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THE EFFECT OF AGING ON SPEECH PERCEPTION IN NOISE

City University of New York PH.D. 1980

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THE EFFECT OF AGING ON SPEECH PERCEPTION IN NOISE

by

CAROLE L. MAYER

A dissertation submitted to the Graduate Faculty in Speech and Hearing Sciences in partial fulfillment of the requirements for the degree of Doctor of Philosophy, The City University of New York.

1980

This manuscript has been read and accepted for the Graduate Faculty in Speech and Hearing Sciences in satisfaction of the dissertation requirement for the degree of Doctor of Philosophy.

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ACKNOWLEDGEMENTS

There are so many who contributed to the completion of this project that the task of thanking them individually is overwhelming. The cooperation that I received while trying to find a random sample of New Yorkers' will always make New York feel like a warm and special place to me; my thanks to all those who made it so.

My gratitude and indebtedness is individually acknowledged:

to Professor Harry Levitt who gave unstintingly of his time, patience, and support in guiding this study to completion; to Professors Juergen Tonndorf and Irving Hochberg who, as members of my committee, contributed their expertise and their time on my behalf;

to my friends and colleagues in the Program in Speech and Hearing Sciences who offered their time and special qualities as talkers for the study: Dr. Susan Waltzman, Ms. Evelyn Pollack, Dr. Toni Gold, Ms. Judy Scheinberg, Mr. Paul Milner, Dr. Stanley Gelfand, Dr. Abraham Greenberg, Mr. Harvey Stromberg; and to those who assisted in collecting the data: Ms. Cheryl Barry, Ms. "Peaches" Pomerantz, Ms. Mary Florentine, Mr. Steven Hoffnung, Mr. Anthony Ciazzo;

to Mr. Harvey Stromberg, senior computer programmer, for his organization and skill in the preparation of the data, and for his unfailing good humor and cooperation in 'filling in' as resident expert on many occasions;

to Dr. Richard E. C. White for his technical expertise and assistance in preparation of the tapes;

to Professor Moe Bergman, my first instructor in this field, for his teachings, his enthusiasm and his example;

and to my children, who became adults during the course of this investigation, for their tolerance and faith in me throughout the duration, for which I have no adequate words.

This research was partially supported by a grant from the Urban Analysis Center in the Office of Urban Policy and Programs, The Graduate School and University Center, The City University of New York.

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CHAPTER I

INTRODUCTION

There has been increasing concern in recent years about the effects of environmental noise on man, and on human communication. Federal, state, and municipal authorities have sought to develop noise codes which would allow commerce and transportation to exist within environmentally reasonable limits. To this end, interest has turned to studies of speech in noise which have traditionally been conducted on young, normal-hearing listeners.

The choide of young listeners was probably dictated at least partially by expediency; studies were generally conducted at universities where the volunteers were highly motivated undergraduate and graduate students with excellent hearing and communicative skills. Similarly, investigations were performed at military installations with young subjects with normal hearing. Data gathered on these subjects offered information on the maximum capacities of the auditory system to discriminate speech in noise. Standards for systems of communication as well as room noise levels have been set on the basis of the results of these studies with young subjects.

The studies do not, however, take into account the changes that occur as a function of biological aging. The deterioration of hearing is believed to begin shortly after the age of 30, and although it is a slow process, a substantial portion of the population normally develops some loss in hearing sensitivity with age. Associated with the loss of hearing sensitivity is a frequently disproportionate loss of the ability to understand speech. It has been found that speech signals which have been degraded in such a way as to reduce the natural redundancy of the message have a more profound effect on the loss in intelligibility for older persons.

The older individual represents a substantial, and growing, proportion of our population. A United Stated health survey (1963) indicated that of 5,822,000 people in the United States with some degree of hearing loss, nearly one-half (2,497,000) are over the age of 65. Life expectancy is continually increasing due to advances in medical science and the United States Department of Health, Education, and Welfare in 1963 estimated that by 1980 the number of citizens 65 years and older would be approximately 24 million.

Substantial numbers of these older people live in the cities where ambient noise levels are considerable. In New York City much of the environmental noise is due to transportation facilities; cars, trucks, and subway trains, as well as the aircraft noise from the three major airports in the metropolitan area. Travel around New York City and among its five boroughs is facilitated by the excellent public transportation system. Recognition of the senior citizen's need for, and use of, that system is evidenced by the introduction in September 1969 of a Senior Citizen's Discount Program by the New York City Office for the Aging. According to that agency, 650,000 identification cards had been issued to persons over the age of 65 years in 1975.

Environmentalists are concerned with the levels of noise in urban areas and the profound psychological and physiological effects that noise has on all citizens. Noise codes frequently have vague language, or fail to specify quantitative measures in decibels at which violations would occur. Allowable noise levels are arrived at as a compromise between what is practical and what is ideal. Noise hazard is more of a determining factor than annoyance or speech interference. Noise control and abatement are issues of concern for citizens of all ages. The body of published literature which reveals that chronological aging has a negative effect on an individual's ability to understand speech, coupled with that literature which indicates that older people have increased difficulty with difficult speech signals (such as those with competing noise) would suggest that the older residents of a major metropolitan area are especially disadvantaged in their attempts to communicate in the noisy city.

The present study was undertaken to examine the ability of selected subjects who ranged in age from 20 to 69 years to discriminate speech materials presented with several samples of noise judged to be typically encountered in New York City. The study sought to answer the following questions:

1. What effect will increasing age have on an individual's ability to perceive a message representative of everyday American speech in the presence of some noises that are typically found in New York City?
2. Will worsening listening conditions as the speech-to-noise ratio decreases, affect a normal-hearing population in the same way?
3. What effect will other factors such as the sex of the listener, sex or accent of the speaker have on the perception of speech in the presence of typical urban noises?

CHAPTER II

REVIEW OF PERTINENT LITERATURE

The following review of pertinent literature is concerned with research on the effects of masking on speech intelligibility as well as the effects of aging on the auditory system, especially as it relates to the preception and interpretation of speech.

THE MASKING OF SPEECH

Auditory masking is generally defined as the threshold shift of the masked sound due to the presence of the masking sound. This is true for complex sounds, such as speech, as well as for pure tones. In addition, for speech situations a noise that is not sufficiently intense to completely mask a speech signal may nevertheless significantly reduce the intelligibility of the speech. This effect is referred to as speech interference, or partial masking.*

Miller (1947) discussed three aspects of the masking noise which affect the interference it might produce. They are:

1. its intensity relative to the intensity of the speech;
2. its power spectrum;
3. its temporal continuity.

The relation between the average speech power and the average noise power is typically expressed as the speech-to-noise ratio (S/N). For most noises encountered in practical situations, S/N should exceed 6 dB for satisfactory communication, although the presence of speech is detectable by a S/N as low as -18 dB.

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*The use of the term 'masking' for this effect in a landmark paper by Miller (1947) has caused some confusion.

Speech interference depends primarily on the relative levels of speech and noise as well as the range of frequencies involved in speech. In general, low frequencies mask this range more effectively than high frequencies. "Human Speech is most seriously masked by an uninterrupted noise which has its power concentrated in the lower third of a spectrum covering the frequency range from 100 to 4000 or 5000 cycles" (Miller, 1947, p. 106).

Interruptions in the masking noise decrease the effectiveness of that noise as a masker; even when the noise is present 80% of the time.

Further, the effect of masking on speech intelligibility is affected by the predictability of the message set. Miller, Heise and Lichten (1951) demonstrated the interaction between the speech-to-noise ratio and the size of the test vocabulary. Pickett (1961) conducted a similar study with the transmission bandwidth as a variable. In both investigations, as the size of the message set increased from 2 words to 32 words the size of the band and/or the S/N ratio had to be increased to maintain a desired level of intelligibility. More recently, Kalikow, Stevens and Elliott (1977) developed two separate message sets to assess the performance of listeners in noise. Both sets require the listener to supply a monosyllabic noun to complete a sentence. The sentences represent both high and low predictability, determined by whether the key word can be predicted from the context of the sentence. Performance of normal hearing listeners show significantly different functions for the two types of sentences.

Another variable of the performance of a listener to speech in noise is the hearing ability of the listener. Until recently most of the data were gathered on young, normal-hearing subjects, tested under laboratory conditions in order to eliminate the confounding aspects of hearing impairment.

Predicting Intelligibility

French and Steinberg (1947) developed a procedure to calculate an index for predicting the intelligibility of speech in noise from the measurement of the spectra and signal levels of the speech and the interfering noise. This index is known as the Articulation Index (AI). Its method of calculation has been modified over the years (Kryter, 1962), and standard methods for the calculation of the AI has been developed by the American National Standards Institute and is published as a Standard, ANSI S3.5 (1969). The AI is calculated from physical measures of the relative levels of speech and noise spectra. Peak signal to rms noise value (S/N) are obtained at the center frequency of twenty relatively narrow bands which have been found to contribute equally to the understanding of speech. The AI is essentially proportional to the average S/N ratio of these twenty bands except that S/N ratios greater than 30 are replaced by 30, and negative S/N ratios are replaced by 0. There are, in addition, some adjustments in the calculations to take into account the greater masking effects of very intense noise, the effect of interruptions, and reverberations. The S3.5 Standard provides alternative computation procedures employing octave and one-third octave band measurements of the speech and noise spectra.

An underlying concept of the AI is that the greater the frequency range over which the speech spectrum exceeds the noise spectrum the greater the value of the index and, concomitantly, the greater the speech intelligibility. A simplified index derived from the Articulation Index was offered by Beranek (1950) for use in predicting the effectiveness of person-to-person speech communication in the presence of noise. Beranek defined the Speech Interference Levels (SIL) as the average level (in dB) of the three contiguous octave bands of noise: 600-1200; 1200-2400; 2400-4800 Hz. The SIL has since been modified to include four octave bands centered on the frequencies 500, 1000, 2000, and 4000 Hz. as ANSI Standard S3.14 (1977).

One of the difficulties in applying the SIL generally is the lack of homogeneity among humans. There are groups for whom the effect of noise (or their ability to communicate in noise) is different from the general population. This may be a result of special training, adaptation, pathology, and/or aging effects.

Relative Levels of Speech and Noise

The most important factor in speech interference has been found to be the signal-to-noise ratio, not the absolute level of either the signal or the noise (Miller, 1947). Long periods of testing at high intensities produce auditory fatigue; therefore the relationship between the S/N ratio and speech interference may be constant for relatively short periods at high presentation levels after which the fatigue would adversely affect the relative intelligibility of the speech. Pollack (1948) found an increase in the effective masking of speech after a thirteen minute exposure to random broad-band noise. This would indicate that a fatigued ear could not discriminate speech sounds as well as the normal ear.

Normally, talkers speaking in noise conditions exceeding 50 dBA automatically raise their voices so as to increase the effective speech-to-noise ratio. A 3 to 7 dB increase in voice level for every 10 dB of noise above this 50 dB has been found to be typical (Kryter, 1970). Typically, a normal-hearing female speaker in a quiet room produces an overall rms speech level of 62 dB SPL at one meter from the lips, the corresponding level for the male voice is 65 dB SPL.

Temporal Continuity

Much of the research on the speech interference aspects of noise has dealt with steady-state noise. Actually, many environmental noises vary over time, such as noise associated with the passage of some sort of vehicle (Shepard and Gunn, 1977). Some investigators have studied specific time-varying noise such as aircraft (Williams et al, 1969; Williams et al, 1971) and traffic noise (Schindler and Vigone, 1976). Much more attention has been focused on the broader aspects of the effects of interrupted noise as a masker of speech.

In general, switching the masking noise off periodically decreases its effectiveness as a masker. The variables which affect the masking effect are the rate of interruption and the duty cycle; i.e., the percentage of time that the noise is present (Miller and Licklider, 1950). Miller and Licklider reported that masking effectiveness is low when noise is interrupted between one two hundred times per second. This is due to the listener's ability to make sense out of the bits of speech heard between the bursts of noise. At very slow rates of interruption, entire words, or groups of words, may be masked yielding an "all or none" perception of the speech. The authors report that noise is effectively continuous when the interruptions are 200 times per second or more frequent. Pollack (1955) also found that the masking effect is enhanced as the interruption rate increases.

Type of Masker

Many studies of speech intelligibility in the presence of noise have used broad-band or band-passed gaussian noise. Criticism of the use of these laboratory noise sources has been that they are not representative of environmental noise. Some investigators have used competing speech sounds as a masking source (Miller, 1947; Pollack and Pickett, 1958; Carhart and Nichols, 1971).

Spatial separation between the speech and the noise is an important consideration. Pollack and Pickett (1958) found that a competing speech signal was more effective as a masker for a test speech signal when it was presented from the same loudspeaker or earphone rather than when the two messages were separated. Miller (1947) reported that competing voices are effective speech maskers regardless of the language being spoken. This, he suggested, is due to the contribution of the voice spectrum to masking rather than the semantic distraction. Carhart and Nichols (1971) reported on several studies conducted at the Northwestern University Auditory Research

Laboratories examining the effect of competing intelligible speech on the perception of a target speech message. They label such interference "perceptual masking", defined as an increased interference with the understanding of one speech signal which appears when a complex background contains speech among its components. They concluded that older individuals tend to have reduced capacity for handling those complex listening situations that include speech.

Studies in which the competing message consisted of several voices allowed for the effects of the acoustic spectra of speech without its semantic contribution. Cooper and Cutts (1971) utilized cafeteria noise and Groen (1969) employed cocktail party noise. In both studies the masking effects were enhanced by the type of masker. Olsen and Carhart (1967) and Rupp and Phillips (1969) used speech spectrum noise with similar results. Carhart and Tillman (1970) masked monosyllabic words with competing sentences and found that speech is a more effective masker than spectrally complex steady-state noise, especially for persons with sensori-neural losses, including presbycusis. Miner and Danhauer (1976) used nine speakers to create a multitalker "babble" effect. They used this as a masker to compare two discrimination tests for normal and hearing-impaired listeners and found that the Modified Rhyme Test revealed an articulation function that was steepest for normal hearing subjects. They concluded that the use of the Modified Rhyme Test with the multitalker masking effectively identified peripheral hearing losses.

In all studies cited, normal hearing individuals and those with conductive losses were able to perform more effectively in noise than those with sensori-neural losses. This was true even when the subjects with sensori-neural losses displayed good discrimination in quiet.

The Effect of Speech in Noise on the Pathological Ear

For the individual with a sensori-neural hearing loss there is a loss of the ability to perceive speech in noise, as stated above. This is, in part, due to the upward spread of masking which has a more severe effect on the higher frequency components of speech where these persons generally have more hearing impairment.

The variability of speech discrimination scores for both normal and hearing-impaired listeners has been noted by several investigators (Simonton and Hedgecock, 1953; Palva, 1955; Rupp and Phillips, 1969; Keith and Tillis, 1972). However, there seems to be general agreement that the effect of a given noise is a complex interaction between the type of speech material, and the status of the auditory system of the listener as well as the well documented variable of the masker spectrum and the speech-to-noise ratio (Shapiro et al, 1972).

Ross et al (1965) sought to prove a 'multiple distortion' hypothesis: a combination of distortions (noise, abnormal difference limen for intensity and/or frequency, reduced linear range, sloping hearing loss) would produce an effect on the pathological ear that was greater than could be explained by the simple additive effort of each individual distortion. They were unable to prove the hypothesis. They did, however, report finding a reduced loss of intelligibility in noise for subjects with sloping high frequency hearing losses. The authors suggested that this was due to the reduction of the masking effect of the white noise in the high frequencies. The energy of the speech signal is primarily concentrated in the lower frequencies and exceeds the white noise energy in those frequencies. For subjects with flat hearing configurations, the sensation level of the noise is reduced less and therefore masks the speech more effectively. The findings of Keith and Tillis (1972) and Olsen et al (1975) support the results of the study by Ross et al regarding the increased masking effect of noise on speech perception for individuals with low-frequency hearing losses.

Other studies have reported a greater shift of discrimination scores for subjects with sensori-neural hearing losses than for normal listeners when speech was delivered in noise (Simonton and Hedgecock, 1953; Palva, 1955). A confounding factor is the extreme variability reported among subjects on tests of speech in noise (Tonndorf, 1952; Simonton and Hedgecock, 1953; Palva 1955; Lightfoot et al, 1956; Ross et al 1965; Cooper and Cutts 1971; Olsen et al, 1975).

Masked speech audiometry has shown significantly depressed scores for persons with brain-stem and temporal lobe lesions. Those with temporal lobe lesions showed scores significantly lower in the ear contralateral to the lesion regardless of whether the right or left temporal lobe was involved. The patients with brain-stem lesions showed no clear pattern, but in general the masked speech results were poorer than for normal subjects. (Morales-Garcia and Poole, 1972; Olsen et al, 1975). These findings support the hypothesis of Kimura (1961) and others regarding the preeminence of the contralateral auditory tract in carrying information to the temporal lobe.

Summary

The effect of noise on the perception of speech has been shown to be affected by several factors. The relative intensities of the speech and the noise signals, the power-frequency spectrum of the speech and of the noise, and the degree of spatial separation between the speech and noise. Other factors include the overall level of the noise, (noises of very high intensity being relatively more damaging to intelligibility), variations in noise level with time, the listener's familiarity with the speech materials, size of the message set, linguistic content, and related variables. Individuals with sensorineural hearing loss experience exaggerated difficulty with speech in the presence of noise; the most adverse effect is noted on those persons with retrocochlear hearing loss.

PRESBYCUSIS

Presbycusis, the hearing loss associated with biological aging, is not a single pathology, but a complex of many possible senescent changes in the ear and the central auditory pathways. A loss of discrimination ability not accounted for by threshold elevation is one of the symptoms typically reported with presbycusis.

Anatomical Changes in the Ear

Degenerative changes of the cochlea begin as early as the second or third decade, and are more severe at the basal end of the cochlea (Nomura and Kirikae, 1968). Schuknecht (1974) has described four types of presbycusis:

<u>Sensory</u> - Characterized by an abrupt high frequency hearing loss, probably due to atrophy of the supporting cells of the organ of Corti and the auditory nerve in the basal end of the cochlea.

<u>Strial</u> - Consistent with a flat hearing loss which usually shows an atrophy of the stria vascularis in the apical half of the cochlea.

<u>Cochlear Conductive</u> - With a descending audiometric configuration which may be attributed to a disorder in the motion mechanics of the cochlear duct because of a stiffening of the basilar membrane.

<u>Neural</u> - In which a loss of speech discrimination is greater than would be expected from the hearing loss due to a loss of neurons in the auditory pathways and cochlea. This type of presbycusis has relatively little effect on hearing acuity until later life.

It is evident that there is a complexity of factors contributing to changes in the auditory function of the aging individual. Fowler (1944) warns, "Cardiovascular insufficiencies usually add to or accentaute many diseases of the ears in old people. The senile ear, like the senile body, is a kaleidoscope of pathology, but the tendency in diagnosis is to focus on a single lesion." Schuknecht (1955) emphasizes that atrophy of the neural population of the auditory pathways and the cortex develops independently of cerebral arteriosclerosis, although the two may coexist. He believes that a spiral ganglion deficit alone could not account for the clinical manifestations of presbycusis, and suggests that the most reasonable explanation is an additional deficit in the population of the second, third, and fourth order neurons.

Often it is difficult to distinguish the normal changes of aging from the alterations caused by injury or disease. The term 'sociocusis' has been suggested by Glorig and Nixon (1962) to describe the combined effects of biological aging and lifetime exposure to the fairly high levels of environmental noise encountered in our society.

Threshold Changes for Pure Tones with Age

The deterioration of hearing with increasing age has been a fact of life since earliest history. Studies conducted on the Mabaan tribesmen of the southern Sudan, a society protected from the noise of a modern industrial culture, seemed to reveal a group impervious to sensory loss (Rosen et al, 1962; Rosen et al, 1964). In a reanalysis of the data, Bergman (1966) suggested that the homogeniety of the hearing levels obtained for the Mabaans might be attributed to diet as well as hereditary factors for this isolated tribe. For the majority of the world's citizens, hearing loss generally begins sometime after the age of 30 and proceeds to some degree for the remainder of their life span.

Hinchcliffe (1962b), testing a group of subjects aged 30 to 70 years, found a linear decrement in hearing level (in dB) with age for the frequencies 250 through 4000 Hz. The frequencies 6000 and 8000

Hz did not fall into the same pattern, but demonstrated a more abrupt drop as a function of increasing age.

One hundred and seventy subjects between the ages of 51 and 92 years were examined by Klotz and Kilbane (1966). An increase in the pure tone thresholds of no more than 10 dB per decade was found to the age of 80 for the frequencies 250, 500, and 1000 Hz. Above the age of 80 there was a steeper decrement per decade. Klotz and Kilbane also report that the women over the age of 60 in their study had significantly better hearing than the men.

Glorig and Nixon (1962) compared thresholds obtained in several studies of their own and of other investigators (Corso, 1959; Hinchcliffe, 1959) for a total of 2518 subjects ranging in age from 20 to 79 years. They adjusted thresholds for the groups by using the mean levels found for the youngest group (20-29) as zero re: American Standards Institute (ASA) 1951 (this actually altered the mean threshold by less than 5 dB in every instance). Curves were then plotted for the frequencies 1000, 2000, 3000, 4000 and 6000 Hz. Their findings revealed a systematic decline of hearing acuity with each increasing decade. Included in this sample were subjects who had been determined to be free of positive otological history and noise exposure, as well as subjects who had been accepted for the study without screening. This is displayed in Table 1.

For means of comparison, results of a study conducted by Corso (1963) are displayed in Table 2; these are the average mean thresholds of men and women having no known otological pathology and a minimal

Table 1. Effect of Age on Average Threshold Values (After Glorig and Nixon, 1963). All entries are in dB SPL.

Age Range (years)	Frequency (Hertz)				
	1000	2000	3000	4000	6000
20-29*	17	17	16	15	28
30-39	17	18	19	21	34
40-49	17	21	22	28	40
50-59	18	24	28	32	48
60-69	20	31	37	42	60
70-79	30	44	50	52	74

* Adjustment made using actual mean hearing threshold levels of 20-29 year old group as 0dB ASA

Table 2. Effect of Age on Average Threshold Values for Men and Women (After Corso, 1963). All entries are in dB SPL.

