To the Graduate Council:

I am submitting herewith a dissertation written by Carole Johnson entitled "Loudspeaker-to-Listener Distance: Effects on Phoneme Recognition of Adults with Normal Hearing and High Frequency Hearing Loss." I have examined the final copy of this dissertation for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy, with a major in Speech and Hearing Science.

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We have read this dissertation
and recommend its acceptance:

Accepted for the Council:

Vice Provost and
Dean of The Graduate School

LOUDSPEAKER-TO-LISTENER DISTANCE: EFFECTS ON PHONEME RECOGNITION OF ADULTS WITH NORMAL HEARING AND HIGH FREQUENCY HEARING LOSS

A Dissertation

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ABSTRACT

Loudspeaker-to-listener distance was assessed for consonant and vowel identification scores of 12 adults with normal-hearing and 12 adults with high frequency hearing loss in a 415 m3 (i.e., 18 m x 7.2 m x 3.2 m) lecture hall, with a 1.5 s reverberation time, and a 3.3 m critical distance. Outside the critical distance of the lecture hall, the contribution of direct speech energy was negligible as the sound was primarily composed of reflected energy. Each listener was seated at two distances within the critical distance (i.e., 1 and 2 m) and three distances outside the critical distance (i.e., 4, 8, and 15 m) at a zero degree azimuth to the separation between two loudspeakers placed side-by-side. One loudspeaker presented consonant-vowel-consonant-vowel (i.e., CVCV) items from a nonsense syllable test, at 77 dB-A at 1 m. The 24 listeners were tested at all five distances in two speech-to-noise ratio (i.e., S/N) conditions. These were: (1) varied S/N in which the speech level decreased with distance in relation to a 45 dB-A ambient noise level, resulting in a +32 dB S/N at 1 m to a +23 dB S/N at 15 m, and (2) fixed S/N in which a multi-talker babble was presented through the other loudspeaker and adjusted to maintain a +15 dB S/N at all five distances. All 12 hearing-impaired adults were tested

without a hearing aid. Only 42% (i.e., 5 of 12) of the hearing-impaired listeners wore hearing aids in their personal lives.

Vowel and consonant scores of the normal-hearing adults were significantly better than of the adults with high frequency hearing loss. Consonant scores were higher within the critical distance than outside the critical distance, with no decrease in performance as distance increased in the reverberant field. Vowel scores were unaffected by distance except in the extreme conditions, with scores at 1 m being significantly better than at 15 m. Both consonant and vowel scores were significantly better in the varied than the fixed S/N condition. For both consonant and vowel scores, the Groups x Distances and S/N Conditions x Distances interactions were not significant suggesting similar trends in performance for these conditions. The results of this study suggested that unless a listener moves to <u>within</u> the critical distance of a speech source, decreasing loudspeaker-to-listener distance from one point to another in the reverberant field may not improve aural phoneme identification.

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CHAPTER I

INTRODUCTION

Statement of the Problem

The speech recognition of both hearing-impaired children and adults is worse in noise and reverberation than in quiet and nonreverberant listening conditions (Finitzo-Hieber & Tillman, 1978; Gelfand & Hochberg, 1976; Gelfand & Simon, 1979; Houtgast & Steeneken, 1973; Moncur & Dirks, 1967; Nabelek & Pickett, 1974a). To secure good listening conditions for hearing-impaired listeners, it has been recommended that the reverberation time should be less than .6 s (Borrild, 1978; Finitzo-Hieber & Tillman, 1978; John, 1960; Niemoeller, 1968) and the speech-to-noise ratio (i.e., S/N) be greater than +15 decibels (i.e., dB) (Crum & Matkin, 1976; Finitzo-Hieber & Tillman, 1978; Gengel, 1971; Sanders, 1965).

Hearing-impaired listeners often communicate in environments that exceed the recommended limitations for both noise and reverberation. For example, the median ambient noise level (A-weighted) was 56 dB for occupied classrooms for the hearing-impaired (Bess, Sinclair, & Riggs, 1984). The median A-weighted level of a teacher's

lecture voice is 71 dB at 1 m (Pearsons, Bennett, & Fiddell, 1977). Therefore, the S/N is +15 dB at that distance. Since the level of speech decreases with distance and most students sit farther than 1 m from the teacher, the S/N at most seats is less than the recommended minimum level for hearing-impaired listeners.

Similarly, most classrooms exceed recommended limits of reverberation times for hearing-impaired listeners. McCroskey & Devens (1975) reported that the reverberation times of classrooms ranged between 0.47 to 1.21 s, whereas Ross (1978) reported even longer reverberation times of 1.2 to 3.4 s. If the listener moves closer to the sound source, the detrimental effects of reverberation can be reduced. However, to achieve a marked improvement in speech recognition, the listener needs to be within the so called critical distance, which is no more than 3 m for averaged sized rooms (Beranek, 1978; Nabelek & Nabelek, 1985; Peutz, 1971).

