	II
22.	70	32	III
23.	0	32	IV
24.	70	16	I

Subject 6

	TC	SL	LIST
1.	40	40	I
2.	70	40	II
3.	30	40	III
4.	60	32	IV
5.	60	24	II
6.	0	32	III
7.	30	32	IV
8.	40	32	I
9.	50	24	III
10.	70	32	IV
11.	70	24	I
12.	0	40	II
13.	40	16	IV
14.	50	40	I
15.	60	40	II
16.	50	32	III
17.	50	16	I
18.	0	24	II
19.	0	16	III
20.	30	16	IV
21.	60	16	II
22.	30	24	III
23.	70	16	IV
24.	40	24	I

	Subject 7			Subject 8			Subject 9		
	TC	SL	LIST	TC	SL	LIST	TC	SL	LIST
1.	40	32	I	0	40	I	60	40	I
2.	0	24	II	60	40	II	70	40	II
3.	70	32	III	50	32	III	50	40	III
4.	40	40	IV	70	32	IV	60	32	IV
5.	70	16	II	40	32	II	50	32	II
6.	30	32	III	70	16	III	50	16	III
7.	60	16	IV	40	24	IV	60	24	IV
8.	30	16	I	0	32	I	70	32	I
9.	60	24	III	60	24	III	70	24	III
10.	0	32	IV	30	24	IV	50	24	IV
11.	0	16	I	50	40	I	0	40	I
12.	60	32	II	50	24	II	40	32	II
13.	30	40	IV	0	16	IV	30	32	IV
14.	50	40	I	40	16	I	30	40	I
15.	70	40	II	30	32	II	40	40	II
16.	50	16	III	70	24	III	0	32	III
17.	60	40	I	50	16	I	60	16	I
18.	70	24	II	40	40	II	30	24	II
19.	40	24	III	60	32	III	40	16	III
20.	50	24	IV	0	24	IV	0	24	IV
21.	0	40	II	70	40	II	40	24	II
22.	30	24	III	60	16	III	30	16	III
23.	40	16	IV	30	16	IV	70	16	IV
24.	50	32	I	30	40	I	0	16	I

APPENDIX I

TEST RESULTS OF 9 SUBJECTS

Discrimination score in percent shown for each subject plus the NU-6 list number shown in parenthesis

SL	TC	1	2	3	4	5	6	7	8	9
16	0%	76% (3)	60% (2)	42% (4)	78% (1)	50% (4)	84% (4)	56% (2)	64% (4)	86% (1)
24	0%	74% (2)	66% (1)	54% (1)	78% (4)	64% (2)	82% (4)	60% (2)	70% (4)	98% (4)
32	0%	92% (3)	84% (1)	64% (1)	90% (4)	62% (4)	68% (1)	56% (4)	64% (1)	86% (3)
40	0%	68% (2)	72% (2)	60% (3)	88% (3)	68% (2)	64% (2)	60% (1)	52% (1)	86% (1)
$\bar{x}$		77.5%	70.5%	55%	83.5%	61%	74.5%	58%	62.5%	89%
16	30%	68% (4)	54% (3)	38% (1)	72% (2)	46% (3)	62% (2)	44% (1)	72% (4)	86% (3)
24	30%	72% (3)	72% (4)	44% (3)	80% (4)	52% (4)	80% (4)	58% (3)	72% (4)	88% (2)
32	30%	78% (4)	64% (3)	40% (1)	86% (1)	58% (1)	68% (3)	48% (3)	62% (2)	88% (4)
40	30%	72% (3)	78% (4)	44% (3)	80% (1)	46% (3)	42% (3)	54% (4)	64% (1)	86% (1)
$\bar{x}$		72.5%	67%	41.5%	79.5%	50%	63%	57%	67.5%	87%
16	40%	64% (1)	52% (4)	20% (2)	64% (4)	40% (1)	54% (1)	40% (4)	52% (1)	78% (3)
24	40%	60% (1)	56% (1)	24% (3)	72% (2)	38% (2)	52% (1)	28% (3)	50% (4)	88% (2)
32	40%	72% (1)	72% (4)	40% (3)	88% (3)	48% (1)	64% (4)	44% (1)	24% (2)	80% (2)
40	40%	58% (1)	58% (3)	32% (2)	86% (3)	40% (3)	64% (2)	44% (4)	64% (2)	90% (2)
$\bar{x}$		63.5%	59.5%	29%	77.5%	41.5%	58.5%	39%	47.5%	84%
16	50%	54% (1)	48% (2)	16% (4)	76% (4)	26% (1)	52% (1)	24% (3)	54% (1)	74% (3)
24	50%	66% (3)	60% (3)	24% (4)	66% (2)	42% (2)	38% (3)	40% (4)	44% (2)	58% (4)
32	50%	70% (3)	72% (1)	38% (1)	84% (3)	42% (2)	68% (2)	50% (1)	30% (3)	64% (2)
40	50%	74% (1)	76% (4)	28% (2)	78% (1)	52% (3)	60% (3)	54% (1)	46% (1)	74% (3)
$\bar{x}$		66%	64%	26.5%	76%	40.5%	54.5%	42%	43.5%	67.5%
16	60%	36% (2)	42% (3)	18% (2)	46% (1)	28% (4)	44% (4)	12% (4)	26% (3)	82% (1)
24	60%	44% (2)	46% (3)	18% (4)	60% (2)	16% (2)	54% (4)	32% (3)	36% (3)	50% (4)
32	60%	42% (4)	52% (1)	24% (4)	78% (4)	34% (4)	52% (2)	28% (2)	36% (3)	40% (4)
40	60%	36% (2)	50% (2)	18% (1)	80% (2)	38% (3)	60% (1)	48% (1)	22% (2)	38% (1)
$\bar{x}$		39.5%	47.5%	19.5%	66%	29%	52.5%	30%	30%	52.5%
16	70%	0% (4)	12% (2)	2% (1)	10% (3)	4% (1)	0% (3)	0% (2)	0% (3)	58% (4)
24	70%	0% (1)	20% (2)	10% (2)	16% (1)	2% (4)	0% (1)	22% (2)	0% (3)	34% (3)
32	70%	0% (4)	16% (1)	4% (2)	20% (3)	4% (3)	20% (2)	0% (3)	6% (4)	18% (1)
40	70%	0% (2)	22% (4)	0% (3)	22% (2)	10% (1)	0% (3)	16% (2)	4% (2)	6% (2)
$\bar{x}$		0%	17.5%	4%	17%	5%	5%	9.5%	2.5%	29%