Age Range (years)	Frequency (Hertz)								
	250	500	1000	1500	2000	3000	4000	6000	8000
MEN									
18–24	27	11	6	7	8	13	14	30	27
26–32	28	14	7	8	9	14	22	38	33
34–40	23	12	9	9	10	16	24	39	37
43–49	29	17	13	18	20	24	35	48	40
51–57	32	15	13	15	20	25	36	49	46
59–65	35	20	16	20	26	40	50	61	55
WOMEN									
18–24	23	9	4	4	4	9	10	19	18
26–32	25	13	7	9	9	8	8	20	23
34–40	26	11	6	8	10	10	13	26	26
43–49	25	10	9	13	19	15	19	35	30
51–57	31	19	14	15	24	19	24	38	39
59–65	36	20	15	17	27	22	27	45	43

exposure to high intensity noise. The age grouping in Corso's study is somewhat different from the Glorig and Nixon decade division, and the upper limit does not exceed 65 years, however the two studies show good agreement, and would appear to be representative of presbycusic changes in pure tone thresholds. A more severe decrease in hearing with age is evident for men than for women in the Corso study, except below 1000 Hz for the older group. Corso states that noticeable presbycusis begins at about 32 years of age for men, and about 37 years for women. There is a frequency-dependence noted in the threshold shifts, particularly at 4000 Hz and above.

The variability of older subjects is frequently referred to in the literature, and this point is emphasized by Melrose, Welsh and Luterman (1963) in their study of 52 Spanish-American War veterans aged 74 to 89 years. The mean age of these subjects was 82 years. Pure tone results show mean thresholds of 9.15 dB at 250 Hz decreasing in a regular manner to 61.7 dB at 8000 Hz. The three-frequency pure tone average was 18 dB; the mean speech reception threshold (SRT) was 17.3 dB, and the mean speech discrimination score (tested at 40 dB above SRT) was 78%. Nevertheless, the authors point out that three subjects, all over the age of 80, had pure tone thresholds within normal limits.

Palva and Jokinen (1970) tested 149 subjects 20-89 years old divided into decade groups, and found the threshold to decline first in the fifth decade (40-49 years). The threshold change in this study was also strongly frequency-dependent; the difference between the youngest group (20-29) and the oldest (80-89) with reference to frequency was 15.7 dB at 500 Hz as compared with 39.2 dB at 4000 Hz and 60.5 dB at 8000 Hz (mean scores for the right ears). Scores for undistorted speech discrimination were very good: the decrement with age was from 97.6% to 87.8% (mean scores for the right ears) for Finnish lists of phonetically balanced words. Seventy percent of the subjects of this investigation were women; no analysis was done for sex differences.

Rosen and his associates (Rosen et al, 1962; Rosen et al, 1964) studied the Mabaans, a primitive African tribe who live in a remote area near the border between Sudan and Ethiopia. The Mabaans hearing does not show the same decrement in the higher frequencies as is commonly found among the peoples of industrial civilizations. The Mabaan society is non-industrial, agrarian, quiet. The tribesmen are free from presbycusis, arteriosclerosis and cardiac disease as well. The investigators suggested a combination of causes for this resistance to the expected concommitants of aging; noise-free environment, vegetarian diet and a peaceful culture. In a subsequent analysis of the data Bergman (1966) suggests that the isolation of this tribe adds a dimension of genetic selection that may be a primary cause of their retention of good hearing sensitivity into old age.

Problems of Speech Perception

Clinically, the major complaint of the presbycusic patient is that he is unable to understand what he hears. This loss of discrimination, frequently worse than would be predicted by pure tone thresholds, was first described by Gaeth (1948) as "phonemic regression". It has been the focus of many investigations which have found decreased discrimination as a function of age (Pestalozza and Shore, 1955; Klotz and Kilbane, 1962; Harbert et al, 1966; Feldman and Reger, 1967; Punch and McConnell, 1969; Jokinen, 1973).

Feldman and Reger (1967) looked for a relationship between reaction time, which is a centrally mediated function, and hearing. They tested a non-clinical population for speech discrimination and visual, tactile, and auditory reaction time. They reported a systematic decrease of discrimination scores for the subjects over the age of 50; about 5 percentage points per decade. The reaction time task showed a gradual increase as a function of age. This increase was linear for the tactile and visual tasks, and linear for the auditory task up to the age of 70, but showed an abrupt drop for the ninth decade. They concluded that the deterioration of the reaction time task is a behavioral indication of generalized deterioration occurring with age at all levels of the nervous system.

In addition, Feldman and Reger's results agree with those of Goetzinger et al (1961) in identifying a less severe loss of intelligibility for speech with age than had previously been reported by Pestalozza and Shore (1955) and Gaeth (1948). In general it should be noted that the clinical populations showed more dramatic effects of aging.

Melrose et al (1963) found that a group of Spanish-American War veterans, who were free from active otological pathology and without lifetime exposure to extreme noise levels, performed unusually well on speech discrimination tests. The mean speech discrimination score was 78%. The authors reported that 30% of the subjects scored in excess of 90% on the CID W-22 word lists.

There is some concern that speech materials may be testing a listener's familarity with the words as well as his discrimination. It would, therefore, be difficult to differentiate between a central hearing disorder and a disturbance of the speech function (Konig, 1969).

Use of Distorted Speech Materials

The decrease in speech discrimination with age is a clinical finding typical of presbyacusis. However, the redundancy of the language allows the listener with a sensori-neural hearing loss to utilize additional cues to understand the message meaning. Studies have been undertaken to use reduced redundancy as a diagnostic tool in site of lesion testing. Bocca (1958) reported the results on distorted and difficult speech materials for older subjects to be similar to the results for patients with temporal lobe tumors. He inferred from these findings that auditory discrimination is cortical in nature. Investigations have been conducted to test this hypothesis.

Typically, studies have shown that the aging auditory system is particularly affected by changes in the temporal characteristics of speech. Kirikae (1969) noted a much more severe deterioration of discrimination on filtered and time-altered speech tests for subjects aged 60-75 years than for younger listeners. Sticht and Gray (1969) found that age, rather than mere hearing acuity had the most adverse effect on the discrimination of time-compressed speech. They suggested that information processing over sensory channels is reduced in aging individuals, manifesting itself when one uses reverberated speech, overlapping speech (SSW) and interrupted speech. In the distorted speech tests the older subjects showed decreases in performance, with the most dramatic changes occurring on those tasks which involved overlapping words (the Staggered Spondaic Word Test of Katz) and interrupted speech. The authors suggest that this deterioration with age, even in the presence of normal hearing, is related to a gradual decrease in time-related processing abilities.

Antonelli (1970) conducted an investigation to determine the effect of drugs which act directly upon the reticular formation. He found a change in intelligibility for time-compressed speech and, to a lesser degree, binaurally switched speech. He postulated that the ascending reticular activity appears capable of influencing the time constant of sensory integrative processes. He further suggested that the absence of retrocochlear findings on auditory tests indicate that the problem of discrimination in aging subjects is due to a more diffuse neural degeneration than that of the VIIth nerve alone.

Berruecos (1970) was able to substantially increase discrimination scores for older subjects when delivering time-compressed speech binaurally rather than monaurally. This improvement was considerably more than could be attributed to interaural summation. The findings point to the benefit of increased redundancy of binaural presentation to a system which has experienced a progressive reduction of neural pathways and synaptic interrelations due to senescent changes.

Other investigators have studied the effect of time-altered speech on older individuals. Pestalozza and Shore (1955), Calaero and Lazzone (1957), and de Quiros (1964), among others, have shown a deterioration with age for accelerated speech. Luterman et al (1966) matched a presbycusic population to younger listeners (mean age 35.4 years) with the same degree of sensori-neural loss. A third group of young, normal hearing subjects was included in the study. The authors found no significant differences in the performance among the three groups for either speeded or expanded speech materials. Clinically, it seems that older listeners find slow speech easier to understand. It is surprising, therefore, to note from this study that expanding speech did not reveal improved scores for the older population. The investigators suggest that the problem of the elderly is not in the perception of the message unit, but in the integrating and processing of complex signals.

There are repeated references in the literature to the wide variability of the results of both redundant and distorted speech discrimination tests, especially with older subjects. Feldman and Reger (1967) refer to "a number of presbycusic populations that make up the presbycusic universe rather than a single population which is representative of all aged persons."

Bergman (1968) observed that the rate of information processing is reduced with age. He used a speeded message, increased from a normal 140 wpm to 350 wpm. Young subjects required a slight increase in intensity to perform normally, older subjects, however, could not achieve scores above 45%, and were judged to be unable to function under these conditions.

Konkle et al (1977) reported similar age effects on time-altered speech materials. They found that increments in the percentage of time-compression appeared to play a more prominent role as age increased. This supported their hypothesis that the aging process has a detrimental effect upon the perceptual processing of the temporal characteristics of speech.

Jerger (1960) proposed that central auditory processing was governed by a "subtlety principle"; that is to say, one required more complex stimuli to identify lesions on the higher levels of the central auditory pathways than those at lower levels. That temporally altered speech has been shown to be sensitive to centrally based disorders of auditory processing, lends support to the theory that during the aging process there is a diffuse neural degeneration that has a direct detrimental effect on speech perception.

Filtered speech has been used to determine the effects of frequency reduction on speech discrimination tasks. Harbert, Young and Menduke (1966) found that scores for filtered speech were disproportionately lower for subjects over the age of 60 than for a matched group of younger subjects with congenital neural losses. Antonelli (1970) presented complex filtered speech that low-passed at approximately 500 Hz to young and old listeners, and found a decrease in discrimination scores for the older subjects.

Palva and Jokinen (1970) reported a study of 149 subjects aged

20 to 89 years who were presented with dichotically filtered speech. Bands of 480-720 Hz and 1800-2400 Hz were presented together to one ear at a time and compared with the results obtained when the two bands were delivered dichotically. They noted a significant decrease of discrimination with increasing age, becoming most significant beyond the age of 50. The authors mentioned an increasing individual variability with increasing age. The results of this investigation indicated a right ear advantage, relative to both the dichotic and left ear presentations, that was especially marked for the subjects above the age of 60 years. This advantage had not been evident in either pure tone thresholds or undistorted speech test scores.

Jerger (1973) compared the results of elderly patients, younger patients with matched degree and configuration of hearing loss, and normal listeners for distorted speech materials. He found with the aid of low intensity discrimination tests (5 dB SL), sentence identification with competing messages, and sentence in competing message with 50% compression that the elderly subjects scores less well than the younger, hearing-impaired subjects. He concluded that there exists a progressive degenerative effect of biological aging on speech intelligibility, even when hearing loss remained constant. The phenomenon is directly related to the difficulty of the listening task. Jerger points to the dramatic effects of stress in the time domain.

The effects of noise to mask and, thereby, reduce the redundancy of the message has been studied by many investigators. Jokinen

(1973), testing the discrimination of 120 subjects between the ages of 20 and 87 years in quiet and in various signal-to-noise conditions, found a significant difference in the performance of listeners over the age of 50 in noise compared to that of the younger subjects. He noted a wide variability of individual responses, as had been mentioned by previous investigators. The results of the study by Jokinen agree with the work of Morales-Garcia and Poole (1972), further substantiating the similar performance of between patients with intracranial lesions and older individuals without pathology. That is, in both studies there was a regular degradation of speech intelligibility in noise as a function of age.

Smith and Prather (1971) found that the discrimination scores of younger listeners were better than those of older subjects at several levels, and in a number of speech-to-noise conditions. They failed to find, however, that the two groups performed in substantially different ways as the listening conditions became progressively poorer. In this investigation the speech materials employed were simple consonant/vowel syllables, whereas the more typical speech materials in studies of this kind are phonetically balanced word lists in English (usually CID W-22 word lists) or in other languages. It may be speculated that the processing required for CV discrimination is of a kind that is less affected by loss of central auditory function.

A recent study by Schindler and Vigone (1976) compared discrimination scores of young females with those of older adults (40-50 years) in the presence of taped traffic noise at several signal-to-noise levels (+10 to -35). The results revealed the expected decrement with increasing age. The authors noted wide individual variability, but reported significantly depressed performances of the older subjects in noise conditions of -10 S/N and worse. These findings further point to the beginning of deterioration of the central auditory pathways by the fifth decade.

In order to more directly compare some of the studies published over the past 15 years, Table 3 was prepared. The tabulated studies are concerned with the perception of degraded speech signals by an older subject or across a population of increasing age.

The speech materials were phonetically balanced monosyllabic word lists; Jerger (1973) also included synthetic sentences (third-order approximations) with competing speech signals and Bergman (1971) used the sentence material developed for the CHABA group. Several means of degrading the speech signal were used in the various studies: time alteration such as compression (Luterman et al, 1966; Stitch and Gray, 1969; Jerger, 1973; Konkle et al, 1977) and expansion (Luterman et al, 1966); filtered speech (Kirikae et al, 1964; Palva and Jokinen, 1970); reverberated speech (Bergman, 1971) and speech presented with a competing message (Ross et al, 1965; Jerger, 1973; Jokinen, 1973).

All of the studies in Table 3 show a decrement of measured speech perception for the degraded signal with increasing age, regardless of the speech materials or the differing methods of de-

Table 3. Comparison of Results of Research in Degraded Speech Signals as a Function of Increasing Age.

AUTHORS	POPULATION TYPE	# SUBJECT	AGE RANGE	SPEECH MATERIALS	TYPE OF DEGRADATION	AGE EFFECT
Kirikae et al (1964)	Non-clinical	10	20-30	Monosylbls. (Japan)	1. Low-pass filter	+
					2. Binaural alternating speech	+
	Non-clinical	10	50-70			
					3. Interrupt.	+
Ross et al (1965)	Non-clinical		30-56	Monosylbls.	Speech in noise	+
	Clinical		22-72			+
Luterman et al (1966)	Non-clinical	18	20-38		Compression and expansion	+
	Clinical	18	20-40			+
	Clinical	18	79-87			+
Stitch and Gray (1969)	Non-clinical	14	27-65	Monosylbls.	Compression	+
	Clinical	14	48-69			+
Palva and Jokinen (1970)	Clinical	149	20-89	Monosylbls. (Finnish)	1. Filtered, Binaural present.	+
					2. Filtered, monaural	++

Table 3, continued.

AUTHORS	POPULATION TYPE	# SUBJECT	AGE RANGE	SPEECH MATERIALS	TYPE OF DEGRADATION	AGE EFFECT
Bergman (1971)	Non-clinical	282	20-89	Sentences	Reverberation	+
				Sentences	Interruption	++
				Spondees	SSW	+
Jerger (1973)	Clinical	2162 (4095 ears)	6-89	Monosylbls.	Competing Speech	+
	Clinical	10	Adults	Sentences	Competing speech @ normal speed and with compression	+
	Clinical	18	Presbycusic adults	"		
				Monosylbls.	5 dB SL	+
Jokinen (1973)	Clinical	120	20-87	Monosylbls. (Finnish)	Speech in noise	+
Konkle et al 1977)	Non-clinical	118	54-75+	Monosylbls.	Compression	+

grading the speech signal.

Summary

Changes in hearing with age are caused by structural alterations in the peripheral and central auditory pathways. These are due to senescent changes as well as alterations caused by disease, injury, or a lifetime of exposure to environmental noise in industrial societies. For any combination of these causes, many individuals experience, by the fifth decade of life, a loss of hearing for pure tones, especially for the higher frequencies. In addition, a loss of the ability to discriminate speech, sometimes referred to as "phonemic regression", is a common finding in older subjects. When the speech signal is degraded in some way, so as to decrease the redundancy of the signal, older subjects show a more dramatic loss of understanding than either normal-hearing or hearing-impaired younger subjects.

Concluding Comments

The preceeding review of the pertinent literature indicates that noise interferes with speech perception by all listeners, but most especially by the older listener. Previous studies have examined the effect of age on speech perception in noise but, too frequently, there were confounding factors such as, for example, the use of a clinical population with possibly undiagnosed disorders of the auditory periphery. Noise exists in all industrial societies, but is most extreme in large cities. In these same metropolitan areas are large concentrations of older citizens. It was felt that the older residents of a city might be especially disadvantaged by the environmental noise in which most citizens need frequently to communicate. To determine whether this hypothesis was valid, the present study was undertaken.

CHAPTER III

PROCEDURE

Speech Material

Material was selected which would demonstrate discrimination of connected speech in simulated real-life situations. To this end, sentences were used which had been developed by the Armed Forces National Research Council Committee on Hearing and Bioacoustics (CHABA). These sentences are representative of American English discourse in terms of frequency of word occurrence, grammatical structure, varied sentence length, sentence type (question, declaration, etc.) and idiom (Davis and Silverman, 1970). Each list of ten sentences has 50 key words which are scored for a maximum possible score of 100 percent. The sentences provide contextual cues which are available in everyday connected speech.

Ten CHABA lists have been standardized and equated with one another. The experimental design, however, required eleven lists; one list was thus repeated for each set of tapes. The replicated list was varied, and care was taken to present it with at least three other lists intervening. In addition, the duplications were analyzed so that if there were evidence of higher scores on the second presentation of a list they could be accounted for in the data.

Noise Stimuli

Environmental noises typical of New York City were used. Subway and traffic noises were chosen because they represented typical noises in which New Yorkers of all ages would often need to communicate.

Tapes of subway noises were selected from the extensive set of recordings previously obtained under a study for the Urban Analysis Center by Danto (1973). One sample was chosen as representative of the noise within a typical subway car while travelling at uniform speed. The second was selected to be representative of the noise in the interior of the subway car as the train is slowing down with the brakes squealing. The second sample had relatively more high frequency energy produced by the squealing brakes.

Recordings of traffic noise were obtained at Fifth Avenue and 42nd Street, facing the intersection from the northwest corner on a weekday during mid-morning, using a Uher 4200 tape recorder. Two samples of traffic noise were selected: one was chosen to include heavy vehicles (primarily buses), and the second was selected as representative of the steady sounds of automobile traffic.

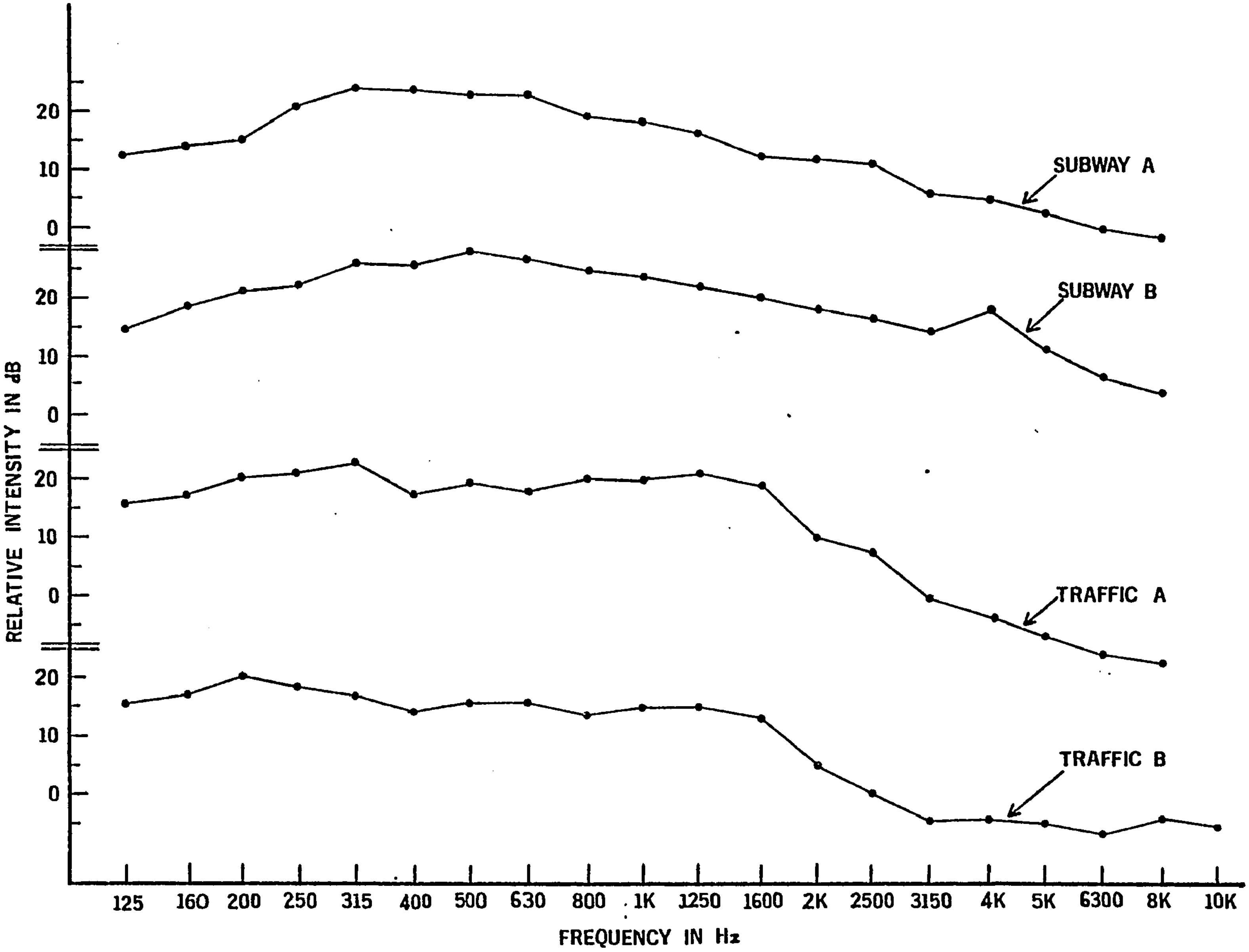
The four noise samples were designated:

Subway Noise A - Interior of the train at steady speed
Subway Noise B - Interior of the train, brakes squealing
Traffic Noise A - Traffic which includes heavy vehicles
Traffic Noise B - Automobile traffic

Figure 1 shows the spectra for the four noise samples. Each sample was dubbed on two Ampex AG 500 tape recorders, separated by leader tape to make the sections easily identifiable, and used for all subsequent noise taping.