Speaker-to-listener distance is an important factor in speech recognition. Peutz (1971) investigated the effect of loudspeaker-to-listener distance on the speech recognition of normal-hearing listeners in rooms of different volume and reverberation time. These rooms had low background noise and favorable S/Ns (i.e., +20 dB or greater) so that speech recognition scores were affected

only by reverberation. He reported that speech recognition scores decreased as distance increased up to a certain point. Beyond this point, scores stayed the same and were independent of the distance between the loudspeaker-and-listener. Peutz (1971) found this point to be the critical distance of each room. The critical distance is the point at which the direct and reflected sound energy are equal (Beranek, 1984; Nabelek & Nabelek, 1985; Peutz, 1971). Beyond the critical distance, Peutz (1971) concluded that the full effect of masking by reverberation occurred and remained constant, regardless of the loudspeaker-to-listener distance. These results were replicated in a classroom in which the S/N ranged from +17 to +21 dB depending on the distance from the source (Johnson, Nabelek, Asp, & Danhauer, 1988).

In an earlier study with normal-hearing listeners, Crum and Tillman (1973) found that speech recognition scores were significantly better at 6 ft than at 12 and 24 ft from the speech source in a classrooms with 0.4, 0.8, and 1.2 s of reverberation time and S/Ns of 0 dB, +6 dB, and quiet. Scores at 12 and 24 ft were not significantly different from each other. They suggested that the 12 and 24 ft distances were beyond the critical distance of the room.

Peutz (1971) and Johnson et al. (1988) tested performance in rooms with very favorable levels of background noise so that the S/Ns remained high (i.e., +17 dB or better) even though of the level of the speech decreased as distance increased. To simulate typical classroom conditions, Crum and Tillman (1973) tested subjects in unfavorable S/Ns which remained fixed at each distance by adjusting the level of a multi-talker babble background noise. Thus, normal-hearing listeners demonstrated similar trends in performance within and outside the critical distance in both favorable and unfavorable S/Ns. That is, scores were significantly higher within the critical distance than outside, with no significant decrease in performance with increasing loudspeaker-to-listener distance in the reverberant field.

Some studies (Borrhild, 1978; Fisher, 1964; Miller & Niemoeller, 1967; Ross & Giolas, 1971; Ross, Giolas, & Carver, 1973; Watson, 1964) reported that speech recognition scores of hearing-impaired listeners decreased as speaker-to-listener distance increased. However, none of the above studies determined the performance of hearing-impaired listeners at several distances within and beyond the critical distance.

Among chronic health problems, hearing loss is the third most prevalent in the elderly (NCHS, 1987). A recent survey indicated that 30% of those persons over age 65 have experienced some form of hearing loss (Skafte, 1982). The most common type is high frequency hearing loss. For example, presbycusis most often manifests itself as a hearing loss above 2000 Hertz (i.e., Hz) (Schuknecht, 1974). Similarly, many of the school-age children in our country who have high frequency hearing loss have not been identified (Anderson, 1967; Woodford & O'Farrell, 1983).

Most adults with a high frequency hearing loss may not be aware of their problem due to normal low frequency hearing sensitivity, normal speech reception thresholds (i.e., SRTs), and good speech recognition in quiet rooms with short reverberation times. It is not known how these hearing-impaired adults perform at various distances from the sound source. In a quiet environment (i.e., S/N of +20 dB or better), hearing-impaired adults may perform similarly to normal-hearing listeners, both within and outside the critical distance of reverberant rooms. However, adults with high frequency hearing loss may perform differently in a reverberant room in which the S/N is poorer than +20 dB. For example, their scores may decrease with distance both within and outside the

critical distance since the combined effects of noise and reverberation are more detrimental than the sum of each factor taken separately (Crum & Tillman, 1978; Nabelek & Mason, 1981).

The type of speech stimuli may affect speech recognition scores as a function of distance from the sound source. For example, Johnson et al. (1988) reported that normal-hearing listeners' consonant identification scores significantly decreased with distance, whereas vowel scores were unaffected by distance. Nabelek (1988) showed that hearing-impaired listeners made more vowel identification errors in reverberation than normal-hearing listeners. Therefore, both consonant and vowel identification scores of hearing-impaired listeners may be affected by distance.

Purpose

The purpose of this study was to assess consonant and vowel identification at several distances both within and beyond the critical distance of a room. The performance of a group of normal-hearing adults was compared to that of a group of adults with high frequency hearing loss. A lecture hall with a volume of 415 m3 (i.e., 18 m x 7.2 m x 3.2 m), a reverberation time of 1.5 s, and a

critical distance of 3.3 m was selected for this study. Listeners were seated at five distances: 1, 2, 4, 8, and 15 m from a loudspeaker. Performance was assessed in two noise conditions: (1) "varied" S/N, in which the level of the ambient noise was constant and level of the speech decreased with distance, resulting in a declining S/N with distance (i.e., from +32 dB at 1 m to +23 dB at 15 m) and (2) "fixed" S/N, in which the level of a multi-talker babble noise was adjusted to maintain a +15 dB at each distance.

Rationale

Adults who have high frequency hearing loss are often considered "borderline" candidates for hearing aids since routine audiometric testing usually indicates normal SRTs and good speech recognition scores in quiet. However, most of these adults may experience difficulty in speech recognition in "real life" listening situations involving a variety of speaker-to-listener distances. It is important to determine the effect of loudspeaker-to-listener distance on their speech recognition in a lecture hall with reverberation commonly encountered in classrooms (McCroskey & Devens, 1975; Ross, 1978), small churches and auditoriums (Nabelek & Nabelek, 1985).

The signal-to-noise ratio in the lecture hall may result in significant differences in performance with distance. In the "varied" condition, the S/N simulated a quiet environment, similar to that encountered in an auditorium. The S/N was primarily dependent on the level of the speech. Although the S/N decreased with distance (i.e., +32 dB at 1 m to +23 dB at 15 m), it remained relatively high. However, this condition does not represent typical listening situations encountered in everyday life. Thus, the "fixed" condition was added for two reasons. First, the "fixed" condition was used to evaluate the effects of distance while S/N was held constant. This eliminated the possible contamination of results by decreasing S/N with distance. Second, a multi-talker babble was introduced to maintain a +15 dB at each distance to more closely approximate a realistic classroom situation. The +15 dB S/N was chosen since it is within the range recommended for classrooms of the hearing-impaired (Crum & Matkin, 1976; Finitzo-Hieber & Tillman, 1978; Gengel, 1971; Sanders, 1965).

Experimental Questions

The following experimental questions were posed in this study:

Consonant Identification

For consonants, is there a significant difference:

1. between identification scores for adults with normal and high frequency hearing loss?;

2. among identification scores obtained at the loudspeaker-to-listener distances of 1, 2, 4, 8, or 15 m?;

3. between identification scores obtained in the varied (i.e., +32 to +23 dB) and fixed (i.e., +15 dB) S/N conditions?; or

4. Is there a significant interaction for identification scores between;

   a. listener groups and distances (G x D)?;

   b. listener groups and S/N conditions (G x N)?;

   c. distances and S/N conditions (D x N)?; and

   d. or among identification scores for listener groups, distances, and S/N conditions (G x D x N)?

Vowel Identification

For vowels, is there a significant difference:

1. between identification scores for adults with normal and high frequency hearing loss?;

2. among identification scores obtained at the loudspeaker-to-listener distances of 1, 2, 4, 8, or 15 m?;

3. between identification scores obtained in the varied (i.e., +32 to +23 dB) and fixed (i.e., +15 dB) S/N conditions?; or

4. Is there a significant interaction for identification scores between;

a. listener groups and distances (G x D)?;

b. listener groups and S/N conditions (G x N)?;

c. distances and S/N conditions (D x N)?; and

d. or among identification scores for listener groups, distances, and S/N conditions (G x D x N)?

CHAPTER II

REVIEW OF THE LITERATURE

In order to understand the principles of this study, a review of the literature is provided on the: (1) inverse square law and critical distance; (2) the effects of noise and reverberation; and (3) of speaker-to-listener distance on the speech recognition of normal and hearing-impaired listeners.

Inverse Square Law and Critical Distance

The inverse square law stipulates that the level of direct sound decreases by 6 dB each time the distance from the sound source is doubled (Beranek, 1986; Nabelek & Nabelek, 1985; Peutz, 1971). The speaker-to-listener distance may be an important factor in speech communication because the intensity of conversational speech is 65 dB sound pressure level (i.e., SPL) at 1 meter (i.e., m) (Fletcher, 1953) and may decrease to very low levels at greater distances. Therefore, speaker-to-listener distance is crucial for conversations taking place outdoors. However, it is less critical indoors because the SPL of speech is a sum of the direct sound and sounds reflected

from the room boundaries. In general, the inverse square law does not apply for distances greater than about 1 m in relatively small rooms. In such rooms, the listener is mainly surrounded by a reverberant field and speech levels stay nearly constant with distance (Pearsons, Bennett, & Fiddell, 1977).

The SPL of a sound as a function of the distance from the source in a room is illustrated in Figure 1. The straight line "a" represents the relative level of a direct sound as a function of its distance from the source. The level of a reflected sound, represented by line "b," is the same throughout the room, but depends on the volume and reverberation time of the room. The total sound energy in the room is a sum of the direct and reflected sounds and is represented by curve "c". At point "D", where lines "a" and "b" intersect, the direct and reflected sounds are equal and represent the critical distance of the room. The critical distance of each room is proportional to the square root of its volume and is inversely proportional to the square root of its reverberation time (Beranek, 1984; Nabelek & Nabelek, 1985; Peutz, 1971). It is postulated that beyond the critical distance, the full effect of masking by reverberation occurs and remains constant, independent of the distance between the speaker and listener (Nabelek & Nabelek, 1985; Peutz, 1971).