Since previous studies of speech in noise have used gaussian noise, there was an interest in comparing these real-life noises

Fig. 1 Spectra of two samples of subway noise (A and B) and two samples of traffic noise (A and B) used in the study.



RELATIVE INTENSITY IN dB
20
10
0
20
10
0
20
10
0
20
10
0
SUBWAY A
SUBWAY B
TRAFFIC A
TRAFFIC B
125
160
200
250
315
400
500
630
800
1K
1250
1600
2K
2500
3150
4K
5K
6300
8K
10K
FREQUENCY IN Hz

with laboratory-generated gaussian noise. Recordings of gaussian noise were obtained using a white noise generator and a General Radio 1925 Multifilter. The multifilter was used to match the spectra of the laboratory-generated gaussian noise to each of the subway and traffic noise samples.

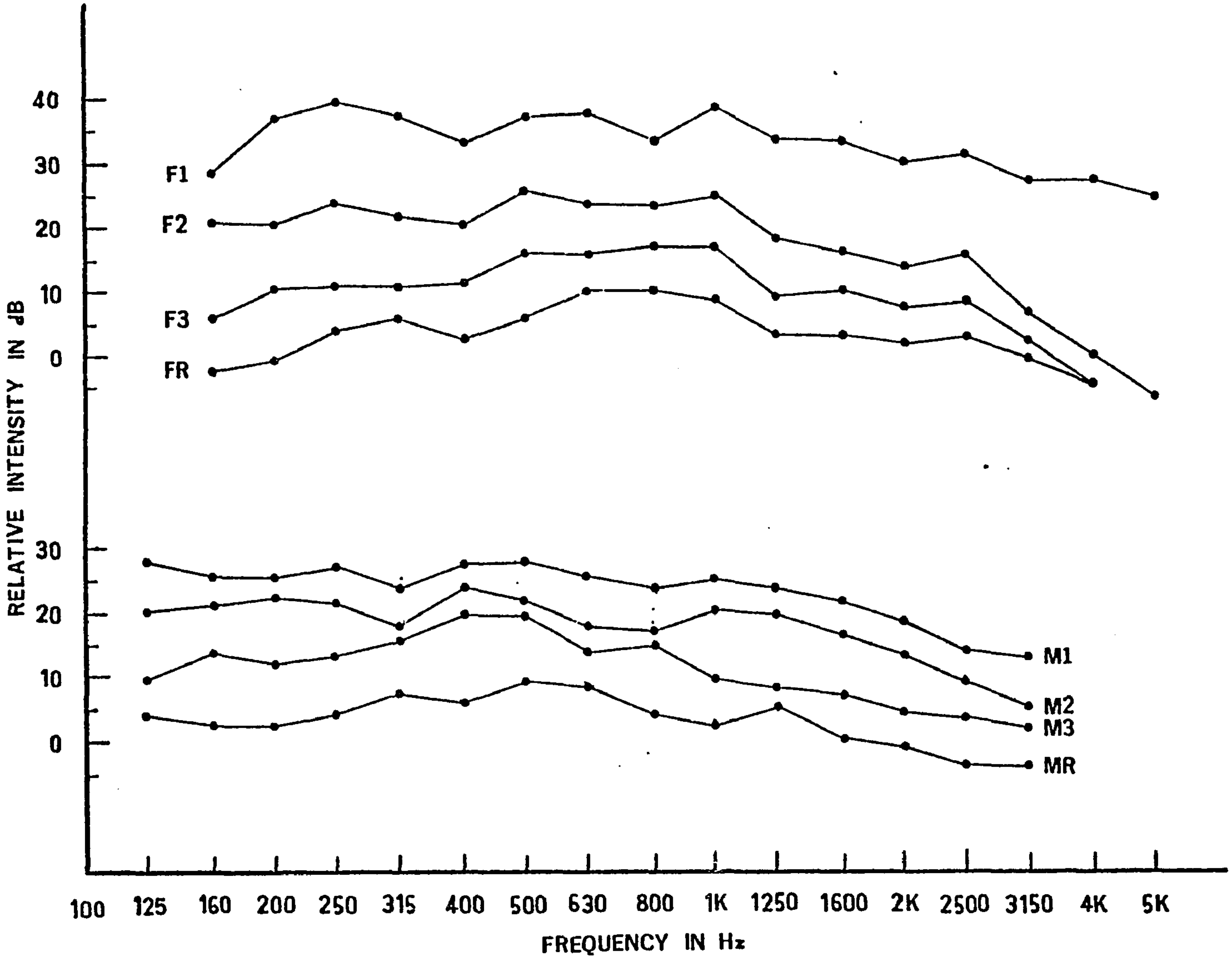
Speakers

A male and a female speaker were selected whose speech, in the judgment of the researchers, was representative of East coast patterns without marked regional accents and with clear, precise articulation. They were designated the reference speakers, and they recorded all the CHABA sentences. Three male and three female speakers with speech patterns judged to be typical of the New York metropolitan area also recorded the sentences. Figure 2 shows the results of a one-third octave band analysis of the speech spectra of the eight speakers.

Preparing the Tapes

All speech materials were recorded on an Ampex AG 500 tape recorder with an AKG D202 microphone in an IAC 1600 series acoustic chamber. Level recordings were made of the speech recording, and an average level for each sentence list was obtained for each speaker. The average level was obtained by averaging the peaks of the individual words. Equalized dubbings were made, using a tolerance of ± 2 dB. A 1000 Hz calibration tone was added to the beginning of each speaker's lists at the average level for that speaker.

Fig. 2 Spectra of speaker voices used in the study. Female reference speaker (FR) and three female speakers with speech typical of the New York City area (F 1; F 2; F 3); Male reference speaker (MR) and three male speakers with speech typical of the New York City area (M 1; M 2; M 3).


RELATIVE INTENSITY IN dB
40
30
20
10
0
30
20
10
0
F1
F2
F3
FR
M1
M2
M3
MR
100
125
160
200
250
315
400
500
630
800
1K
1250
1600
2K
2500
3150
4K
5K
FREQUENCY IN Hz

In assembling the final tapes, the speech material was dubbed onto one track of a Uher 4200 Stereo tape recorder and noise was dubbed onto the lower track of the same tape. Each track was then played through the B & K Graphic Level Recorder, peaks were averaged, and a 1000 Hz calibration tone was recorded and spliced at the beginning of the tape for each track its level being equal to the average level of that track.

Experimental Design

The design of the investigation called for three signal-to-noise ratios which would yield discrimination scores of 90%, 70%, and 50% (± 5%) for young listeners with normal hearing. The speech materials were pilot-tested on students from the Graduate School and University Center of City University of New York. Each talker was found to require a different signal-to-noise ratio to yield the target scores.

For the presentation of the sentence material, the first list was always presented in the quiet condition by the reference speaker. After the initial presentation in quiet, each subject was presented with ten lists with varying noise conditions; these were arranged in a quasi-random manner. Each of the real noise samples was presented, coupled with a list, at each of the presentation levels; every speaker was heard with each noise sample. The exception to this was that the laboratory replications were only matched to the reference speakers, always at the middle level (S/N 2) for the sentence material. Table 4 shows the complete design.

Table 4. Experimental Design for Each Listener Group
(Listener groups defined in Table 4 a)

Speakers

		Reference	N.Y.C. #1	N.Y.C. #2	N.Y.C. #3
Noise Types	Quiet	No Noise			
	Real Subway	S/N 2	S/N 1	S/N 2	S/N 3
	Real Traffic	S/N 2	S/N 3	S/N 2	S/N 1
	Subway Lab	S/N 2			
	Traffic Lab	S/N 2			

S/N 1 = Approximately 90% Level for young, normal hearing subjects.

S/N 2 = Approximately 70% Level for young, normal hearing subjects.

S/N 3 = Approximately 50% Level for young, normal hearing subjects.

Each subject heard all of the speakers of one sex paired with all of the noise samples designated either 'A' or 'B'. In each decade, half the male subjects listened to male speakers, half to female speakers. The female subjects were divided in the same manner. Within each of these groupings, half the subjects listened to sample 'A' and half to sample 'B'.

Levels of presentation never exceeded 91 dBA. Data were available for the subway noise, and modal levels were chosen. The levels used were:

Subway Noise	'A'	84 dBA
Subway Noise	'B'	82 dBA
Traffic Noise	'A'	85 dBA
Traffic Noise	'B'	84 dBA

Speech was attentuated relative to the noise levels to achieve the target scores for the pilot tests, and then kept at those levels throughout the course of the investigation.

Subjects

The criteria for the study were essentially normal hearing, English as a first language, discrimination within normal limits in quiet, and no active otological pathology.

Threshold testing was done, using the Carhart-Jerger method. In order for a subject to be included in this study his hearing level needed to fall within the following levels for the frequencies tested:

500 Hz	1000 Hz	2000 Hz	3000 Hz	4000 Hz
30 dB	30 dB	30 dB	30 dB	40 dB

These criteria were chosen so as to include, with high probability, only subjects with unimpaired hearing. Data of Corso, (1963), Glorig and Nixon (1963) and Maurer and Rupp (1979) show that a majority of normal hearing persons would satisfy these criteria up to the age of 70. This set of criteria was also similar to that used by Bergman (1971b) and Bergman et al (1976). These criteria were also considered adequate for the levels of ambient noise occurring at the test sites used in this study.

Bergman (1968) found that subjects who had spoken English and were fluent in English for more than 40 years, but for whom English was a second language, revealed significantly lower scores on degraded speech materials than those for whom English was a native language. To eliminate this confounding effect, all subjects were native English speakers.

It has been mentioned that the first sentence presentation was always in a quiet condition. This was used as a screening device; only those subjects who scored 96% or better on undistorted speech were included in the population. Abnormal discrimination scores might be indicative of pathology which would have masked the variables being examined in this study.

One hundred and sixty subjects were included in the study, divided into groups of 32 for each of the five decades (20-29 through 60-69). The design for each of these decade groups is shown in

Table 4 a.

Equipment and Calibration Procedures

Two Beltone 10D audiometers with TDH 39 earphones in MX-41/AR cushions were used throughout the testing; physical calibration checks were run every two weeks of the data collection using a Bruel and Kjaer 1613 Sound Level Meter and ANSI 1969 standards.

Three Uher 4400 tape recorders were used to present the speech material and noise samples. Each tape recorder was connected to a Daven attenuator to which had been attached a Hewlett-Packard A-33 impedance matching transformer. The attenuator was adjustable in ten- and one-decibel steps. TDH 39 earphones in MX-41/AR cushions were used; subjects heard the speech and noise mixed binaurally. The examiner monitored the speech and stopped the recorder between sentences so as to allow the subject sufficient time to repeat what was heard.

An RCA sound level meter Model WE-130A was used to check the levels of the calibration tones on each track of each tape before every test session. The RCA meter compared favorably to the B & K sound level meter (± 2 dB) on an artificial ear, and was lighter in weight and more portable to carry into the field.

After the first list of sentences were presented in quiet, the noise level was adjusted for each set of sentences according to the experimental condition being tested.

Table 4 a. Experimental Design for Listeners.

Within each cell all listeners heard all conditions shown in Table 3. This was repeated for each of the age decades. A total of 160 listeners were studied.

		A	B
MALE LISTENERS	Male Speakers	4 Subjects	4 Subjects
	Female Speakers	4 Subjects	4 Subjects
FEMALE LISTENERS	Male Speakers	4 Subjects	4 Subjects
	Female Speakers	4 Subjects	4 Subjects

Test Procedures

A questionnaire was developed to provide information regarding the age, educational and professional background, medical and family history, language background and previous history of exposure to high-intensity noise of each volunteer. This form is Appendix I.

Testing was done in the field; attempt was made to select a wide cross-section of subjects, ages 20 through 69 who might have the experience of trying to communicate on the subway or on busy streets in the course of a normal day in New York City. The 'field' included a basement storage room in a City building, church rectory, sound-treated test chambers, a senior citizen's center on the noisy Grand Concourse in the Bronx, a suburban living room, and many other diverse sites. The criteria for hearing levels were set as described above.

When the subjects had completed the background questionnaire and had passed the audiometric test, the listening task was begun. The following instructions were given before each test:

> You are going to hear several men (or women) speaking. They will be saying simple sentences, the sort of speech you might hear every day, such as "Lock the door when you leave the house." and "Please get me an apple".
> The first group of sentences will be heard in quiet, and they should be quite easy for you to hear. Please repeat everything that you hear him (her) say. After the first sentences, I will add some noises. They will be very much like what you hear when riding a subway or walking around the city. Some noises will be loud and annoying, but at no time will they be loud enough to harm you or, for that matter, as loud as some of the sounds that you actually hear in the city! Some of the time the noises might be distracting and interfere with your hearing or understanding what is said. Please repeat everything you hear and, if you are not sure, try and guess. I will

> be scoring each word separately, so if you hear only part of a sentence repeat that - even if it doesn't make any sense to you. Do you understand? Are there any questions? Here we go.

The subjects were given as much time as they needed for each sentence, as the tapes were interrupted between each sentence, but no sentence was replayed after the initial presentation. Responses were recorded on a prepared copy of the ten lists by the examiner. A sample copy is attached as Appendix II. The list which was repeated was recorded in a different color pen/pencil so as to keep the responses separate.

The sentence lists have 50 key words. They are underlined in the copy used during data collection. These are the only words scored. Correct responses are credited with two percentage points for a total maximum score of 100%. Every key word was scored separately, even if the response was an incomplete sentence or single word. The response was considered incorrect unless it was complete; a response of "that" for "that's" would be given no credit.

After the data were collected and analyzed, it was apparent that all those collected on certain days showed unusually high intelligibility scores. Error was suspected; those data were eliminated, and other subjects were tested to be included in the investigation.

Responses were coded as to the number of correct words per sentence for later computer analysis. The data were subjected to two separate analyses of variance. The first examined the factors of age, speaker sex, listener sex and noise sample in a four-way analysis of variance. The design is shown in Table 4 a. Each cell of the design contained the data from four listeners, for four replications of the same condition. The design was balanced so that an equal number of male listeners and female listeners heard male speakers and vice versa. Each of these groups (i.e. male listeners hearing male speakers) was further sub-divided into all speakers combined with either noise sample A or noise sample B. The design was repeated for each of the five decades studied.

The second analysis examined those factors which were common to all listeners. Each listener heard four different speakers of one sex at three different signal/noise ratios for one sample of real subway and traffic noises and the laboratory-simulated noises with matching spectra. This second experimental design is shown in Table 4. A subdivision of this analysis examined speaker accent, as will be discussed later.

Throughout the data analysis, the arcsine transformation was used to stabilize the error variance of the intelligibility scores which are in the form of percentages. (The error variance of an estimated percentage is $P(100-P)/N$, where P is the percentage being estimated and N is the number of trials on which the estimate is based. The error variance changed as a function of P, thereby violating the assumption of homogeniety of the error variance. This also caused problems of relative weighting when fitting curves to the data. The inverse sine transformation $y = 2 \arcsin p/100$ has an error variance which is relatively stable with y (Brownlee, 1965). The estimates used in the special case, where the measured percentage is p = 0% or p = 100%, are: 2 (arcsine $\overline{1/2N}$ in the case where p = 0%, and 2 (arcsine 1-1/2N) in the case where p = 100%.

CHAPTER IV

RESULTS

Significant aging effects were noted for all noise conditions, for both the real and the laboratory-simulated subway and traffic noises.

The results of the analyses of variance which examined factors across subjects are shown in Tables 5 through 14. A separate analysis of variance was performed for each of the following ten experimental conditions:

i. Typical New York speaker in subway noise at S/N 2.
ii. Reference speaker in subway noise at S/N 2.
iii. Reference speaker in laboratory-simulated subway noise S/N 2.
iv. Typical New York speaker in traffic noise at S/N 2.
v. Reference speaker in traffic noise at S/N 2.
vi. Reference speaker in simulated traffic noise at S/N 2.
vii. Typical New York speaker in subway noise at S/N 1.
viii. Typical New York speaker in subway noise at S/N 3.
ix. Typical New York speaker in traffic noise at S/N 1.
x. Typical New York speaker in traffic noise at S/N 3.

The factors considered in each analysis were:

Age by decade (D) included were the third through the seventh decade: 20-29 years; 30-39 years; 40-49 years; 50-59 years; and 60-69 years.

Speaker sex (S); one reference speaker and three typical New York speakers of each sex recorded identical material in the same combination of noise sources, levels, and samples.

Listener sex (L); half the listeners of each sex heard all four male speakers, and the other half heard all four female speakers.

Noise sample (T); half the listeners heard noise sample A which differed in spectrum from noise sample B. Sample A, for both subway and traffic sources, had less high frequency power than sample B. The same difference in spectrum shape obtained for the laboratory-simulated noise samples A and B, as they were generated to match the original noise samples in spectrum shape.

An asterisk appears next to the last column marked 'Significant' for those factors which met, or fell below, the .05 level of significance. These factors are summarized in Table 15. The ten test conditions are found on the abscissa, and the individual factors and combination of factors which proved to be significant are on the ordinate. In Table 15, an asterisk in a row indicates that the factor in that column met the criteria for statistical significance. Two factors were found to be significant for most of the experimental conditions. These are Speaker Sex (S) which is significant in nine of the ten conditions, and Age (D) which is significant in eight of the ten conditions. One interaction was found to be statistically significant in more than half of the conditions, that of Speaker Sex by Noise Sample (ST), which proved significant in six of the conditions. The above two main effects and interaction appear to be the most important effects across the ten conditions. In addition, there appeared to be a trend toward a large number of factors achieving statistical significance in the presence of traffic noise, as opposed to subway noise and for S/N 1 compared to other signal-to-noise ratios.

Table 16 gives the discrimination scores, averaged across individual speakers, for speaker sex. This is divided into real noise

TABLE 5

ANALYSIS OF VARIANCE: TYPICAL NEW YORK SPEAKERS

SOURCE OF VARIATION		DEGREES OF FREEDOM	MEAN SQUARES	F	SIGNIFICANCE LEVEL
D	AGE DECADE	4	0.278	1.52	.200
L	LISTENER SEX	1	0.634	3.48	.862
DL	D X L INTERACTION	4	0.439	2.40	.053
S	SPEAKER SEX	1	2.463	3.55	.001*
DS	D X S INTERACTION	4	0.130	0.71	.589
LS	L X S INTERACTION	1	0.150	0.52	.629
DLS	D X L X S INTERACTION	4	0.193	1.05	.483
T	NOISE SAMPLE	1	0.013	0.07	.789
DT	D X T INTERACTION	4	0.262	1.43	.227
LT	L X T INTERACTION	1	1.137	6.17	.014*
DLT	D X L X T INTERACTION	4	0.409	2.23	.069
ST	S X T INTERACTION	1	0.312	1.71	.191
DST	D X S X T INTERACTION	4	0.054	0.29	.382
LST	L X S X T INTERACTION	1	0.104	0.57	.540
DLST	D X L X S X T INTERACTION	4	0.199	1.09	.366
RESIDUAL		120	0.183		

TABLE 6

ANALYSIS OF VARIANCE: REFERENCE SPEAKERS IN SUBWAY NOISE AT S/N 2.

SOURCE OF VARIATION		DEGREES OF FREEDOM	MEAN SQUARES	F	SIGNIFICANCE LEVEL
D	AGE DECADE	4	2.078	9.45	.001*
L	LISTENER SEX	1	0.665	3.02	.081
DL	D X L INTERACTION	4	0.474	2.16	.077
S	SPEAKER SEX	1	1.651	7.51	.007*
DS	D X S INTERACTION	4	0.442	2.01	.096
LS	L X S INTERACTION	1	0.178	0.81	.628
DLS	D X L X S INTERACTION	4	0.247	1.12	.349
T	NOISE SAMPLE	1	0.151	0.69	.587
DT	D X T INTERACTION	4	0.273	1.24	.295
LT	L X T INTERACTION	1	0.004	0.02	.885
DLT	D X L X T INTERACTION	4	0.171	0.78	.644
ST	S X T INTERACTION	1	6.192	26.16	.001*
DST	D X S X T INTERACTION	4	0.256	1.16	.330
LST	L X S X T INTERACTION	1	0.034	0.15	.699
DLST	D X L X S X T INTERACTION	4	0.118	0.54	.714
RESIDUAL		120	0.220		

TABLE 7

ANALYSIS OF VARIANCE: REFERENCE SPEAKERS IN LABORATORY-SIMULATED SUBWAY NOISE AT S/N 2.

SOURCE OF VARIATION		DEGREES OF FREEDOM	MEAN SQUARES	F	SIGNIFICANCE LEVEL
D	AGE DECADE	4	0.812	2.15	.078
L	LISTENER SEX	1	0.683	1.81	.178
DL	D X L INTERACTION	4	0.656	1.74	.145
S	SPEAKER SEX	1	18.454	48.67	.001*
DS	D X S INTERACTION	4	0.876	2.32	.060
LS	L X S INTERACTION	1	3.165	8.38	.005*
DLS	D X L X S INTERACTION	4	0.362	0.96	.566
T	NOISE SAMPLE	1	0.619	1.64	.200
DT	D X T INTERACTION	4	0.360	0.95	.562
LT	L X T INTERACTION	1	0.324	0.86	.641
DLT	D X L X T INTERACTION	4	0.044	0.12	.274
ST	S X T INTERACTION	1	0.168	0.45	.512
DST	D X S X T INTERACTION	4	0.714	1.89	.115
LST	L X S X T INTERACTION	1	0.023	0.06	.802
DLST	D X L X S X T INTERACTION	4	0.191	0.51	.734
RESIDUAL		120	0.378		

TABLE 8

ANALYSIS OF VARIANCE: TYPICAL NEW YORK SPEAKERS IN TRAFFIC NOISE AT S/N 2.