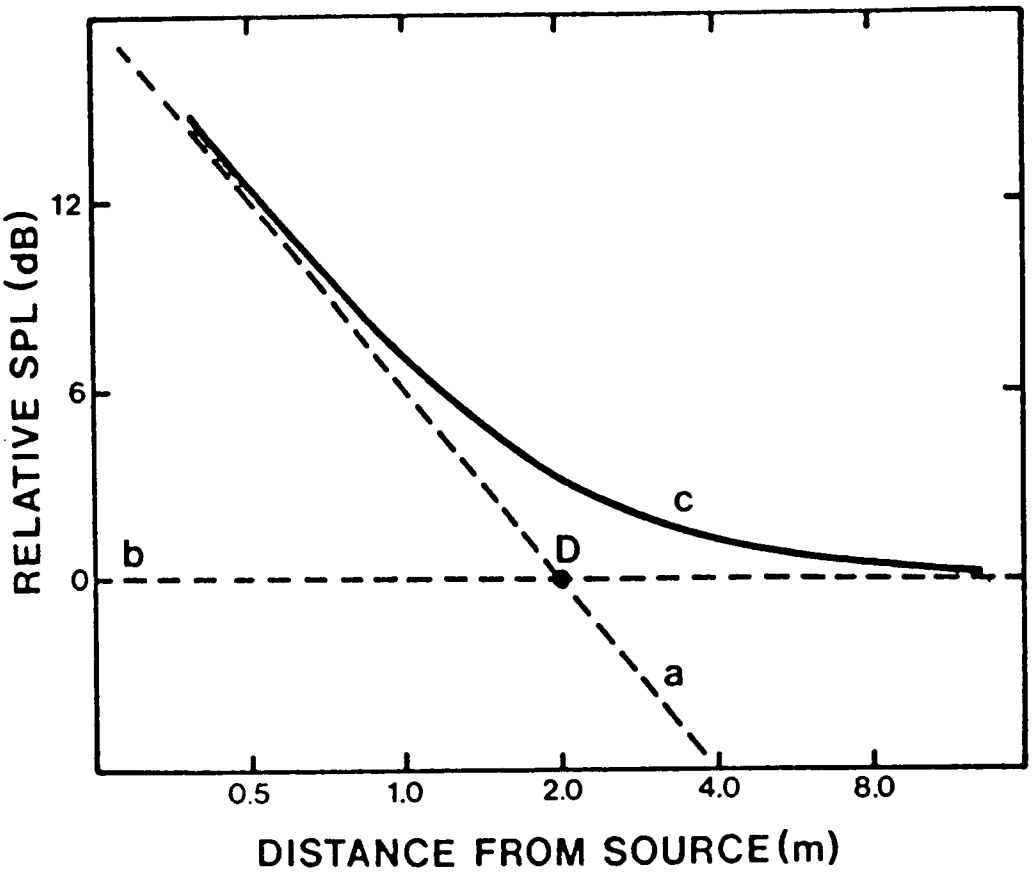


Figure 1. SPL in a room as a function of distance from source: (a) direct, (b) reverberant, and (c) total sound energy. Intersection of curves a and b (point D) defines the critical distance (Taken from Nabelek & Nabelek, 1985).

The formula for critical distance is derived, in principle, from its definition (Beranek, 1984). The formula for the intensity of direct sound (i.e., Id) is:

$$Id = N/4\pi d^2$$

where:

N = power of the sound source;

d = distance.

The direct energy radiates in a spherical wave from the sound source.

The formula for the intensity of reflected sound (i.e., Ir) can be expressed:

$$Ir = 4N(1 - \bar{\alpha})/ S\bar{\alpha}$$

where:

N = power of the reflected sound;

$\bar{\alpha}$ = average absorption coefficient for the room;

S = surface of the boundaries in m2.

The intensity of the reflected sound depends primarily on the average sound absorption coefficient of the room. The greater the absorption coefficient, the less intense is the reflected sound energy.

By definition, the critical distance is the point where the direct and reflected sound energy are equal. Therefore, it follows that:

$$Id = Ir.$$

Substituting in the respective formulas, we obtain:

$$N/4\pi d^2 = 4N(1 - \bar{\alpha})/S\bar{\alpha},$$

from which the critical distance is:

$$d = S\bar{\alpha}/16\pi(1 - \bar{\alpha}).$$

The $S\bar{\alpha}$ can be specified from Sabine's formula for room reverberation time:

$$T = 0.163\ V/S\bar{\alpha}$$

therefore,

$$S\bar{\alpha} = 0.163\ V/T,$$

where:

T = reverberation time, in seconds;

V = volume, in m3;

0.163 = a coefficient in Sabine's reverberation time formula for metric measures.

Thus, $S\bar{\alpha}$ can be substituted in the above equation for critical distance to obtain:

$$d^2 = 0.163V/16\pi T(1 - \bar{\alpha}),$$

or:

$$d = \sqrt{0.0032\ V/T(1 - \bar{\alpha})},$$

and finally:

$$d = 0.057\ \sqrt{(V/T(1 - \bar{\alpha}))}.$$

If we assume a completely reflective room, $\alpha = 0$, the approximate formula for critical distance is:

$$d = 0.057\ \sqrt{V/T} \approx 0.06\ \sqrt{V/T}.$$

However, if a assume a highly absorptive room, $\alpha = 0.9$, the approximate formula is:

$$d = 0.18\ \sqrt{V/T} \approx 0.2\ \sqrt{V/T}.$$

The Effects of Noise and Reverberation on Speech Recognition

To understand the impact of speaker-to-listener distance on communication, it is important to be aware of the effects of noise and reverberation on the speech recognition of normal and hearing-impaired listeners.

Normal-Hearing Listeners

With the exception of anechoic chambers, all rooms have some reverberation. Reverberation time is about 0.2 s in audiometric test boothes, is between 0.4 and 0.8 s in small offices and living rooms, and is up to 1.5 s in small churches and auditoriums (Nabelek & Nabelek, 1985). In quiet environments, normal-hearing listeners can tolerate up to 1.2 s without severely affecting speech discrimination (Nabelek & Nabelek, 1985).

Within the group of normal-hearing listeners, some factors have been found to significantly affect speech recognition in reverberation. One of those factors is age. Speech recognition in a reverberant corridor was poorer for elderly subjects than for young adults (Bergman, Blumenfield, Cascardo, Dash, Levitt, & Marguiles, 1976). Elderly subjects have higher speech reception thresholds in reverberant than in nonreverberant conditions (Duquesnoy & Plomp, 1980). More recently, Nabelek and Robinson (1982)

reported that 27 year-olds performed significantly better than 10, 42, 54, 64, or 72 year-olds on speech perception tasks with reverberation times of 0.4, 0.8, and 1.2 s.

The 10 year-old children in the Nabelek and Robinson (1982) study performed 7% poorer than the 27 year-old young adults. Similarly, Neuman and Hochberg (1983) demonstrated that children's speech recognition scores in 0.4 and 0.6 s of reverberation time increased when the age of the children increased from 5 to 13 years. In addition, binaural scores of children were approximately 3% better than monaural scores in both studies.

Special requirements for room acoustics for children and elderly adults have been advocated (Nabelek & Nabelek, 1980; Plomp & Duquesnoy, 1980). For example, in reverberation, children and elderly adults may need as much as a 10 dB higher SPL of speech than young adult listeners for comparable speech understanding.

The native language of listeners is another factor that can influence speech recognition. Nonnative listeners with normal-hearing have lower speech recognition scores in reverberation than native listeners (Bergman, 1980; Nabelek & Donahue, 1983). For example, in 2.5 s of reverberation time, Bergman (1980) reported that elderly persons, who did not speak Hebrew as their first language and who spoke with an accent obtained, on the average, a

20% lower score than native Hebrew speakers. Similarly, Nabelek and Donahue (1983) reported that nonnative English listeners scored, on the average, 10% lower than native listeners in 0.8 and 1.2 s of reverberation time. Thus, nonnative listeners, who have good understanding with no reverberation, may have difficulty with speech recognition in reverberation times encountered in most rooms (Nabelek & Donahue, 1982).

In addition to reverberation, noise is present in most listening situations. Both reverberation and noise make speech recognition more difficult. For example, Peutz (1971) reported that with a reverberation time of 0.5 s, normal-hearing listeners obtained a speech recognition score of 95% when the S/N was high. The scores decreased to 82% and 60% when the S/N was +10 and 0 dB, respectively. For a reverberation time of 1.0 s, scores decreased to 90%, 75%, and 50%, for the same S/Ns, respectively. Thus, speech recognition scores of normal-hearing listeners can be very low when both noise and reverberation are present.

Hearing-Impaired Listeners

As with the normal-hearing listeners, the speech recognition of hearing-impaired listeners is significantly reduced when both noise and reverberation are present (Finitzo-Hieber & Tillman, 1978; Gelfand & Hochberg, 1976;

Gelfand & Silman, 1979; Houtgast & Steeneken, 1973; Moncur & Dirks, 1967; Nabelek & Mason, 1981; Nabelek & Pickett, 1974a). It has been recommended that reverberation in rooms used by hearing-impaired listeners should be less than 0.6 s (Borrhild, 1978; Finitzo-Hieber & Tillman, 1978; John, 1960; Niemoeller, 1968) and S/Ns should be greater than +15 dB (Crum & Matkin, 1976; Finitzo-Hieber & Tillman, 1978; Gengel, 1971; Sanders, 1965).

For hearing-impaired listeners, the combined effects of noise and reverberation are more detrimental to speech recognition than the sum of these factors measured separately (Finitzo-Hieber & Tillman, 1978; Nabelek & Mason, 1981; Nabelek & Pickett, 1974a; 1974b).