SOURCE OF VARIATION		DEGREES OF FREEDOM	MEAN SQUARES	F	SIGNIFICANCE LEVEL
D	AGE DECADE	4	1.342	4.44	.003*
L	LISTENER SEX	1	0.088	0.30	.694
DL	D X L INTERACTION	4	0.548	1.81	.130
S	SPEAKER SEX	1	2.622	8.33	.005*
DS	D X S INTERACTION	4	0.457	1.51	.203
LS	L X S INTERACTION	1	0.598	1.97	.160
DLS	D X L X S INTERACTION	4	0.159	1.51	.733
T	NOISE SAMPLE	1	0.321	1.06	.306
DT	D X T INTERACTION	4	0.862	2.91	.024*
LT	L X T INTERACTION	1	0.062	0.21	.656
DLT	D X L X T INTERACTION	4	0.318	1.05	.388
ST	S X T INTERACTION	1	0.521	1.72	.189
DST	D X S X T INTERACTION	4	1.075	3.55	.009*
LST	L X S X T INTERACTION	1	0.017	0.06	.809
DLST	D X L X S X T INTERACTION	4	0.224	0.74	.570
RESIDUAL		120	0.303		

TABLE 9

ANALYSIS OF VARIANCE: REFERENCE SPEAKERS IN TRAFFIC NOISE AT S/N 2.

SOURCE OF VARIATION		DEGREES OF FREEDOM	MEAN SQUARES	F	SIGNIFICANCE LEVEL
D	AGE DECADE	4	2.007	9.98	.001*
L	LISTENER SEX	1	0.094	0.47	.502
DL	D X L INTERACTION	4	0.789	3.93	.005*
S	SPEAKER SEX	1	6.775	33.68	.001*
DS	D X S INTERACTION	4	0.627	3.12	.018
LS	L X S INTERACTION	1	0.023	0.11	.737
DLS	D X L X S INTERACTION	4	0.002	0.01	.999
T	NOISE SAMPLE	1	0.067	0.28	.607
DT	D X T INTERACTION	4	0.296	1.47	.214
LT	L X T INTERACTION	1	0.139	0.70	.588
DLT	D X L X T INTERACTION	4	0.264	1.31	.268
ST	S X T INTERACTION	1	0.238	1.18	.279
DST	D X S X T INTERACTION	4	0.704	3.50	.010*
LST	L X S X T INTERACTION	1	0.005	0.02	.866
DLST	D X L X S X T INTERACTION	4	0.068	1.34	.852
RESIDUAL		120	0.201		

TABLE 10

ANALYSIS OF VARIANCE: REFERENCE SPEAKERS IN LABORATORY-SIMULATED TRAFFIC NOISE AT S/N 2.

SOURCE OF VARIATION		DEGREES OF FREEDOM	MEAN SQUARES	F	SIGNIFICANCE LEVEL
D	AGE DECADE	4	1.526	5.42	.001*
L	LISTENER SEX	1	0.001	0.00	.950
DL	D X L INTERACTION	4	0.577	2.06	.089
S	SPEAKER SEX	1	2.011	7.14	.008*
DS	D X S INTERACTION	4	0.986	3.99	.010*
LS	L X S INTERACTION	1	0.893	3.17	.074
DLS	D X L X S INTERACTION	4	0.129	0.46	.770
T	NOISE SAMPLE	1	7.504	26.64	.001*
DT	D X T INTERACTION	4	0.362	1.28	.299
LT	L X T INTERACTION	1	0.248	0.68	.647
DLT	D X L X T INTERACTION	4	0.101	0.36	.239
ST	S X T INTERACTION	1	1.953	6.83	.009*
DST	D X S X T INTERACTION	4	0.392	1.39	.240
LST	L X S X T INTERACTION	1	1.206	4.29	.038*
DLST	D X L X S X T INTERACTION	4	0.563	2.00	.098
RESIDUAL		120	0.282		

TABLE 11

ANALYSIS OF VARIANCE: TYPICAL NEW YORK SPEAKERS IN SUBWAY NOISE AT S/N 1.

SOURCE OF VARIATION		DEGREES OF FREEDOM	MEAN SQUARES	F	SIGNIFICANCE LEVEL
D	AGE DECADE	4	0.937	6.34	.001*
L	LISTENER SEX	1	0.868	4.94	.026*
DL	D X L INTERACTION	4	0.167	1.24	.895
S	SPEAKER SEX	1	5.897	43.64	.001*
DS	D X S INTERACTION	4	0.257	1.90	.113
LS	L X S INTERACTION	1	0.102	0.76	.810
DLS	D X L X S INTERACTION	4	0.023	0.17	.850
T	NOISE SAMPLE	1	0.346	2.56	.108
DT	D X T INTERACTION	4	0.237	1.76	.141
LT	L X T INTERACTION	1	0.582	4.31	.038*
DLT	D X L X T INTERACTION	4	0.081	0.63	.648
ST	S X T INTERACTION	1	0.986	7.30	.008*
DST	D X S X T INTERACTION	4	0.201	1.49	.209
LST	L X S X T INTERACTION	1	1.359	2.66	.102
DLST	D X L X S X T INTERACTION	4	0.062	0.46	.771
RESIDUAL		120	0.135		

TABLE 12

ANALYSIS OF VARIANCE: TYPICAL NEW YORK SPEAKERS IN SUBWAY NOISE AT S/N 3.

SOURCE OF VARIATION		DEGREES OF FREEDOM	MEAN SQUARES	F	SIGNIFICANCE LEVEL
D	AGE DECADE	4	0.745	2.56	.041*
L	LISTENER SEX	1	0.080	0.14	.712
DL	D X L INTERACTION	4	0.224	0.77	.550
S	SPEAKER SEX	1	1.342	4.61	.832
DS	D X S INTERACTION	4	0.444	1.52	.198
LS	L X S INTERACTION	1	0.013	0.04	.031
DLS	D X L X S INTERACTION	4	0.454	1.56	.189
T	NOISE SAMPLE	1	0.900	3.09	.077
DT	D X T INTERACTION	4	0.255	0.68	.515
LT	L X T INTERACTION	1	0.317	1.09	.380
DLT	D X L X T INTERACTION	4	0.012	0.04	.994
ST	S X T INTERACTION	1	3.254	11.17	.001*
DST	D X S X T INTERACTION	4	0.259	0.86	.509
LST	L X S X T INTERACTION	1	0.507	1.74	.186
DLST	D X L X S X T INTERACTION	4	0.130	0.45	.776
RESIDUAL		120	0.291		

TABLE 13

ANALYSIS OF VARIANCE: TYPICAL NEW YORK SPEAKERS IN TRAFFIC NOISE AT S/N 1.

SOURCE OF VARIATION		DEGREES OF FREEDOM	MEAN SQUARES	F	SIGNIFICANCE LEVEL
D	AGE DECADE	4	0.324	2.44	.050*
L	LISTENER SEX	1	0.221	1.67	.196
DL	D X L INTERACTION	4	0.414	3.12	.017*
S	SPEAKER SEX	1	14.511	109.70	.001*
DS	D X S INTERACTION	4	0.037	0.28	.191
LS	L X S INTERACTION	1	0.050	0.48	.547
DLS	D X L X S INTERACTION	4	0.704	0.59	.668
T	NOISE SAMPLE	1	0.813	6.13	.014*
DT	D X T INTERACTION	4	0.513	3.86	.006*
LT	L X T INTERACTION	1	1.752	13.20	.001*
DLT	D X L X T INTERACTION	4	0.207	1.56	.088
ST	S X T INTERACTION	1	0.918	6.92	.009*
DST	D X S X T INTERACTION	4	0.636	4.79	.002*
LST	L X S X T INTERACTION	1	0.873	5.07	.025*
DLST	DX L X S X T INTERACTION	4	0.089	0.67	.618
RESIDUAL		120	0.133		

TABLE 14

ANALYSIS OF VARIANCE: TYPICAL NEW YORK SPEAKERS IN TRAFFIC NOISE AT S/N 3.

SOURCE OF VARIATION		DEGREES OF FREEDOM	MEAN SQUARES	F	SIGNIFICANCE LEVEL
D	AGE DECADE	4	2.643	10.19	.001*
L	LISTENER SEX	1	0.200	0.72	.596
DL	D X L INTERACTION	4	0.628	2.26	.066
S	SPEAKER SEX	1	0.157	0.56	.539
DS	D X S INTERACTION	4	1.048	3.76	.007*
LS	L X S INTERACTION	1	0.008	0.00	.672
DLS	D X L X S INTERACTION	4	0.422	1.51	.262
T	NOISE SAMPLE	1	0.091	0.33	.577
DT	D X T INTERACTION	4	0.633	2.27	.865
LT	L X T INTERACTION	1	0.063	0.23	.640
DLT	D X L X T INTERACTION	4	0.111	0.70	.812
ST	S X T INTERACTION	1	4.269	16.30	.001*
DST	D X S X T INTERACTION	4	1.079	3.54	.006*
LST	L X S X T INTERACTION	1	0.004	0.01	.902
DLST	D X L X S X T INTERACTION	4	0.334	0.84	.506
RESIDUAL		120	0.279		

Table 15. Factors Which Meet the .05 Level of Significance Summarized From Previous ANOVAS.

TABLE NUMBER		(D) DECADE	(L) LSTNR SEX	(S) SPKR SEX	(T) NOISE SAMPLE	DL	DS	LS	DT	LT	ST	DST	LST
(5)	N.Y. Subw. S/N 2			*						*			
(6)	Ref. Subw. S/N 2	*		*							*		
(7)	Ref. S Lab S/N 2			*				*					
(8)	N.Y. Traf. S/N 2	*		*					*			*	
(9)	Ref. Traf. S/N 2	*		*		*	*					*	
(10)	Ref T Lab S/N 2	*		*	*		*				*		*
(11)	N.Y. Subw. S/N 1	*	*	*						*	*		
(12)	N.Y. Subw. S/N 3	*		*							*		
(13)	N.Y. Traf. S/N 1	*		*	*	*			*	*	*	*	*
(14)	N.Y. Traf. S/N 3	*					*				*	*	

Table 16. Mean Discrimination Scores for CHABA Sentences for Speaker Sex for Each Age Decade and Noise Type.

	Real Noise				Laboratory-Simulated Noise			
	Subway		Traffic		Subway		Traffic	
Age Decade	Male	Female	Male	Female	Male	Female	Male	Female
	*(SE 3.3)	(SE 3.3)	(SE 4.4)	(SE 4.4)	(SE 12.6)	(SE 12.6)	(SE 9.9)	(SE 9.9)
20-29	77.6%	82.0%	78.0%	86.6%	73.2%	84.9%	86.0%	75.9%
30-39	75.6	84.4	72.9	88.0	69.2	89.4	77.0	83.5
40-49	70.4	83.5	65.8	85.3	43.7	89.9	67.6	84.5
50-59	68.7	79.7	56.2	76.7	40.4	86.1	49.6	81.4
60-69	57.4	68.6	56.7	63.6	54.4	79.5	55.3	61.7

* Estimate of Standard Error

and laboratory-simulated noise, and further broken into subway and traffic noise for male and female speakers across the ordinate. Each row represents one of the decades, third through seventh, included in the study. The female speakers were significantly more intelligible than the male speakers in nine of the ten conditions, as indicated in Table 15.

The mean discrimination scores showing the effect of age are shown in Table 17. In this table, the columns are divided into real noise and laboratory-simulated noise, and averaged over noise source (subway and traffic). The columns are then divided into the signal/noise levels. Each row represents one of the decades studied.

Figures 3 through 12 show the data plotted as a function of age; each plot contains all the individual observations for that condition. Each figure shows the intelligibility score on the vertical axis. This axis has been subjected to the inverse sine transformation in order to stabilize the error variance of the intelligibility scores (Brownlee, 1965). The right-hand side of the vertical scale shows the percent intelligibility on the transformed axis, the left-side shows the transformed arcsine values.

Each observation is represented by a digit: the numeral 1 is used for the signal/noise level which was shown in the pilot study to yield approximately 90% intelligibility scores for young, normal-hearing subjects (S/N 1); the numeral 2 for the signal/noise ratio which yielded approximately 70% scores for the same group (S/N 2); and 3 for the signal/noise ratio which roughly resulted in a 50% score (S/N 3). A cross is used to represent several observations for

Table 17. Mean Discrimination Scores for CHABA Sentences for Real and Laboratory-Simulated Noise Averaged Across Noise Type for All Subjects.

	Real Noise						Laboratory Noise	
Age Decade	S/N 1	Range	S/N 2	Range	S/N 3	Range	S/N 2	Range
	*(SE: 2)		(SE: 4.4)		(SE 2.8)		(SE 3.2)	
20-29	94%	86-99	81%	62-94	60%	43-75	80	64-92
30-39	93%	84-98	80%	61-94	52%	35-68	80	64-92
40-49	91%	81-97	77%	57-92	53%	37-69	73	56-87
50-59	86%	75-94	71%	51-88	39%	23-56	66	48-81
60-69	86%	75-94	62%	41-81	36%	21-53	63	45-79

* Estimate of Standard Error

those cases in which two or more observations fell on the same point. The solid curve is a quadratic polynomial fitted to the data by the method of least squares.

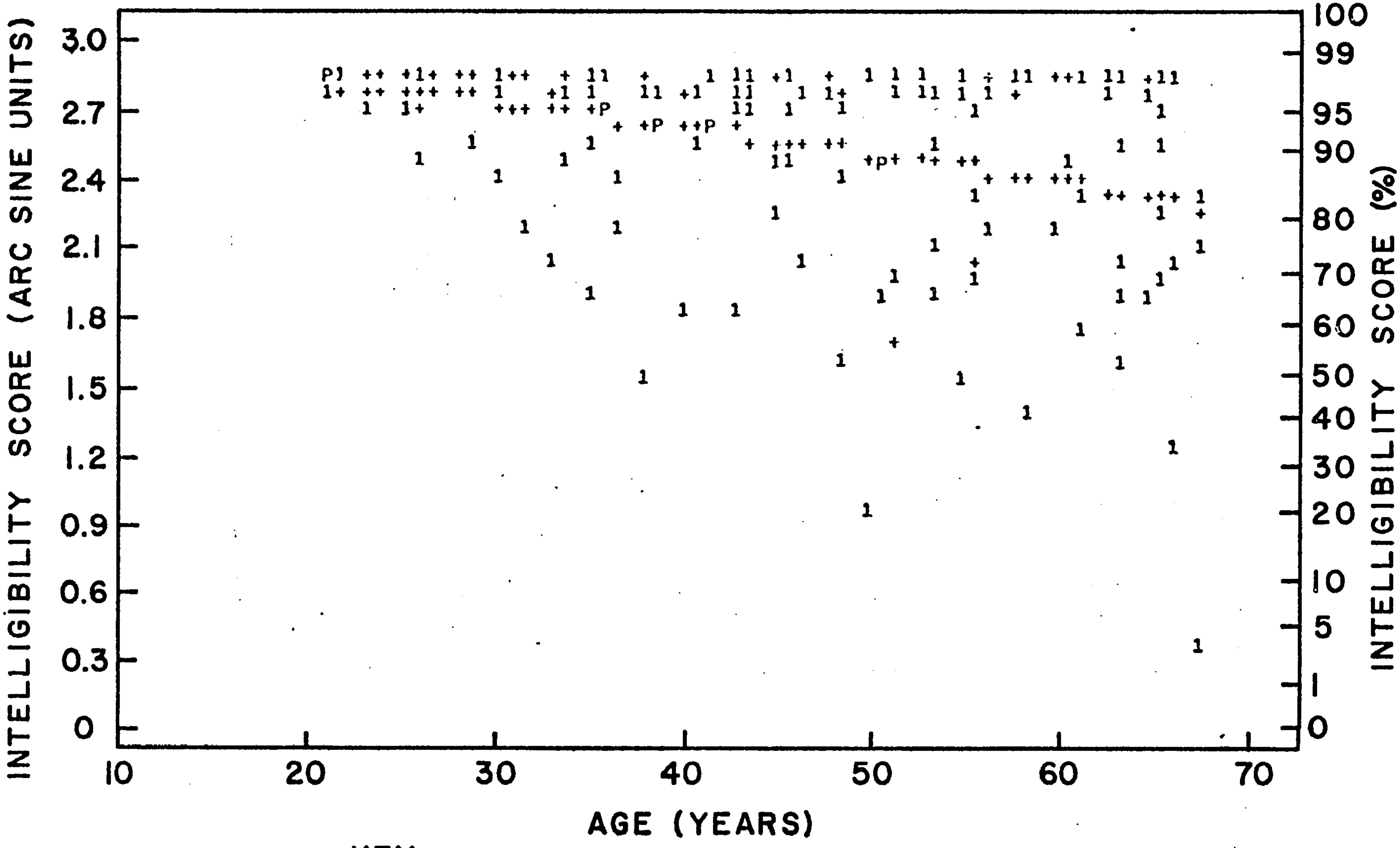
The plots depict the data divided according to noise source: subway, traffic, simulated subway and simulated traffic. The plots indicate a wide variance in individual responses, with a tendency toward a wider scatter for the poorer listening conditions. They further show the tendency toward declining intelligibility scores with increasing age.

Figures 3 through 8 plot the data averaged across speakers and display signal/noise level as a function of age. Figures 3, 4 and 5 represent subway noise; Figures 6, 7 and 8 plot the data for traffic noise. For means of comparison, these curves are plotted together on the same graph in Figure 9.

Figures 10 through 13 plot the reference speakers in the laboratory-simulated noise at S/N 2. The plots are divided into Speaker Sex (Figures 10 and 12 are the male speaker) and Noise Source (Figures 10 and 11 are the subway simulation). Laboratory-simulated noise was always presented at the middle level: S/N 2, and only as a background for the reference speakers. The actual subway and traffic noises were presented at all three levels. At S/N 2, the listener heard both a reference speaker and a typical New York speaker.

The general trend in all curves plotted in the Figures above is to reveal a decreased intelligibility score as the age of the subjects increases. This is most pronounced for the poorest signal/

Fig. 3. Plot of scores for speaker of both sexes with subway noise at S/N 1.



KEY

1. S/N LEVEL 1 + MULTIPLE PLOT
2. S/N LEVEL 2 P PREDICTED
3. S/N LEVEL 3

Fig. 4. Plot of scores for speakers of both sexes with subway noise at S/N 2.

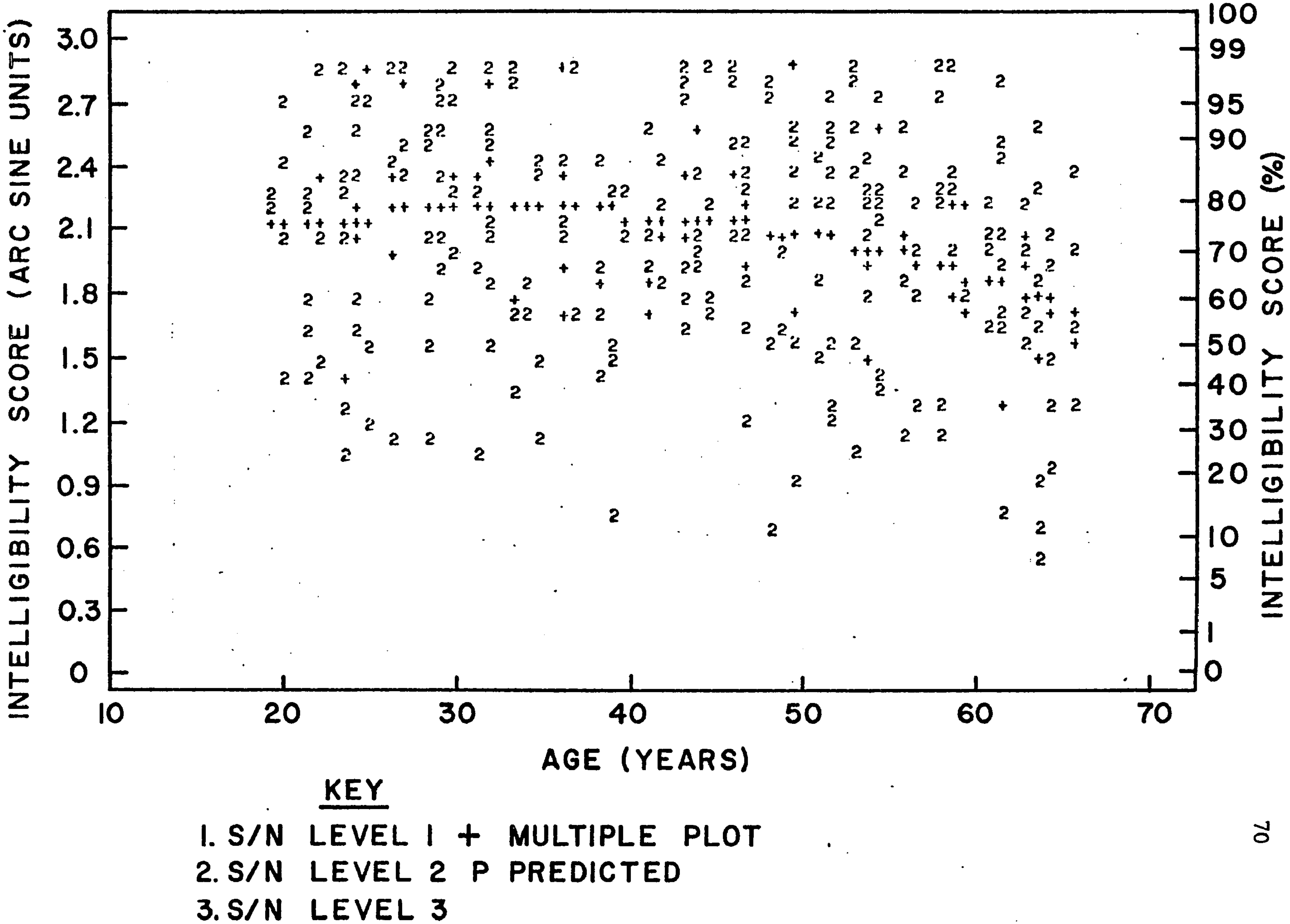
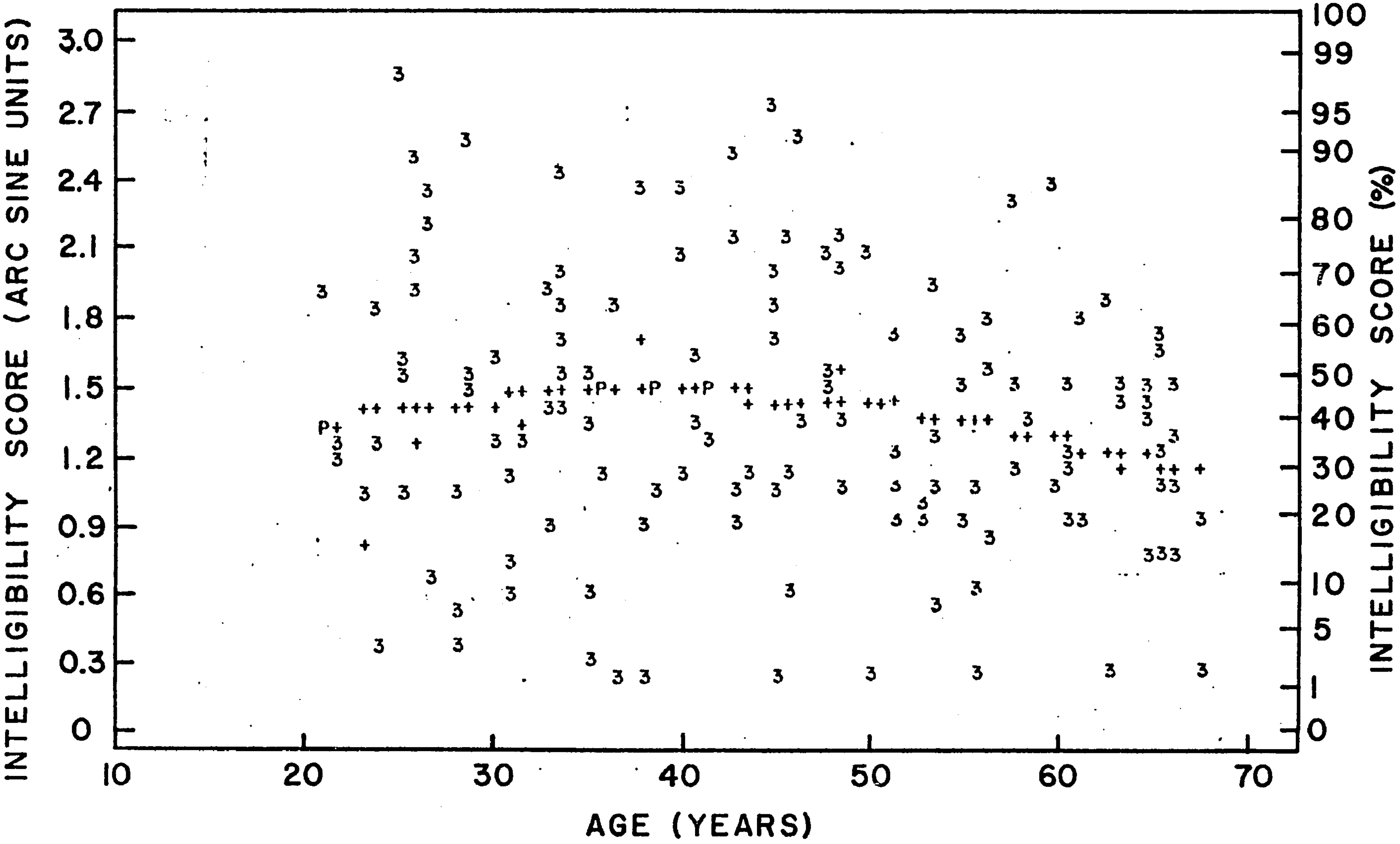

INTELLIGIBILITY SCORE (ARC SINE UNITS)
3.0
2.7
2.4
2.1
1.8
1.5
1.2
0.9
0.6
0.3
0
10
20
30
40
50
60
70
AGE (YEARS)
INTELLIGIBILITY SCORE (%)
100
99
95
90
80
70
60
50
40
30
20
10
5
1
0
KEY
1. S/N LEVEL 1
2. S/N LEVEL 2
3. S/N LEVEL 3
+ MULTIPLE PLOT
P PREDICTED

Fig. 5. Plot of scores for speakers at both sexes with subway noise at S/N 3.



KEY

1. S/N LEVEL 1 + MULTIPLE PLOT
2. S/N LEVEL 2 P PREDICTED
3. S/N LEVEL 3

Fig. 6. Plot of scores for speakers of both sexes with traffic noise at S/N 1.

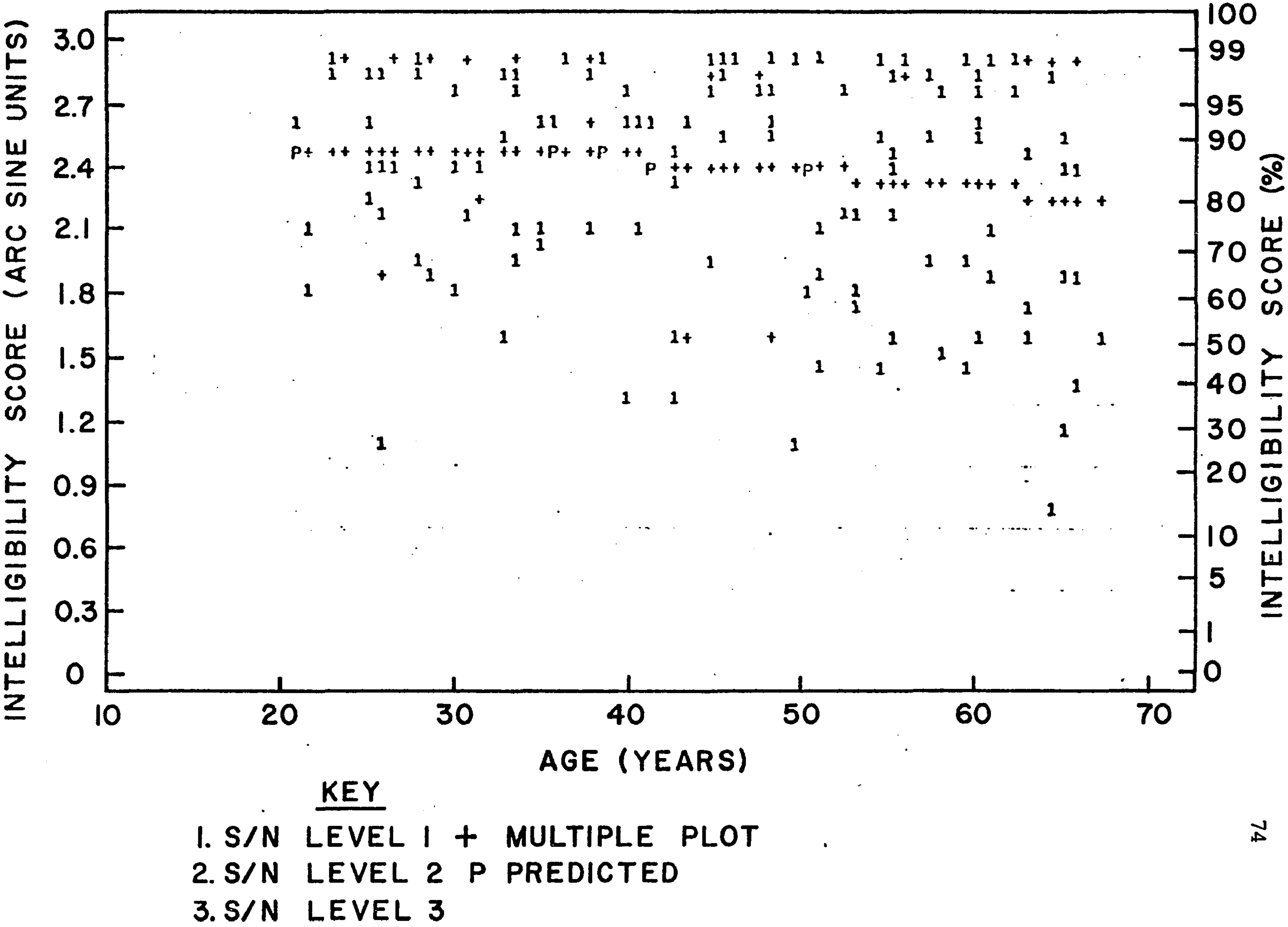

INTELLIGIBILITY SCORE (ARC SINE UNITS)
3.0
2.7
2.4
2.1
1.8
1.5
1.2
0.9
0.6
0.3
0
INTELLIGIBILITY SCORE (%)
100
99
95
90
80
70
60
50
40
30
20
10
5
1
0
10
20
30
40
50
60
70
AGE (YEARS)
KEY
1. S/N LEVEL 1
2. S/N LEVEL 2
3. S/N LEVEL 3
+ MULTIPLE PLOT
P PREDICTED

Fig. 7. Plot of scores for speakers of both sexes with traffic noise at S/N 2.

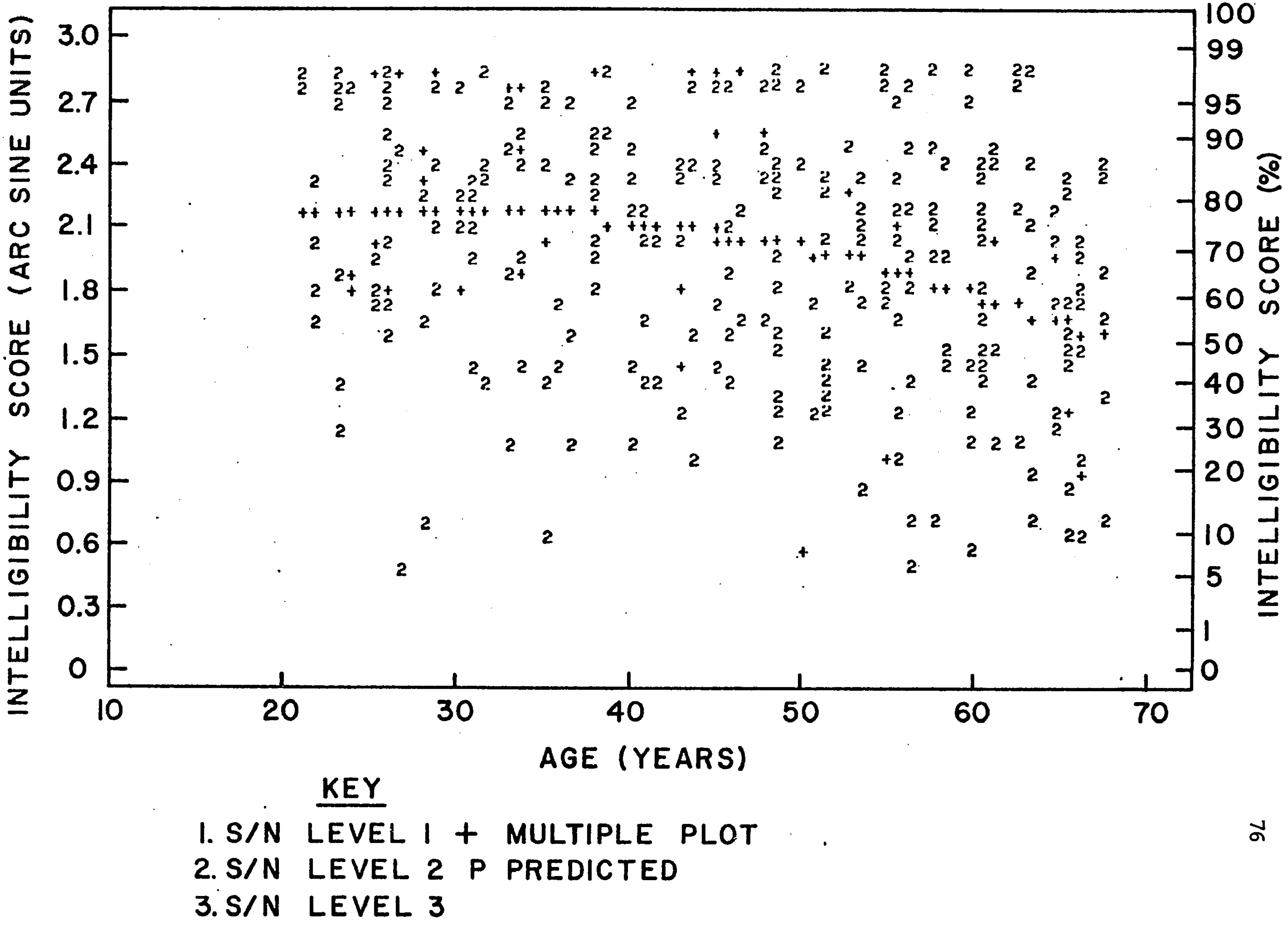
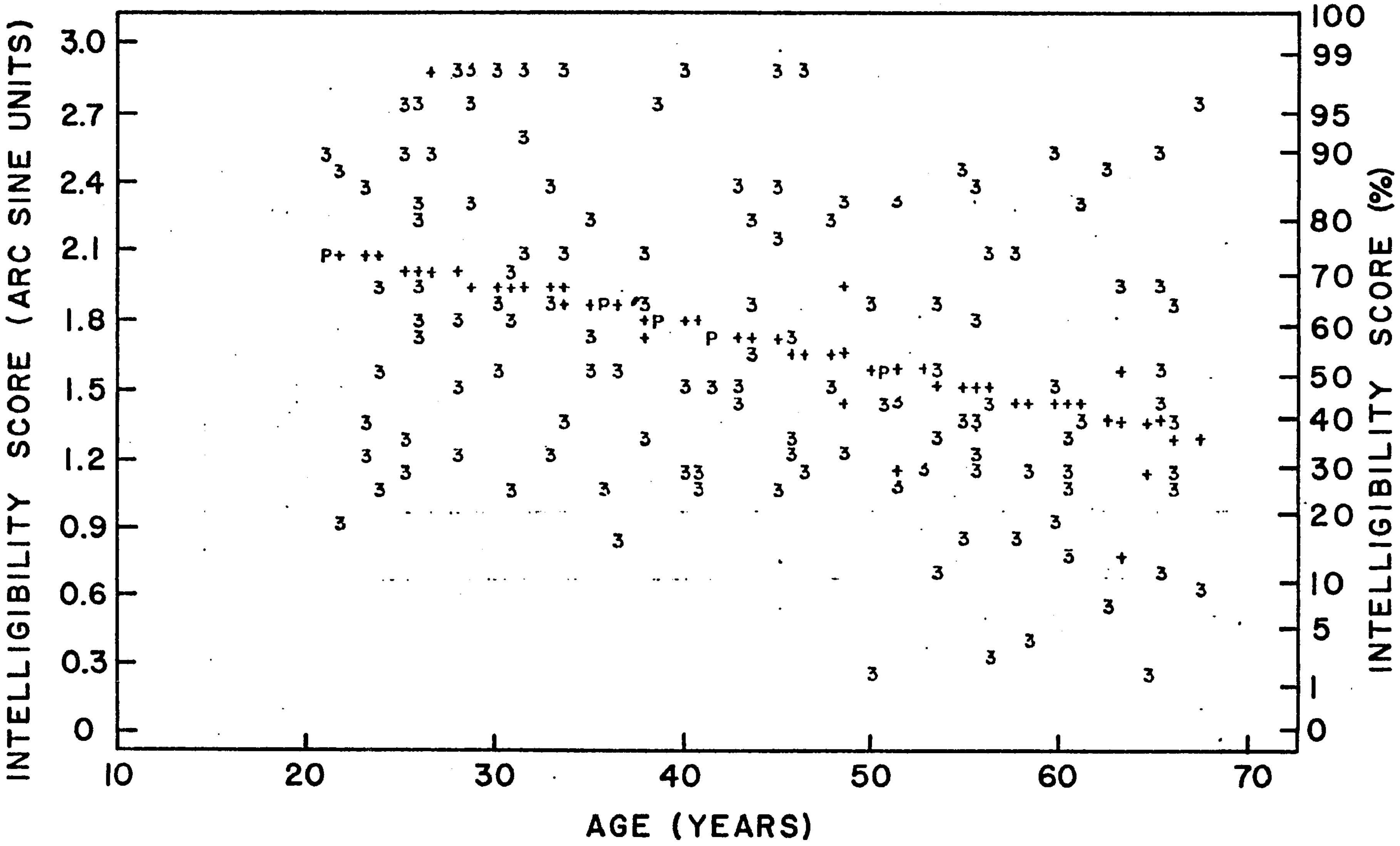

INTELLIGIBILITY SCORE (ARC SINE UNITS)
3.0
2.7
2.4
2.1
1.8
1.5
1.2
0.9
0.6
0.3
0
INTELLIGIBILITY SCORE (%)
100
99
95
90
80
70
60
50
40
30
20
10
5
1
0
10
20
30
40
50
60
70
AGE (YEARS)
KEY
1. S/N LEVEL 1 + MULTIPLE PLOT
2. S/N LEVEL 2 P PREDICTED
3. S/N LEVEL 3

Fig. 8. Plot of scores of speakers of both sexes with traffic noise at S/N 3.



KEY

1. S/N LEVEL 1 + MULTIPLE PLOT
2. S/N LEVEL 2 P PREDICTED
3. S/N LEVEL 3

Fig. 9. Comparison of plots for subway and traffic noise at S/N 1; S/N 2; and S/N 3.

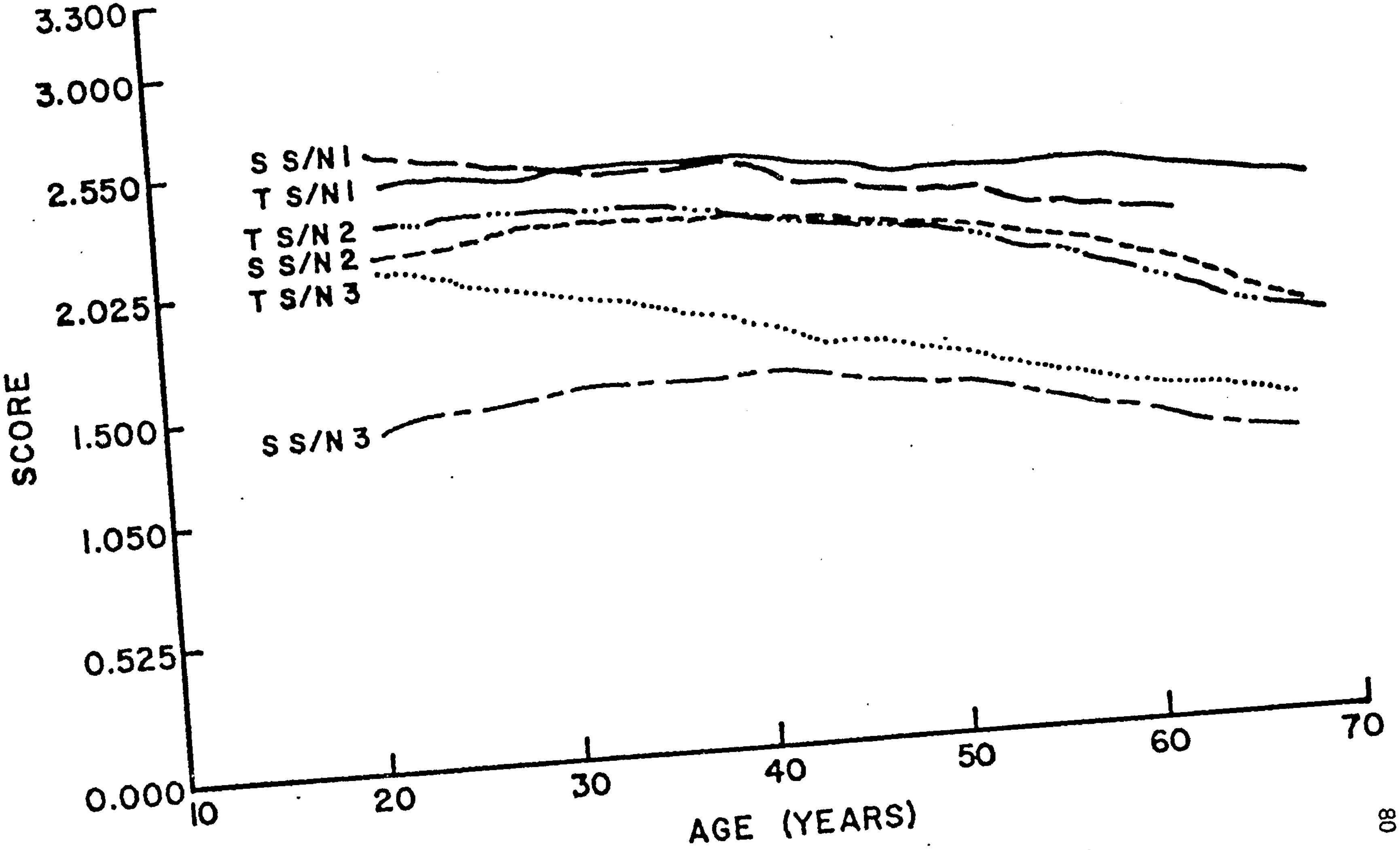

S S/N 1
T S/N 1
T S/N 2
S S/N 2
T S/N 3
S S/N 3
3.300
3.000
2.550
2.025
1.500
1.050
0.525
0.000
SCORE
10
20
30
40
50
60
70
AGE (YEARS)

Fig. 10. Plot of scores for male reference speaker with laboratory-simulated subway noise at S/N 2.