Finitzo-Hieber and Tillman (1978) investigated the monosyllabic word discrimination abilities of normal and hearing-impaired children under twelve combined conditions of noise (i.e., quiet and S/Ns of +12, +6, and 0 dB S/N) and reverberation (i.e., 0, 0.4, and 1.2 s). Subjects were tested with and without hearing aids. Without hearing aids, hearing-impaired children's percent of words incorrectly identified were 21.8% and 45.3% greater in +6 dB and 0 dB S/N, respectively, than in the quiet condition with 0 s of reverberation time (i.e., anechoic chamber). The percent of words incorrectly identified in quiet, but with 0.4 s of reverberation time was 8.3% greater than for the quiet

and nonreverberant condition. When the percent of words missed in the +6 dB and 0 dB S/N conditions were added to that for the 0.4 s of reverberation time condition, the predicted percent of words missed relative to the quiet and nonreverberant condition were 30.1% (i.e., 21.8% + 8.3% = 30.1%) for +6 dB S/N with 0.4 s of reverberation time and 53.6% (i.e., 45.3% + 8.3% = 53.6%) for +0 dB S/N with 0.4 s of reverberation time. However, the actual percent of words missed were 33.0% and 58.7%, respectively, exceeding the predicted values obtained by summing the effects of noise and reverberation, separately.

Nabelek and Mason (1981) showed the same effect for hearing-impaired adults. They investigated the effect of noise (i.e., quiet and +5 dB S/N) and reverberation time (i.e., 0.1 and 0.5 s) on binaural and monaural speech recognition abilities of hearing-impaired adults. Word discrimination scores decreased 16.0% when the reverberation time increased from 0.1 s to 0.5 s. The scores decreased 20.2% when reverberation time was 0.1 s and S/N decreased from quiet to +5 dB. Thus, the predicted decrease in scores was 36.2% for the combined condition of 0.5 s of reverberation time in +5 dB S/N. However, the actual decrease in scores was 57.2%. This was 21.0% greater than the sum of the effects of noise and reverberation added separately.

All of the above mentioned studies showed that both noise and reverberation can significantly reduce speech recognition for hearing-impaired listeners. Moreover, it has been demonstrated that the combined effects of noise and reverberation are more detrimental than that of the factors added separately.

Effect of Speaker-to-Listener Distance on Speech Recognition

Normal-Hearing Listeners

The effect of speaker-to-listener distance on normal-hearing listeners' speech recognition has been investigated in relatively quiet (i.e., S/N +17 dB or greater) environments, like auditoriums (Johnson et al., 1988; Peutz, 1971) and noisy classrooms (i.e., less than +6 dB) (Crum & Tillman, 1973).

Peutz (1971) investigated the effect of loudspeaker-to-listener distance on the speech recognition of normal-hearing listeners in rooms of different sizes (i.e., 70 m3 to 13000 m3) and reverberation times (i.e., 0 to more than 8 s). Speech stimuli were consonant-vowel-consonant (CVC) word lists with both meaningful mono-syllabic words and nonsense syllables. The stimuli were presented to listeners at a 0 degree azimuth via a loudspeaker. Listeners were tested at varying distances

from the source. The level of the speech decreased with distance. Thus, with a constant level of ambient noise, the S/N also decreased or varied with distance. However, since the rooms that were tested had such low ambient noise and favorable S/Ns (i.e., +20 dB or better), S/N was not a factor in performance for any of the distances tested. Peutz (1971) found that speech recognition gradually declined with increasing distance up to a certain point, but beyond that point, scores remained constant and independent of the distance between loudspeaker and listener. He found that this point was equal to the critical distance of each room. He stated that the speech recognition of normal-hearing listeners as a function of distance from the source in a room was very simple to predict. Within the critical distance, or Dc, speech recognition scores decrease with increasing speaker-to-listener distance. However, outside Dc, speech recognition scores are similar regardless of where the listener is seated.

More recently, Johnson, Nabelek, Asp, and Danhauer (1988) investigated effects of distance from a sound source on the recognition of consonants and vowels in a lecture hall by 12 normal-hearing young adult listeners. The hall had a volume of 415 m3 and reverberation time of 1.9 s. The critical distance of the hall was

calculated to be 3 m using the equation (i.e., 0.2 $\sqrt{V/T}$). Consonant-vowel-consonant-vowel (CVCV) items from the Nonsense Syllable Test (Edgerton & Danhauer, 1979) were presented to the listeners at an average A-weighted level of 75 dB measured at 1 m from the loudspeaker. The level of the speech decreased with distance. Thus, with a constant A-weighted level of ambient noise (i.e., 54 dB), the S/N also decreased with distance.