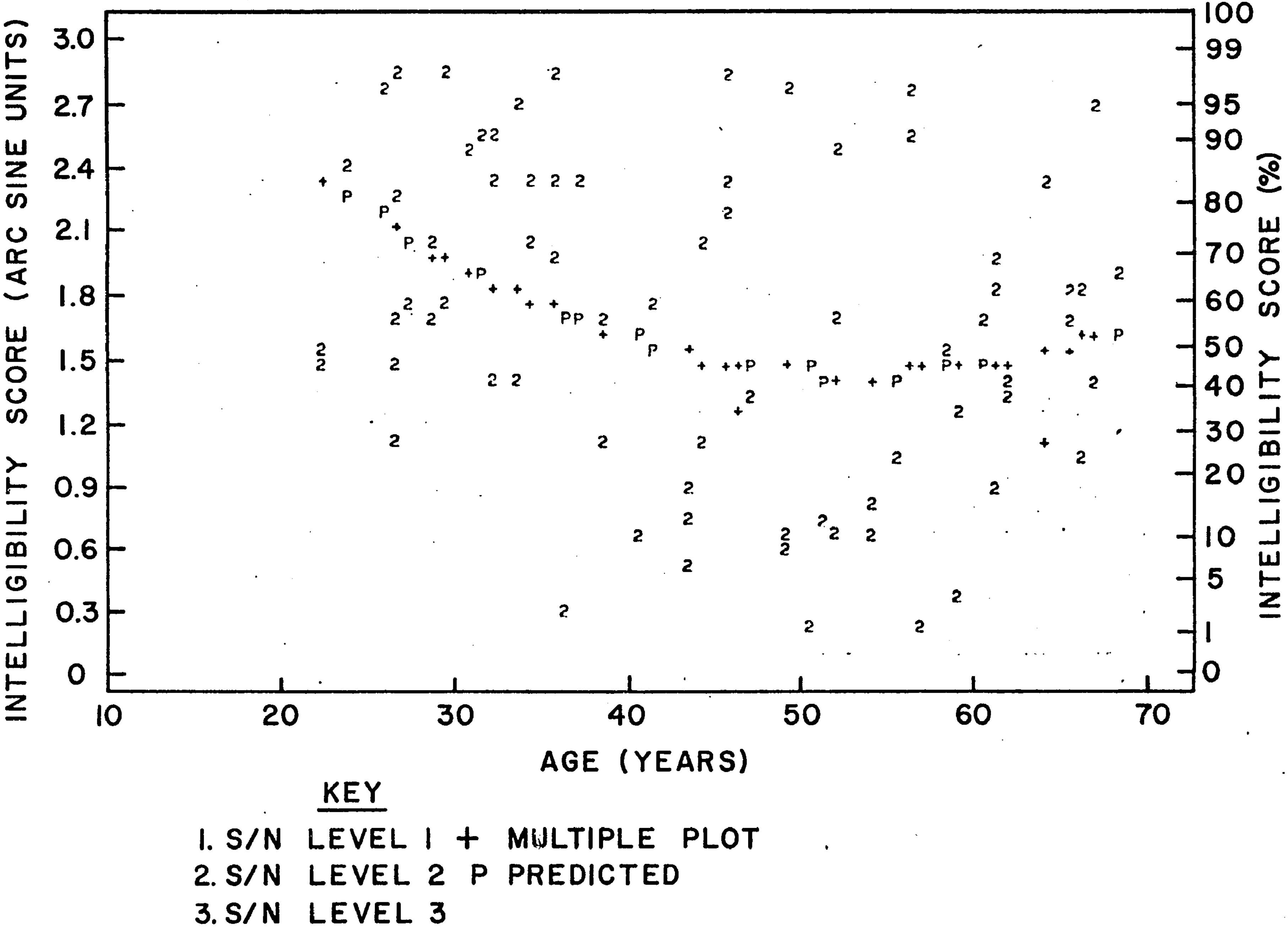

INTELLIGIBILITY SCORE (ARC SINE UNITS)
3.0
2.7
2.4
2.1
1.8
1.5
1.2
0.9
0.6
0.3
0
INTELLIGIBILITY SCORE (%)
100
99
95
90
80
70
60
50
40
30
20
10
5
1
0
10
20
30
40
50
60
70
AGE (YEARS)
KEY
1. S/N LEVEL 1
2. S/N LEVEL 2
3. S/N LEVEL 3
+ MULTIPLE PLOT
P PREDICTED

Fig. 11. Plot of scores for female reference speaker with laboratory-simulated subway noise at S/N 2.

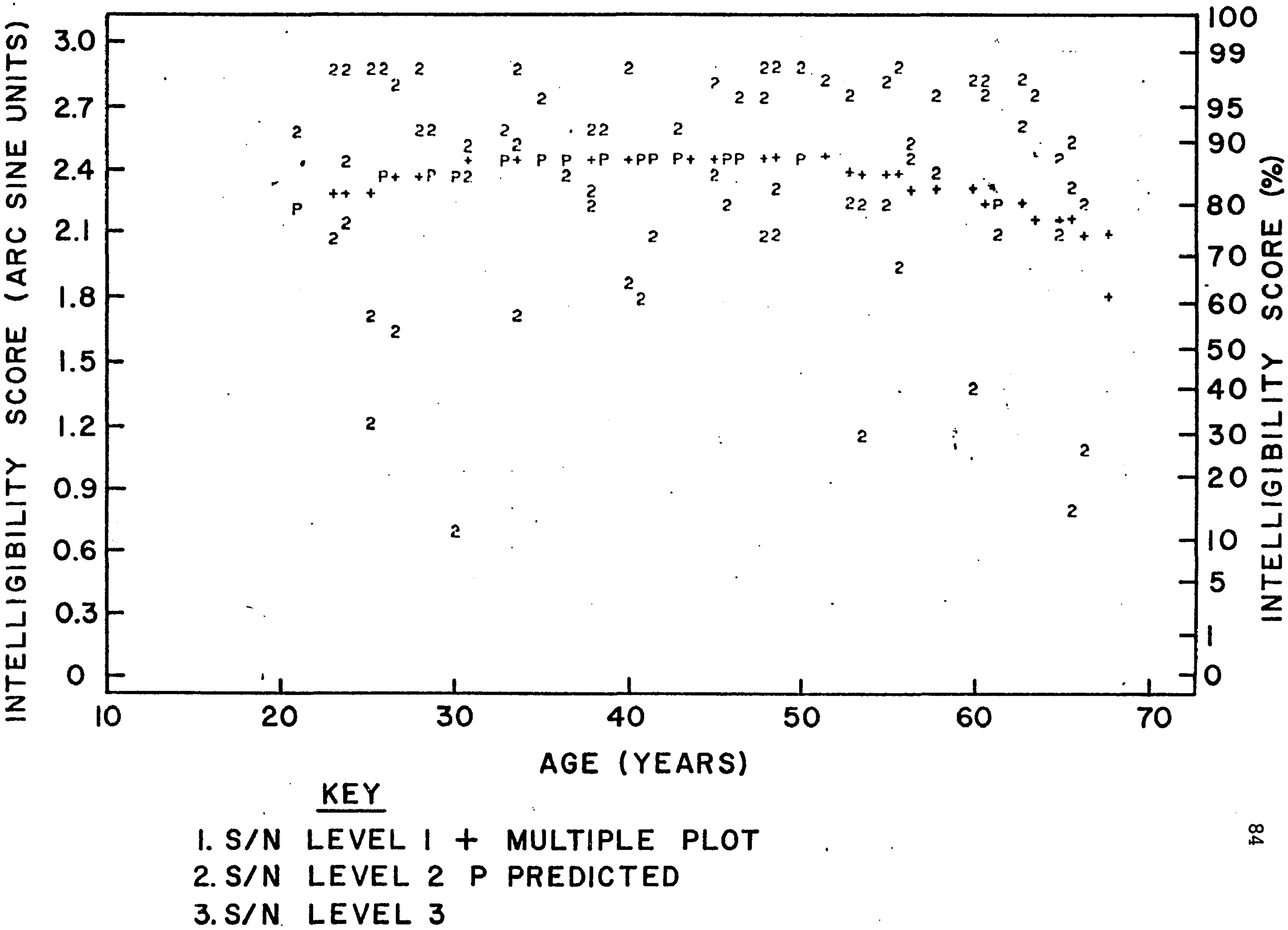
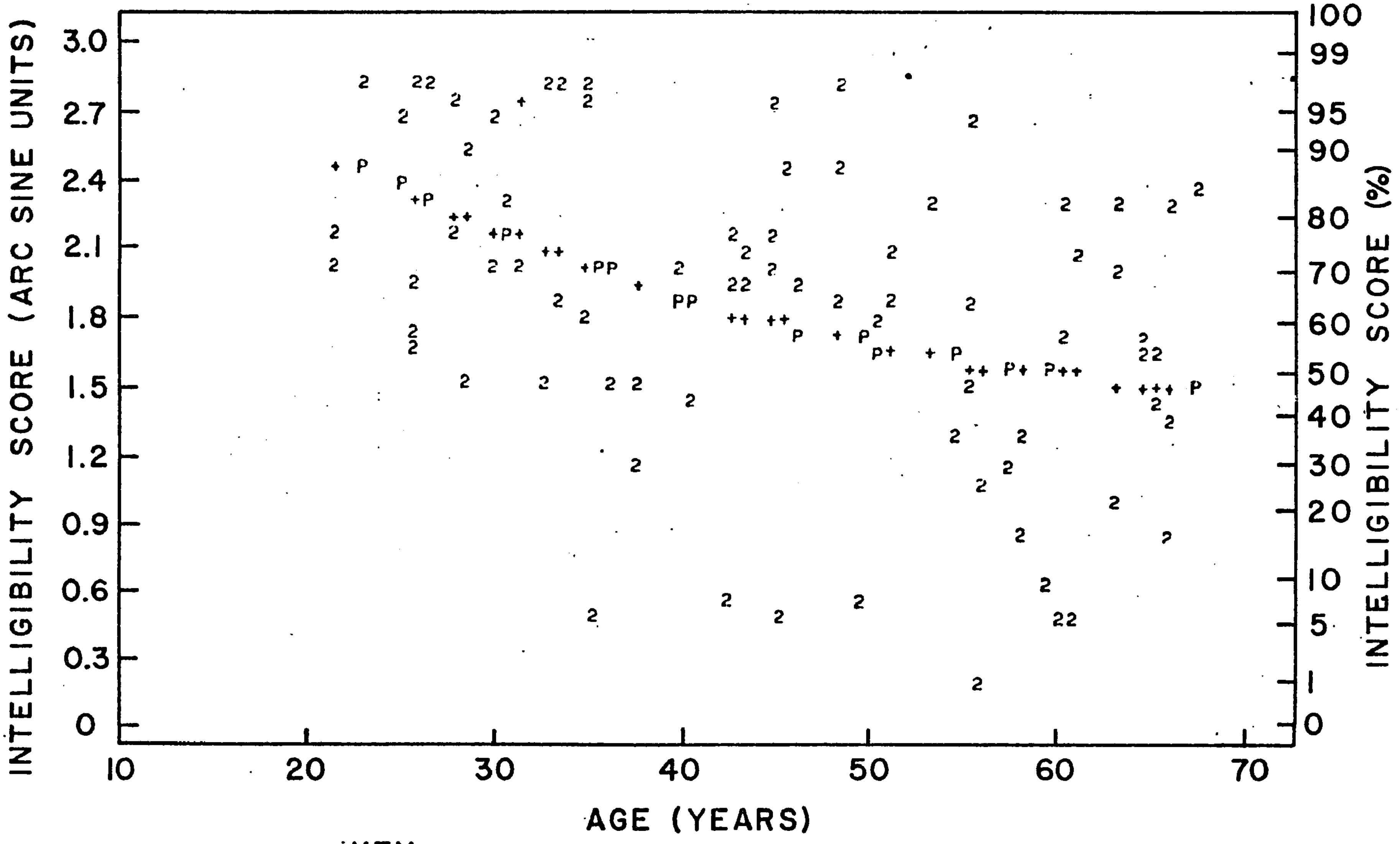

INTELLIGIBILITY SCORE (ARC SINE UNITS)
3.0
2.7
2.4
2.1
1.8
1.5
1.2
0.9
0.6
0.3
0
INTELLIGIBILITY SCORE (%)
100
99
95
90
80
70
60
50
40
30
20
10
5
1
0
10
20
30
40
50
60
70
AGE (YEARS)
KEY
1. S/N LEVEL 1 + MULTIPLE PLOT
2. S/N LEVEL 2 P PREDICTED
3. S/N LEVEL 3

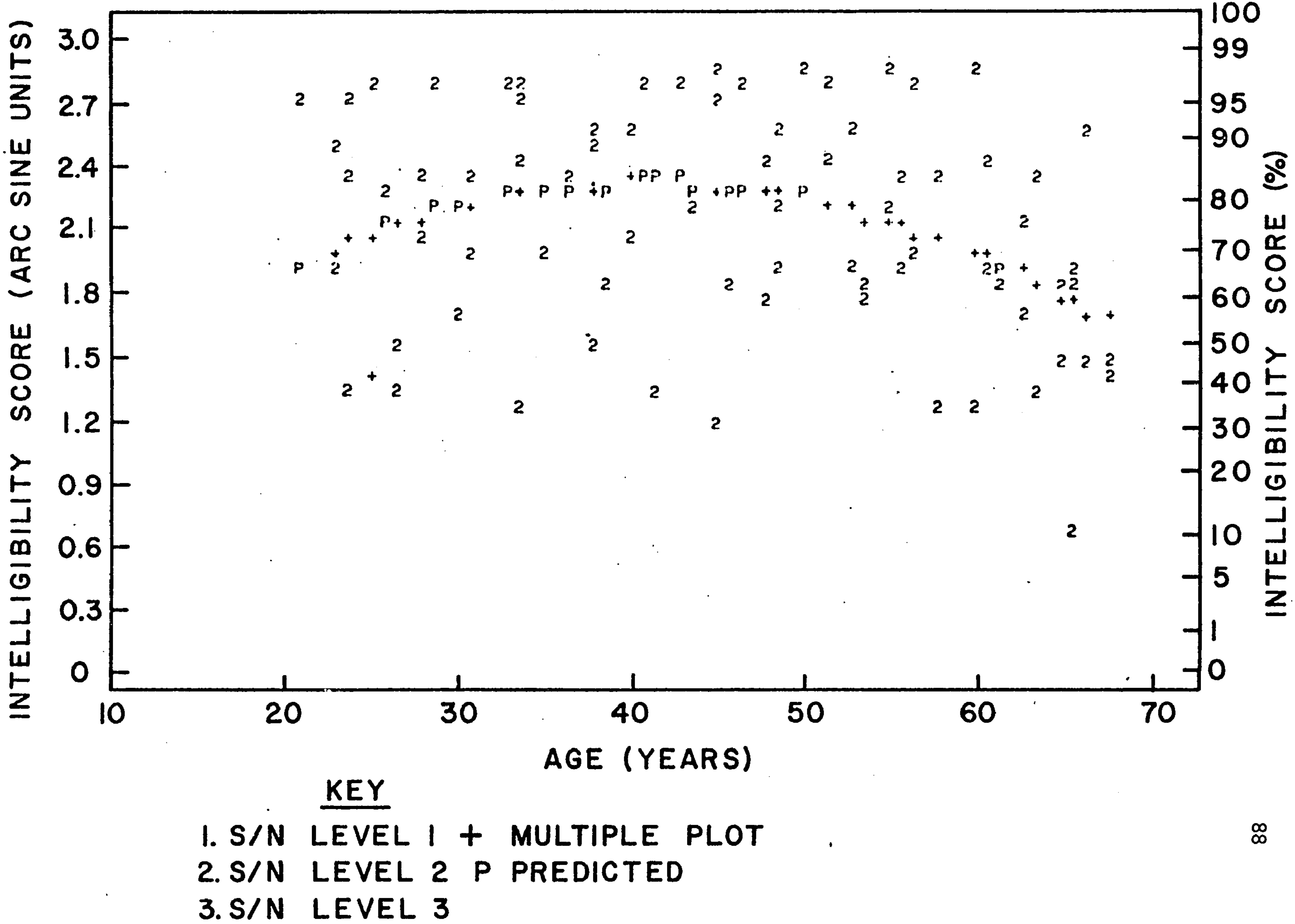
Fig. 12. Plot of scores for male reference speaker with laboratory-simulated traffic noise at S/N 2.



KEY

1. S/N LEVEL 1 + MULTIPLE PLOT
2. S/N LEVEL 2 P PREDICTED
3. S/N LEVEL 3

Fig. 13. Plot of scores for female reference speaker with laboratory-simulated traffic noise at S/N 2.


INTELLIGIBILITY SCORE (ARC SINE UNITS)
3.0
2.7
2.4
2.1
1.8
1.5
1.2
0.9
0.6
0.3
0
INTELLIGIBILITY SCORE (%)
100
99
95
90
80
70
60
50
40
30
20
10
5
1
0
10
20
30
40
50
60
70
AGE (YEARS)
KEY
1. S/N LEVEL 1 + MULTIPLE PLOT
2. S/N LEVEL 2 P PREDICTED
3. S/N LEVEL 3

noise condition (S/N 3).

In a separate analysis, speaker accent was examined to determine if there was a difference in the intelligibility between the speech of the reference talker as compared with that of the talkers with accents commonly heard in the metropolitan New York area. In order to do this, a comparison was made of individual speakers within the design of the study. Each listener heard two speakers at each signal/noise ratio. The reference speakers were used and a speaker typical of the New York City area at S/N 2; at S/N 1 and S/N 3 the two speakers had accents typically heard in the New York area.

Tables 18 and 19 show the results of the analysis of variance which examine Speaker Accent (A), by comparing the reference speaker and a randomly selected New York speaker at S/N 2. A five-factor factorial design was analyzed, the factors were:

Age by Decade (D)
Speaker Sex (S)
Listener Sex (L)
Noise Sample (T)
Speaker Accent (A)

The first analysis (Table 18) is concerned with the factors in the presence of subway noise. The main effects which meet the criteria for statistical significance are: Age (D); Speaker Sex (S); Listener Sex (L); and Noise Sample (T). The interactions of factors which were significant included Age and Listener Sex (DL); Age, Speaker Sex and Noise Sample (DST); Age and Speaker Accent (DA); and

TABLE 18
ANALYSIS OF VARIANCE: SPEAKER ACCENT IN SUBWAY NOISE AT S/N 2.

SOURCE OF VARIATION		DEGREE OF FREEDOM	MEAN SQUARES	F	SIGNIFICANCE LEVEL
D	AGE DECADE	4	1.575	7.81	.001*
L	LISTENER SEX	1	1.299	6.44	.011*
DL	D X L INTERACTION	4	0.759	3.77	.006*
S	SPEAKER SEX	1	4.092	20.30	.001*
DS	D X S INTERACTION	4	0.086	1.44	.783
LS	L X S INTERACTION	1	0.009	0.08	.853
DLS	D X L X S INTERACTION	4	0.253	1.25	.285
T	NOISE SAMPLE	1	0.868	0.15	.067
DT	D X T INTERACTION	4	0.249	1.22	.301
LT	L X T INTERACTION	1	0.636	3.15	.073
DLT	D X L X T INTERACTION	4	0.357	0.75	.132
ST	S X T INTERACTION	1	4.643	23.04	.001*
DST	D X S X T INTERACTION	4	0.267	1.33	.260
LST	L X S X T INTERACTION	1	0.128	0.64	.067
DLST	D X L X S X T INTERACTION	4	0.179	0.56	.808
AA	SPEAKER ACCENT	1	0.299	1.47	.225
DA	D X A INTERACTION	4	0.787	3.58	.006*
LA	L X A INTERACTION	1	0.190	0.00	.874
DLA	D X L X A INTERACTION	4	0.155	0.77	.560
SA	S X A INTERACTION	1	0.043	0.21	.652
DSA	D X S X A INTERACTION	4	0.487	2.40	.050*
LSA	L X S X A INTERACTION	1	0.328	1.63	.280
DLSA	D X L X S X A INTERACTION	4	0.158	0.93	.652
TA	T X A INTERACTION	1	0.126	0.62	.564
DTA	D X T X A INTERACTION	4	0.259	1.43	.223
LTA	L X T X A INTERACTION	1	0.498	2.48	.113
DLTA	D X L X T X A INTERACTION	4	0.219	1.09	.362
STA	S X T X A INTERACTION	1	1.861	5.24	.003*
DSTA	D X S X T X A INTERACTION	4	0.042	0.21	.931
LSTA	L X S X T X A INTERACTION	1	0.010	0.05	.822
DLSTA	D X L X S X T X A INTERACTION	4	0.144	0.71	.586
RESIDUAL		240	0.202		

TABLE 19
ANALYSIS OF VARIANCE: SPEAKER ACCENT IN TRAFFIC NOISE AT S/N 2.

SOURCE OF VARIATION		DEGREE OF FREEDOM	MEAN SQUARES	F	SIGNIFICANCE LEVEL
D	AGE DECADE	4	2.969	11.79	.001*
L	LISTENER SEX	1	0.164	0.73	.602
DL	D X L INTERACTION	4	1.233	4.89	.001*
S	SPEAKER SEX	1	8.793	34.86	.001*
DS	D X S INTERACTION	4	0.315	1.25	.290
LS	L X S INTERACTION	1	0.426	1.65	.292
DLS	D X L X S INTERACTION	4	0.948	0.38	.827
T	NOISE SAMPLE	1	0.055	0.22	.646
DT	D X T INTERACTION	4	1.029	4.08	.004*
LT	L X T INTERACTION	1	0.194	0.77	.614
DLT	D X L X T INTERACTION	4	0.398	1.58	.476
ST	S X T INTERACTION	1	0.028	0.11	.741
DST	D X S X T INTERACTION	4	1.465	5.82	.001*
LST	L X S X T INTERACTION	1	0.021	0.08	.773
DLST	D X L X S X T INTERACTION	4	0.238	0.94	.656
AA	SPEAKER ACCENT	1	5.226	20.75	.001*
DA	D X A INTERACTION	4	0.380	1.51	.099
LA	L X A INTERACTION	1	0.008	0.01	.088
DLA	D X L X A INTERACTION	4	0.105	0.42	.798
SA	S X A INTERACTION	1	0.515	2.04	.150
DSA	D X S X A INTERACTION	4	0.759	3.05	.018*
LSA	L X S X A INTERACTION	1	0.193	0.77	.614
DLSA	D X L X S X A INTERACTION	4	0.061	0.24	.813
TA	T X A INTERACTION	1	0.322	1.28	.258
DTA	D X T X A INTERACTION	4	0.151	0.80	.666
LTA	L X T X A INTERACTION	1	0.008	0.03	.866
DLTA	D X L X T X A INTERACTION	4	0.182	0.72	.581
STA	S X T X A INTERACTION	1	0.732	2.91	.086
DSTA	D X S X T X A INTERACTION	4	0.314	1.25	.292
LSTA	L X S X T X A INTERACTION	1	0.002	0.01	.934
DLSTA	D X L X S X T X A INTERACTION	4	0.056	0.22	.925
RESIDUAL		240	0.252		

Speaker Sex, Noise Sample and Speaker Accent (STA).

The second analysis (Table 19) is concerned with the effect of speaker accent when the masking sound was traffic noise. Statistically significant effects were: Age (D); Speaker Sex (S); and Speaker Accent (A) and the interactions of the following factors: Age and Listener Sex (DL); Age, and Noise Sample (DT); Age, Speaker Sex, and Noise Sample (DST), and Age, Speaker Sex, and Speaker Accent (DSA).

Table 20 summarizes Tables 18 and 19; the horizontal axis has the factors which proved to be statistically significant, and the vertical axis the two noise sources that were subjected to the analysis. An asterisk indicates the statistically significant factors.

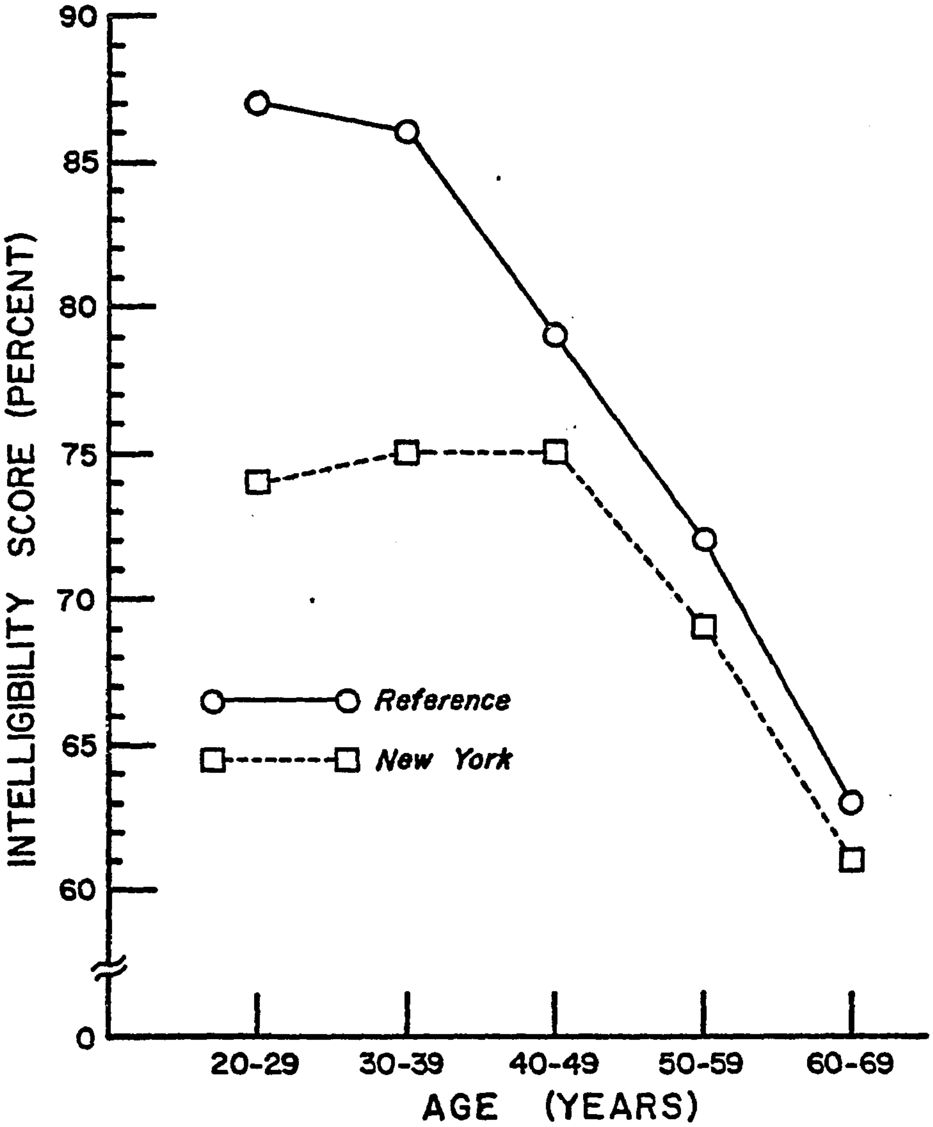
The reference speakers were found to be more intelligible in every decade studied, for both subway and traffic masking noises. Figure 14 illustrates the relative intelligbility curves for speaker accent averaged across Noise Source, Listener Sex, Speaker Sex, and Noise Sample. The scores for the subjects below 40 years show the greatest loss of intelligibility for the typical New York speakers. For the three older groups (40-49 years; 50-59 years; and 60-69 years) the mean intelligibility scores for the two speaker accents were within four percentage points of each other.

The combined effects of Speaker Accent and Speaker Sex did not show any marked interactions. That is, the female reference speaker was more intelligible than the male reference speaker and, of the speakers with accents typical of the New York area, the females were

Table 20. Analysis of Variance for Speaker Accent: Factors Which Meet the .05 Level of Significance. (Summarized from the ANOVAS for Accent)

TABLE NUMBER		AGE DECADE (D)	SPEAKER SEX (S)	LISTENER SEX (L)	NOISE SAMPLE (T)	SPEAKER ACCENT (A)	DL	DA	DT	DST	DSA
(18)	Subway Noise S/N 2	*	*	*	*		*	*		*	
(19)	Traffic Noise S/N 2	*	*			*	*		*	*	*

Fig. 14 Curves of intelligibility scores as a factor of age and speaker accent. (Averaged across noise source, listener sex, speaker sex, and noise sample).


INTELLIGIBILITY SCORE (PERCENT)
90
85
80
75
70
65
60
0
20-29
30-39
40-49
50-59
60-69
AGE (YEARS)
Reference
New York

more intelligible than the males. For both the male and female speakers the reference accents were considerably more intelligible than the "New York" accents. This is displayed in Table 21.

The CHABA sentences range in length from two to twelve words. There was some concern as to whether the longer sentences would be more difficult for the older subjects than for the younger group. A decrement in short-term memory has been associates with aging effects. To test for this, Spearman Rank Correlations were computed to determine whether there was a correlation between sentence length and test score. This was done for each age decade. The data are summarized in Table 22. A consistent negative correlation between sentence length and intelligibility score was obtained for all age groups. That is, the shorter sentences were more intelligible than the longer sentences. The magnitude of this correlation appears to change slightly with age; on the average, it increases from 20 to 49 years of age, after which it decreases again from 50 to 69 years of age. The stability of this correlation across age decades, as indicated by the standard error of the average correlation coefficient for each decade, shows a small increase with increasing age.

When speech stimuli were presented with varying speech-to-noise ratios there was a decided correlation between increasing age and deteriorating listening conditions, i.e. with decreasing S/N ratios. These are presented graphically in Figures 15 through 17. A comparison of the quiet condition and the best signal/noise condition, which had been set to yield approximately 90% scores for the young,

Table 21. Effect of Speaker Sex on Speech Intelligibility Averaged Over Age and Listener Sex for Speaker Accent, Level of Presentation and Noise Type.

Speaker Accent	S/N Level	Noise Type	Speaker Sex Male	 Female
			PERCENTAGES	
New York	1	Subway	88.2	97.5
New York	1	Traffic	75.1	95.2
New York	2	Subway	68.2	79.1
New York	2	Traffic	62.0	73.7
Reference	2	Subway	72.0	80.6
Reference	2	Traffic	70.3	86.9
Reference	2	Subway Lab	56.4	86.2
Reference	2	Traffic Lab	67.9	77.9
New York	3	Subway	35.8	44.8
New York	3	Traffic	54.3	57.4

Table 22. Spearman Rank Correlation of CHABA Sentence Scores vs Sentence Length by Age Decade.

Noise Type	Speaker Accent	Signal/Noise Level	20-29	30-39	40-49	50-59	60-69
Subway	New York	1	-.149	-.248	-.200	-.243	-.204
Subway	New York	2	-.098	-.146	-.104	-.026	+.078
Subway	Reference	2	-.169	-.232	-.360	-.235	-.291
Subway	New York	3	-.018	-.035	-.034	-.063	-.024
Traffic	New York	1	-.146	-.102	-.170	-.114	-.174
Traffic	New York	2	-.207	-.119	-.111	-.146	-.153
Traffic	Reference	2	-.108	-.177	-.219	-.245	-.141
Traffic	New York	3	-.065	-.130	-.199	-.079	+.019
		Average:	-.120	-.149	-.175	-.144	-.111
		Standard Error	.061	.045	.075	.062	.061

normal-hearing pilot group, is shown in Figure 15. It is evident that the noise had a deleterious effect on listeners over the age of 50, even when the speech-to-noise condition was favorable. As seen in Figure 16, the slope of the curves representing intelligibility scores versus age increased markedly as the listening conditions worsen. Figure 17 reveals a similar pattern for the laboratory-simulated noise at S/N 2.

SUMMARY

The data reveal intelligibility scores which decrease as a function of age in the presence of all samples of subway and traffic noise used for this study. In addition to age, statistically significant factors include Speaker Sex, Speaker Accent and the interaction of the factors of Speaker Sex and Noise Sample. Sentence length had a negative effect on intelligibility scores, with only a slightly increased effect with increasing age.

Fig. 15 Curves of intelligibility scores as a function of age for speech in quiet and at S/N 1.

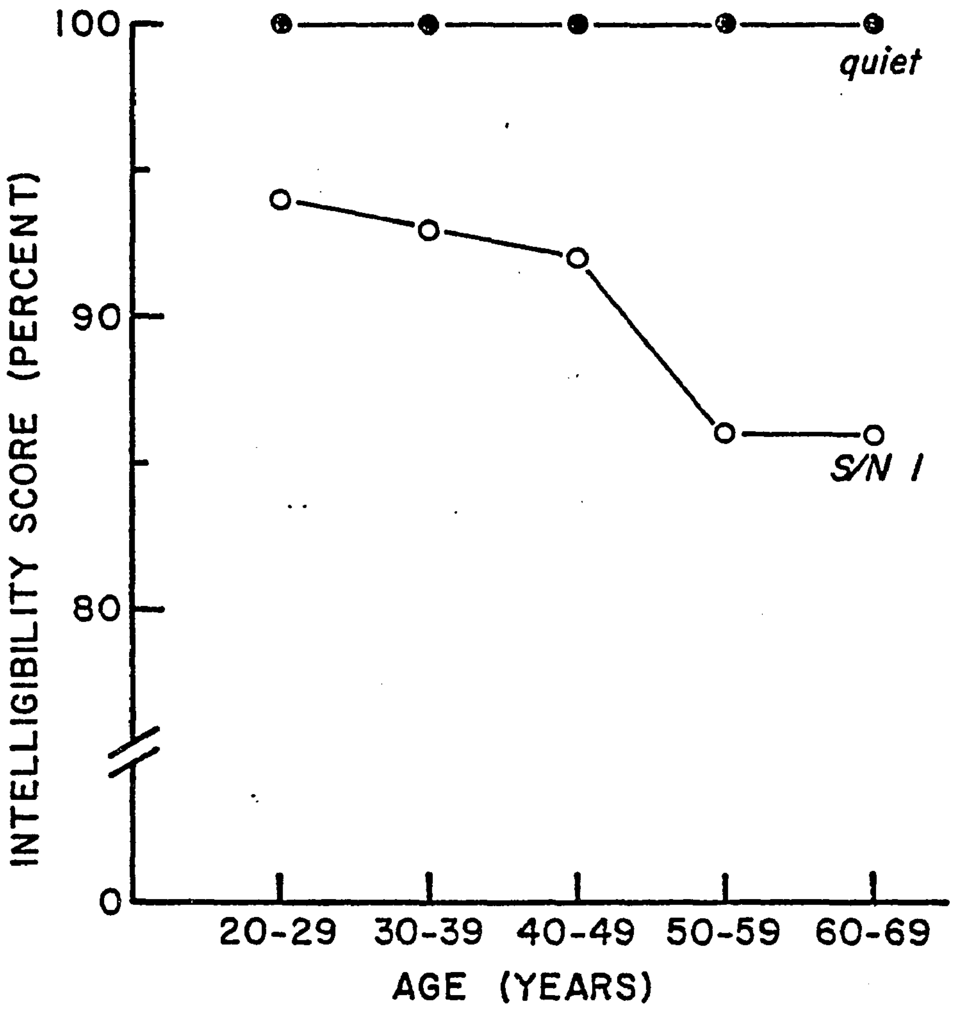

INTELLIGIBILITY SCORE (PERCENT)
100
90
80
0
20-29
30-39
40-49
50-59
60-69
AGE (YEARS)
quiet
S/N I

Fig. 16 Curves of intelligibility scores as a function of age for all three presented signal/noise levels (S/N 1; S/N 2; S/N 3).

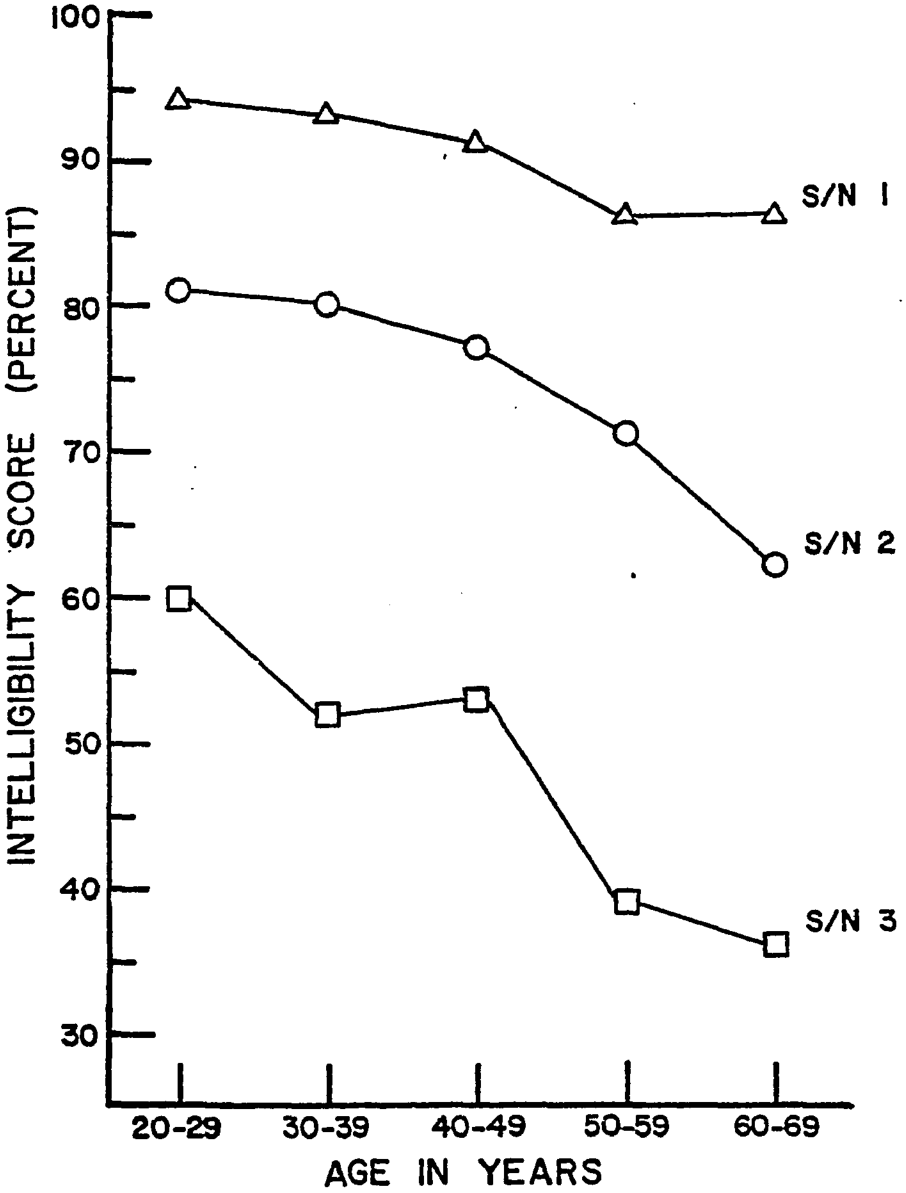
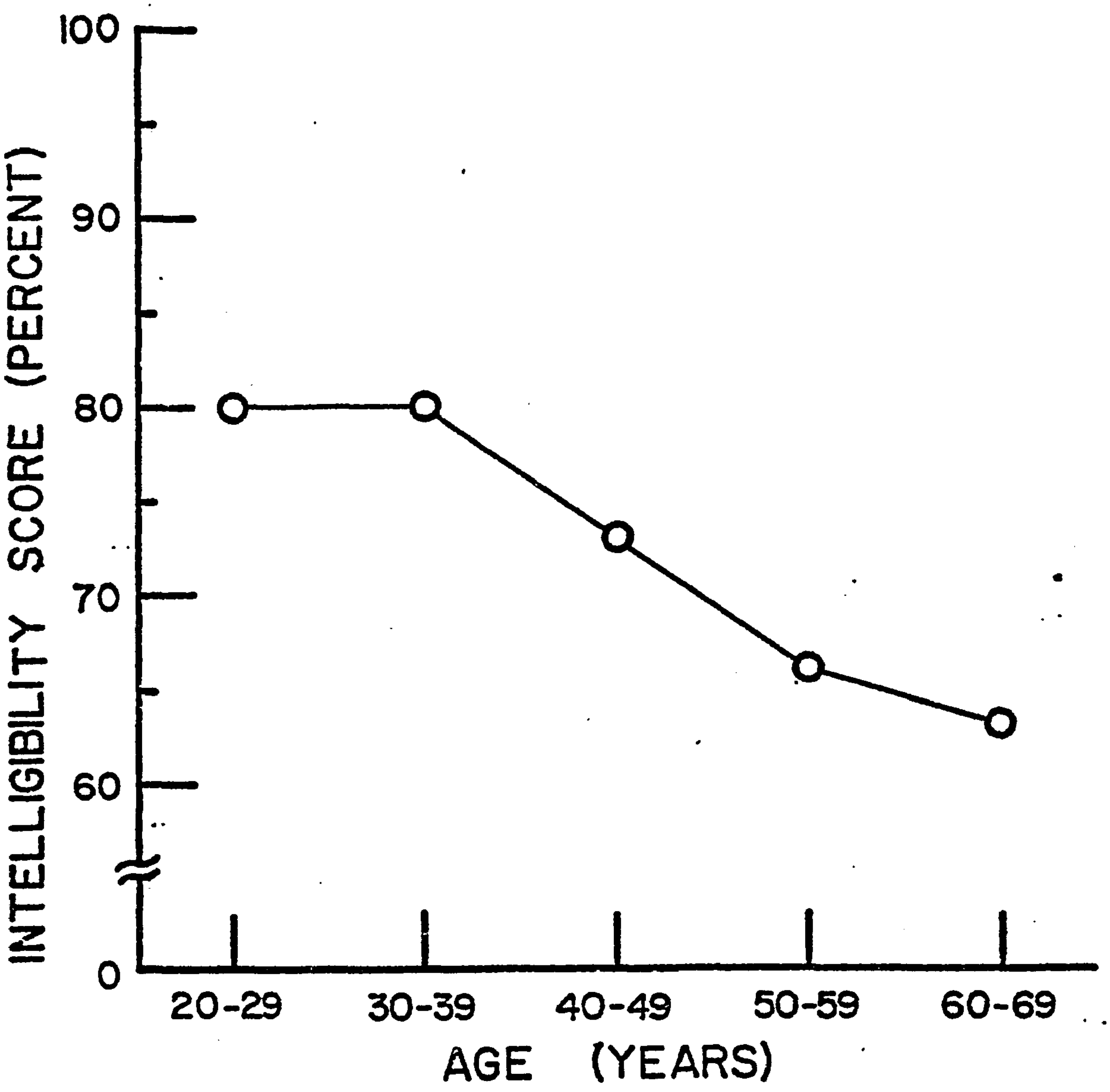

100
90
80
70
60
50
40
30
INTELLIGIBILITY SCORE (PERCENT)
S/N 1
S/N 2
S/N 3
20-29
30-39
40-49
50-59
60-69
AGE IN YEARS

Fig. 17 Curves of intelligibility scores as a function of age for laboratory-simulated noise presented at S/N 2.


INTELLIGIBILITY SCORE (PERCENT)
100
90
80
70
60
0
20-29
30-39
40-49
50-59
60-69
AGE (YEARS)

CHAPTER V

DISCUSSION AND CONCLUSIONS

The primary concern of the present study was whether or not increasing age was a factor in the perception of speech in the presence of selected samples of typical urban noise. The results show that the effects of these noises on speech intelligibility increase significantly with advancing age, and for all noise conditions.

The deterioration in speech perception with age was evident in three levels of signal/noise ratio for two samples of subway noise and two samples of traffic noise, as well as for laboratory-generated replications of each noise sample. It was evident for each of four male and four female speakers. These findings are in agreement with most published studies on the perception of speech which was presented in noise or degraded in some other manner.

The aging effect demonstrated by these data is greater for poorer listening conditions. In comparing the decrease in intelligibility scores from the youngest to the oldest age groups, Figure 16 in Chapter 4 reveals a change of 8% at the best speech-to-noise condition (which had been previously set to yield approximately 90% for the young, normal-hearing pilot group) and a shift of 24% at the poorest speech-to-noise condition. It could be argued that the larger difference relative to the age effect for the poorer listening condition could have resulted from the increased variability of test scores that are closer to the 50% level of intelligibility. To guard against this possibility the data were subjected to an arcsine transformation so that the variability of the measured intelligibility scores would be virtually independent of the level of intelligibility. In arcsine units, the same range across the factor of increasing age is .313 for the best listening condition to .527 for the poorest. Thus, whether the analysis is performed in arcsine units or percent intelligibility scores, the joint effect of increasing age and decreasing signal/noise ratio is essentially the same; the decrease in intelligibility scores with increasing age is larger the poorer the speech-to-noise ratios.