Subjects' phoneme recognition abilities were assessed at three distances of 1 (i.e., within the critical distance), 4, and 8 m. Vowel scores were significantly better than consonant scores. Further, although vowel scores were not significantly affected by distance, consonant scores were significantly better at 1 m than at the 4 and 8 m distances which were not different from each other. Thus, decreasing distance from the sound source beyond the critical distance did not improve speech recognition for the normal-hearing listeners.

Crum and Tillman (1977) investigated the effects of: (1) speaker-to-listener distance (i.e., 6, 12, and 24 ft), (2) reverberation time (i.e., 0, 0.4, 0.8, and 1.2 s), and (3) S/N (i.e., no noise, +6 dB, and +0 dB) on twelve normal-hearing listeners' word recognition ability. Conditions were created to simulate a typical classroom environment. Testing environments included an anechoic and

reverberation chamber. Monosyllabic words were presented via a loudspeaker at 0 degree azimuth to the listeners who were instructed to repeat what they heard. The signal presentation was calibrated to 70 dB SPL at 6 ft in the anechoic chamber. The voltage required to produce that intensity was held constant for all test conditions. Thus, although the level of speech decreased with distance, a multi-talker babble was adjusted such that the S/N was held constant at each distance. In the anechoic chamber, the level of the speech decreased 6 dB with every doubling of distance from the speech source. However, in the reverberation chamber, the only noticeable decrease in levels occurred between 6 and 12 ft, but not between 12 and 24 ft which were not different from each other.

Crum and Tillman (1973) found that speech recognition scores were unaffected by distance in the anechoic chamber. However, for the reverberation only and the reverberation plus noise conditions, performance was significantly better at 6 ft than at 12 or 24 ft which were not significantly different from each other. The 6 ft distance was suggested to be within the critical distance while 12 and 24 ft where outside of this point (Crum & Tillman, 1973). Crum and Tillman (1973) concluded that the influence of distance, reverberation time, and S/N synergistically interact in a way that reduces

recognition of monosyllabic words for normal-hearing listeners in a way that cannot be predicted by summing the effects of those factors separately.

In conclusion, regardless of whether the acoustic space is a quiet auditorium (Peutz, 1971; Johnson et al., 1988) or is a noisy classroom (Crum & Tillman, 1977), normal-hearing listeners' performance is superior within the critical distance than outside this point. Further, performance does not significantly decrease when moving from one point to another farther from the sound source in the reverberant field.

Hearing-Impaired Listeners

Hearing-impaired listeners' speech recognition scores decreased with increasing distance from the sound source (Borrild, 1978; Dale, 1968; Fisher, 1964; Miller & Niemoeller, 1967; Ross & Giolas, 1971; Ross, Giolas & Carver, 1973; Watson, 1964). Unfortunately, there are three major weaknesses with these studies that prevent drawing conclusions regarding how hearing-impaired listeners perform at several distances within and outside of the critical distance.

First, few, if any, of these studies discussed the concept of critical distance or included it as a variable in the experimental design (Dale, 1968; Fisher,

1964; Miller & Niemoeller, 1967; Ross & Giolas, 1971; Ross et al., 1973; Watson, 1964). None of the studies included the volume or reverberation time of the rooms. Thus, no conclusions regarding hearing-impaired listeners' performance within and beyond the critical distance were made.

The second major problem was that performance was assessed at only two distances from the sound source (Watson, 1964; Miller & Niemoeller, 1967; Ross & Giolas, 1971; Ross et al., 1973; Borrild, 1978). For example, Borrild (1978) investigated the effect of speaker-to hearing-aid-microphone distance with ten hearing-impaired children in rooms differing in ambient noise level and reverberation time. Two distances of 60 cm and 3 m were assessed. The closer distance was used to simulate one-on-one teacher-student interaction. The farther distance represented typical lecturing situations encountered by hearing-impaired children in the classroom. The five types of rooms used were a(n): (1) hall; (2) untreated classroom; (3) sound-treated classroom; (4) audiometric room with low ambient noise (i.e., less than 20 dB SPL); and (5) audiometric room with high ambient noise (i.e., 53 dB SPL).

The results indicated that scores were higher in the rooms with lower reverberation times and lower ambient

noise levels. Further, the difference between the scores obtained at 60 cm and 3 m were smaller for the rooms with the more favorable acoustic conditions. For example, for the hall with 2.4 s of reverberation time, the mean percent correct speech recognition score was 55% at 60 cm and 34% at 3 m, which is a difference of 21%. For the sound-treated classroom with a reverberation time of 0.5 s, the mean score was 72% at 60 cm and 68% at 3 m, which is a difference of 4%. Although these results suggest that speech recognition decreases more with distance in rooms with poorer S/Ns and greater reverberation times, no conclusions were made with regard to performance within or outside the critical distance.

A third weakness of the studies (Miller & Niemoeller, 1967; Ross & Giolas, 1971; Ross et al., 1973; Watson, 1964) was that distance was of secondary importance. For example, Ross and Giolas (1971) and Ross et al. (1973) compared an FM auditory trainer with the microphone placed close to the teacher's mouth to personal hearing aids with microphones placed at the students' ear. The students were seated several meters from the speaker in a typical classroom. There were significantly higher word recognition scores for the FM system (M, 58%) than for the personal hearing aids (M, 36%). While these studies showed the benefit of close microphone placement, performance within

and outside the critical distance of the room was not evaluated.