These data are consistent with other published research. Jokinen (1973) observed a correlation between increasing age and signal/noise conditions which decreased from +22 to +2; he found that his results with a presbycusic population closely paralleled those of Morales-Garcia and Poole (1972) obtained in patients with a variety of intercranial lesions. In 1976 Schindler and Vigone presented speech and traffic noise at several signal/noise levels and found a more exaggerated decline in discrimination scores in worsening speech-to-noise conditions for their older group (40-50 years) as compared to their young listeners (19-21 years).

In contrast, Smith and Prather (1971) conducted a similar study presenting consonant/vowel nonsense syllables at several signal/noise ratios. Although they found that in general the younger listeners performed better than the older subjects in a number of speech-to-noise conditions, they did not find a significant difference in the performances of the two groups as the signal/noise ratio became smaller.

The study of Smith and Prather differed from both the Jokinen and the present study in the type of speech materials utilized and also in the fact that younger population was used (maximum age was 50 years). It has been suggested previously that the processing required for CV discrimination might be less affected by the loss of central auditory function. Smith and Prather imply this in the discussion of their results when they suggest that "other types of speech stimuli might well produce different results" (p. 637).

The age related decrement in speech perception noted under all noise conditions was not evident in the quiet condition. One of the criteria for including a subject in the study was that they scored at least 96% on the presentation of the sentences in quiet. However, no subject who met the criteria for hearing sensitivity for pure tones scored less than 96% on the test of speech reception without competing noise. In fact, most of the subjects scored 100%.

The criteria for hearing sensitivity of 30 dB for the frequencies 500 through 3000 Hz and 40 dB at 4000 Hz, which were used for the present study were based on the published data of Corso (1963), Glorig and Nixon (1963) and Maurer and Rupp (1979). It was, however, most difficult to find subjects who met these criteria for hearing thresholds. For each of the sixteen male subjects included in the study above the age of sixty years, approximately 22 did not meet the threshold criterion. It was not quite as difficult to find female subjects over sixty years who had hearing levels better than the criteria, although eight women failed the criteria for every one who met them. It is important to note that audiometric testing was performed after the questionnaire had been completed. Therefore, most individuals with active or severe ear pathology were eliminated from consideration prior to audiometric testing.

The selection procedure employed a threshold criterion which was especially strict for the oldest decade group. It was necessary to find a population essentially without hearing loss in order to isolate the effect of aging on speech perception. In order to avoid measuring intelligibility that is due to peripheral hearing impairment, even though that hearing impairment might be caused by aging, it is quite likely that in the seventh decade of life a special subgroup of persons has been formed. Subjects selected at random would have demonstrated a greater hearing impairment, more for the males than the females of this age group.

As a consequence, the measured loss of speech perception cannot be ascribed to secondary causes (e.g. result of hearing loss which occurs with aging) but rather to a general aging effect in the absence of any other age dependent variable known to cause a reduction in the ability to understand speech. At the same time the findings of the present study represents a most conservative estimate of the effect of chronological aging on the ability to perceive speech signals in the presence of competing noise. In other words, the results of the present study represent an upper bound of the ability to understand speech for the older subjects, e.g. for those between the ages of 60 and 69 years.

Most previous studies have shown a decrement in speech discrimination ability as a function of age with undistorted signals and in the absence of competing messages. The most severe decrements were reported in investigations involving clinical populations (Gaeth, 1948; Pestalozza and Shore, 1955; Harbert et al, 1966), while those studies sampling non-clinical populations (Goetzinger et al, 1961; Melrose et al, 1963; Klotz and Kilbane, 1966; Feldman and Reger, 1967) revealed more gradual changes in speech perception scores with age. Punch and McConnell (1969) performed articulation functions on two groups of older subjects and found that those selected from a non-clinical population yielded substantially better PB max scores. There may well be a confounding effect which is to be expected, when listeners are selected from audiological clinical files simply on account of the reason why those subjects were included in a clinic file, even though there might be no specified or diagnosed disorder.

The investigation by Bergman (1971 b) employed criteria very similar to those of the present study. The 282 adults from age 20 through 89 in Bergman's study who passed the pure tone screening test showed very little decline in their ability to discriminate undistorted test sentences. Subjects above the age of 80 years showed a small decline.

In brief, speech discrimination ability has been shown to decrease with age in most of the published research. In several studies this decline could be attributed to presbycusis or other pathological factors. In this investigation and that of Bergman (1971 b), where strict criteria were established for pure tone hearing levels, no loss was seen for undistorted speech signals delivered in quiet through the age of 79 years.

One of the concerns of the investigation was the effect on speech communication by noise levels typically encountered in the subway system of New York. Danto (1973) found that noise level in the interior of a typical subway car is 94 dBA for more than ten percent of the time. Furthermore, noise on the platform of some stations of the New York City subway system 100 dBA have been measured when several trains were entering or leaving the station at the same time. The present study did not use levels in excess of 91 dBA because of the potential hazards of high levels of noise exposure. In addition, speech-to-noise ratios which would yield average discrimination scores below 50% were not utilized as there was concern for maintaining subject motivation and cooperation throughout the entire listening task.

For the poorest speech-to-noise ratio in this study (S/N 3) the typical values were: Speech level 82 dB SPL, noise level 88 dBA. This is am ambient noise level which is very commonly found throughout the subway system, or at many of the busy intersections of New York City. For a typical subway train, the distrubition of noise levels in the interior of the car ranges from 75 dBA for approximately 90 percent of the time to 95 dBA for more than ten percent of the time. These figures were measured at the center of a "B" train (coach type R32) running between the West Fourth Street and Pacific stations of the IND Rapid Transit line (Danto, 1973). The median noise level was 86 dBA, which is approximately the level presented during most of the experimental conditions used in this study.

The most important factor as regards speech interference is the speech-to-noise ratio, not the absolute level of either the signal or the noise (Miller, 1947). In noisy situations the speaker usually raises his or her voice so as to increase the effective speech-to-noise ratio. A 3 to 7 dB increase in voice level for every 10 dB of noise above a 50 dBA base level has been found to be typical (Kryter, 1970). The speech levels used in this investigation were at an average level of 82 dB SPL, plus or minus 5 dB for individual speakers. This is consistent with the expected level at a distance of one meter from the lips of an average male speaker in an ambient noise level of 85 dBA*. Typically, the average female speaker has a 3 dB less power at the same distance (Kryter, 1970). For the present study, however, the average power of the eight speakers was equalized without distinction as to the sex of the speaker. The speech-to-noise ratio which had been found yield approximately 70% in the pilot study (S/N 2) corresponds to these relative levels. This was the signal/noise ratio employed to contrast speaker accent

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*Allowing a 5 dB increase in speech level for every 10 dB in noise level above 50 dBA yields an increase of (85-50)/10 X 5 dB = 17.5 dB. The expected level at a distance of 1 meter for a typical male speaker in quiet is 65 dB SPL (Kryter, 1970) Thus, for the expected level for this speaker in noise at a level of 85 dBA is 65 + 17.5 = 82.5 dB SPL.

and real vs. laboratory-simulated noise.

Lane and Tranel (1971) have referred to the increased vocal power, as seen in the Lombard sign, as the accommodation to the demands of intelligible communication. It may be assumed, therefore, that the motivation to expend additional vocal effort will be strongly influenced by the need to communicate; with messages eliciting the best efforts in noisy backgrounds in large cities.

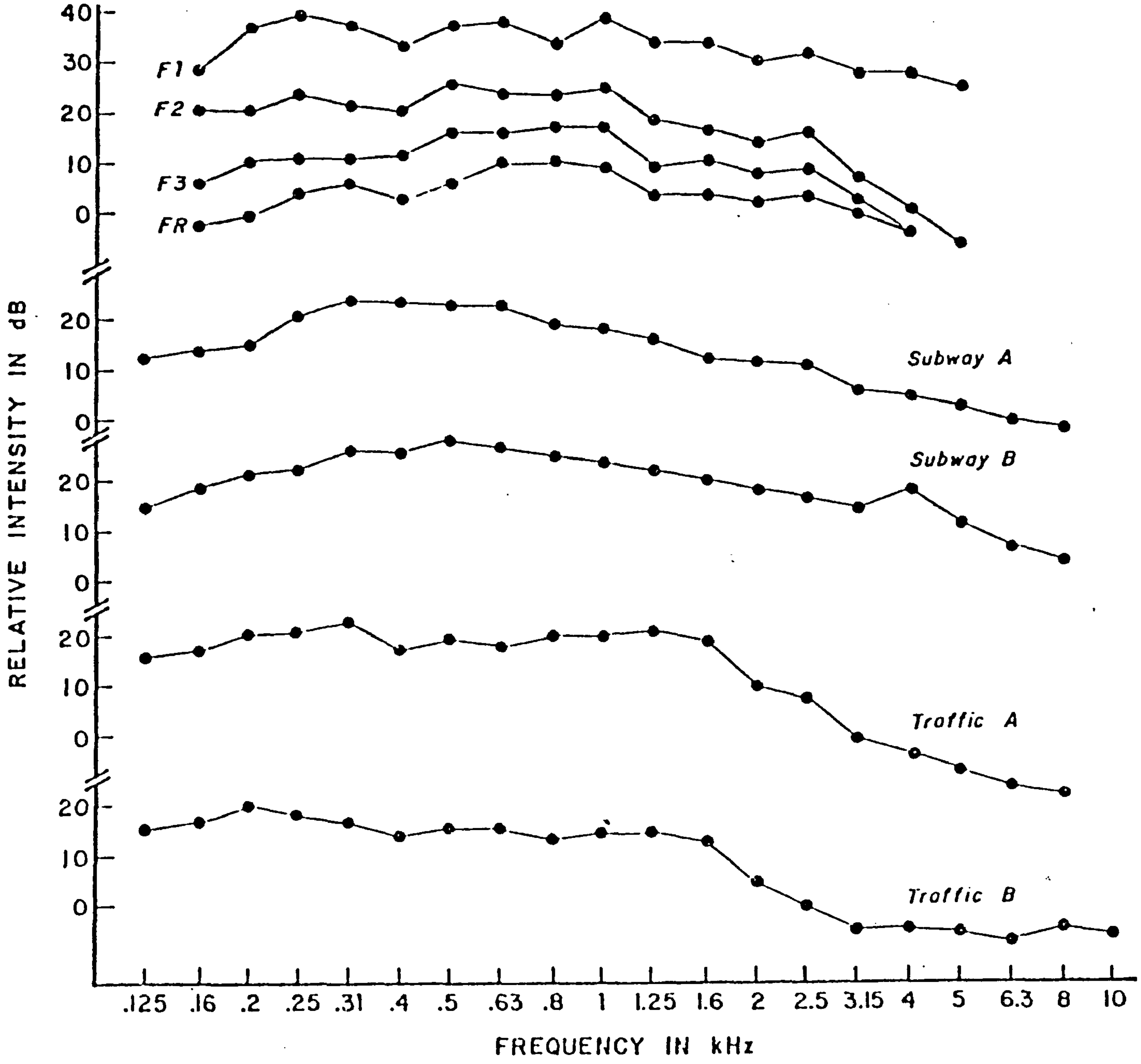
All increase in vocal power in the presence of background noise has been the finding of several investigators using young, normal-hearing speakers as subjects (Kryter, 1946; Hanley and Steer, 1949; Waltzman and Levitt, 1976). Such increase in power is the result of additional vocal effort; to achieve levels of over 80 dB SPL it would be necessary for speakers with soft voices to put forth an extreme effort. As people age their ability to expend this degree of effort is decreased, especially for longer periods of time. It may be speculated if, even with the motivation to speak loudly enough to be heard in noise, the older speaker has enough reserve energy, muscle tone and breath support to sustain loud or shouted conversation.

Examination of the data reveals the advantage of the reference speakers of both sexes (those with educated East Coast speech patterns) over the speakers with patterns typical of the New York metropolitan area. That is, the reference speakers were found to be more intelligible in all experimental conditions for subjects of every age group. The more precise articulation of the two reference speakers may be credited with this advantage.

An interaction between Speaker Sex and Noise Sample was seen in the data for subway noise. As previously noted, the advantage to the intelligibility of the female voice which had been equated for power is attributed to the spectral differences between the male and female voices. Figure 18 is a plot comparing the third-octave band spectra of the male speakers and the two samples of each noise source. Figure 19 is the same spectral comparisons for the female speakers. It should be noted that the female voices show more relative speech power in the high and mid-frequencies, and that the signal/noise ratio in the high frequency range is greater for sample 'A' of the subway noise. An underlying principle of the Articulation Index (AI) is that the intelligibility of speech will be affected by the portion of the speech spectrum which lies above the noise level.

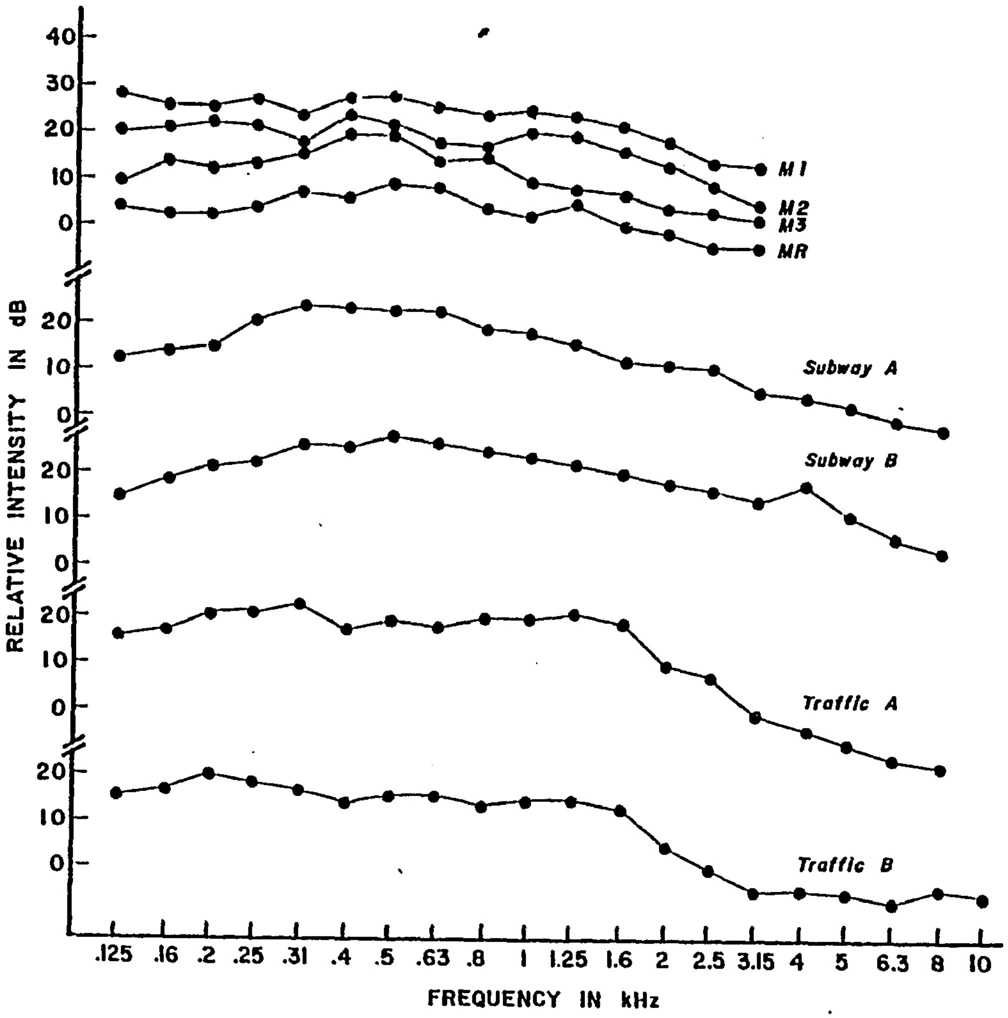
The fact that, in the general population there is a sizeable number of older people with considerable hearing loss, as well as those individuals who have auditory problems primarily affecting the discrimination of speech (first described by Gaeth (1948) as 'phonemic regression') is well documented in the lierature and well known to clinical audiologists. The finding of the present investigation, i.e. a loss of the ability to understand speech in the presence of common levels of urban noise a disability which increases with age for many older individuals who show no significant losses of pure tone hearing or of the ability to understand undistorted speech signals in quiet, point toward a sizeable handicap of the more 'typical' older person.

Fig. 18 One-third octave analyses of four male speakers and two samples each of subway and traffic noise, plotted on comparative scales.



RELATIVE INTENSITY IN dB
FREQUENCY IN kHz
F1
F2
F3
FR
Subway A
Subway B
Traffic A
Traffic B
40
30
20
10
0
20
10
0
20
10
0
20
10
0
20
10
0
.125
.16
.2
.25
.31
.4
.5
.63
.8
1
1.25
1.6
2
2.5
3.15
4
5
6.3
8
10

Fig. 19 One-third octave analyses of four female speakers and two samples each of subway and traffic noise, plotted on comparative scales.


RELATIVE INTENSITY IN dB
40
30
20
10
0
M1
M2
M3
MR
20
10
0
Subway A
20
10
0
Subway B
20
10
0
Traffic A
20
10
0
Traffic B
.125
.16
.2
.25
.31
.4
.5
.63
.8
1
1.25
1.6
2
2.5
3.15
4
5
6.3
8
10
FREQUENCY IN kHz

The question of how significant a group the older, hearing-impaired individuals constitute, especially in our large cities, may be considered in light of some statistics on hearing impairment with age. The incidence of hearing loss in the general population is estimated to be 13.4 million, according to the National Census of the Deaf Population (Schein and Delk, 1974). It is further estimated that at least 15 to 20 percent of individuals over the age of 65 are hearing impaired. Leutnegger and Stovall (1971) have indicated that 1.2 million citizens over the age of 65 live in nursing or retirement homes, and Chafee (1967) suggests that 90% of a confined population of older individuals might be hearing handicapped. Schein and Delk (1974) suggest that the prevalence of hearing impairment will increase in the coming years. They attribute this expected increase to the following factors:

1. Longer life expectancy, therefore more presbycusis;
2. increased noise levels in cities, and demographic changes which would result in a more urbanized population, therefore more sociocusis;
3. improved medical care which would save the lives of those who sustain illness and/or injury resulting in hearing loss.

Typically, the New Yorker over the age of 50 can be expected to have an increasingly difficult time communicating on the city streets and on subway trains or platforms. Much communication on public streets or in the subways is conducted for the exchange of necessary information. The inability of feeling able to get needed information could certainly decrease an individual's mobility and lead to a social isolation.

Previous studies on the effect of noise on speech, including those studies which provided information on which to base standards for allowable noise exposure, have typically used young subjects. The increased difficulty in understanding speech in noise of older people found in this study, in all noise conditions, would suggest the need to re-examine these noise standards. Levels which would allow for reasonable communication for young individuals turned out to be a serious impairment for the older subjects in this study, and this constitutes significant disadvantage to the 'typical' citizen over fifty years of age.

Summary

The study revealed a decrease in the ability to perceive speech in the presence of typical urban noises as a function of increasing age. These findings indicate that the loss of speech intelligibility with age is more severe as the listening conditions worsen. The selection process employed in the present study has a specific subgroup of older subjects (60-69 years) who have identified near-normal hearing and show no losses in their ability to discriminate undistorted speech material in quiet. The increased difficulty to understand speech that these subjects experience in noise compared to younger individuals suggest a sizable handicap for the typical individual in the seventh decade of life.

APPENDIX I: Questionnaire completed by all subjects prior to audiometric testing.

QUESTIONNAIRE

Code #_______________

Test Site_____________

Tester_______________

Test Date_____________

Tapes________________

Name______________________________
Address_________________________________ Phone#______________
Age__________ Date of Birth___________ Place of Birth____________
First language spoken______________ Second language spoken at what age__________
Major Occupation________________ Present Occupation______________
Academic Achievement____
Any problem understanding people talking to you_________________
Any ear infections____
drainage____
head trauma____
tinnitus____
dizziness____
headaches____
nausea____
Have you ever been treated for ear problems____________________
What medications do you take__________________________________
Noise exposure: Military_______________ Industrial_______________
Has anyone in your family had hearing loss_____________________

COMMENTS:

APPENDIX II: CHABA sentences (CID sentences of everyday American speech) Lists A-J. Fifty key words (underlined) for each list.

LIST A

1. Walking's my favorite exercise.
2. Here's a nice quiet place to rest.
3. Our janitor sweeps the floors every night.
4. It would be much easier if everyone would help.
5. Good morning.
6. Open your window before you go to bed!
7. Do you think that she should stay out so late?
8. How do you feel about changing the time when we begin work?
9. Here we go.
10. Move out of the way!

LIST B

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

LIST C

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

LIST D

1. It's time to go.
2. If you don't want these old magazines, throw them out.
3. Do you want to wash up?
4. It's a real dark night so watch your driving.
5. I'll carry the package for you.
6. Did you forget to shut off the water?

LIST D, Cont'd.

7. Fishing in a mountain stream is my idea of a good time.
8. Fathers spend more time with their children than they used to.
9. Be careful not to break your glasses!
10. I'm sorry.

LIST E

1. You can catch the bus across the street.
2. Call her on the phone and tell her the news.
3. I'll catch up with you later.
4. I'll think it over.
5. I don't want to go to the movies tonight.
6. If your tooth hurts that much you ought to see a dentist.
7. Put that cookie back in the box!
8. Stop fooling around!
9. Time's up.
10. How do you spell your name?

LIST F

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

LIST G

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

LIST H

1. Believe me!
2. Let's get a cup of coffee.
3. Let's get out of here before it's too late.
4. I hate driving at night.
5. There was water in the cellar after that heavy rain yesterday.
6. She'll only be gone a few minutes.
7. How do you know?
8. Children like candy.
9. If we don't get rain soon, we'll have no grass.
10. They're not listed in the new phone book.

LIST I

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

LIST J

1. Breakfast is ready.
2. I don't know what's wrong with the car, but it won't start.
3. It sure takes a sharp knife to cut this meat.
4. I haven't read a newspaper since we bought a television set.
5. Weeds are spoiling the yard.
6. Call me a little later!
7. Do you have change for five-dollar bill?
8. How are you?
9. I'd like some ice cream with my pie.
10. I don't think I'll have any dessert.

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