Summary

In an anechoic chamber, sound levels decrease with distance according to the 6 dB rule of the inverse square law. In a room with reverberation, the critical distance is the point at which the level of the direct and reflected sound are equal. Outside the critical distance, the level of sound decreases slightly with distance. The combined effects of noise and reverberation have a detrimental affect on the speech recognition of both normal and hearing-impaired listeners. The effect is greater than summing the effects of each factor separately.

The speech recognition of normal-hearing listeners is affected by distance. Generally, speech recognition scores decrease as speaker-to-listener distance increases up to the critical distance. Outside the critical distance, there is no significant decrease in performance with distance. This effect has been shown for quiet auditoriums and noisy classrooms.

The speech recognition scores of hearing-impaired listeners decrease with increasing distance from the

sound source. However, it is not known how hearing-impaired listeners would perform at several distances within and beyond the critical distance in environments where the S/N decreases with distance or stays constant with distance. Thus, the present study was undertaken to investigate these questions.

CHAPTER III

METHODS

Subjects

Subjects were 12 adults with normal hearing and 12 adults with high frequency hearing loss. Subjects' sex, age, speech reception thresholds (i.e., SRTs) speech recognition scores, and bilateral air conduction thresholds appear in Appendix A.

The normal-hearing listeners were 11 women and 1 man between 23 and 61 years of age (M, 35.4 years). They were selected from the students and staff at the University of Tennessee Department of Audiology and Speech Pathology. Subjects satisfied the following criteria:

1. bilateral pure tone air and bone conduction thresholds less than 25 HTL in dB for the octave frequencies 250 through 8000 Hz;
2. no air bone gaps greater than 5 dB;
3. SRTs less than 25 dB;
4. type A tympanograms (i.e., normal middle ear pressure and compliance), bilaterally.

The high frequency hearing loss listeners were 4 women and 8 men between 44 and 71 years of age (M, 62 years). They were selected from the files of the University of Tennessee Hearing and Speech Center to satisfy the following criteria:

1. bilateral post-lingual mild-to-severe high frequency sensori-neural hearing loss;

2. no significant air bone gaps;

3. SRTs no greater than 25 dB in at least one ear; and

4. type A tympanograms (i.e., normal middle ear pressure and compliance). Forty-two percent of the subjects (i.e., 5 of 12) wore hearing aids (i.e., Subject No. 13, 17, 22, 23, and 24). Table 1 summarizes subjects' sex, ages, and audiometric data for both listener groups.

Speech Stimuli

The choice of stimulus materials was crucial for this study since its purpose was to assess the effects of distance on the intelligibility of speech with as few contextual cues as possible. Although meaningful materials such as sentences or words are representative of typical lecture situations, they also provide the listener with considerable redundancy and would have made the task too easy.

Table 1

Subjects' Age and Audiometric Data (HTL) in Decibels

	Age	SRT	SDS	Audiometric Data (Hz)					
	(y)		(%)	250	500	1000	2000	4000	8000
N.	35.4	.42	99.5	8.7	4.8	3.9	0.2	3.5	6.2
H.I.	62.0	17.3	86.5	17.5	17.7	20.0	36.9	55.6	63.2

N = Normal-hearing.

H.I. = Hearing-impaired.

Nonsense syllables, however, provide a more straightforward measure of phoneme recognition without semantic influences while also providing a means of calculating separate scores for vowels and consonants. Thus, the Auditec of St. Louis Recording of the Nonsense Syllable Test (NST) List A developed by Edgerton and Danhauer (1979) was used in this study. List A consists of 25 consonant-vowel-consonant-vowel (CVCV) items and has six randomizations which appear in Appendix B. The breakdown of the frequency of occurrence of phonemes appearing on List A can also be found in Appendix B.

Ten of 25 of the CVCV items from NST List A were randomly selected to be spectrographically analyzed with the Kay Elemetric Digital Sonograph Model No. 7800 and then printed with the Digital Sonograph Printer Model No. 7900. Both consonants and vowels were measured for their duration, in milliseconds, and relative amplitudes, in dB.

The mean durations were: (1) 152 ms for the initial consonant; (2) 321 ms for the initial vowel; (3) 131.3 ms for the intervocalic consonant; and (4) 348.2 ms for the final vowel. The durations of both consonants and vowels were longer than the durations for connected speech (Umeda, 1975; 1977). Longer segmental duration has been

associated with "clear speech" for hearing-impaired listeners (Picheny, Durlach, & Braida, 1986).

The mean relative amplitudes were: (1) -25.25 dB for the initial consonant; (2) -5 dB for the initial vowel; (3) -30.1 dB for the intervocalic consonant; and (4) -4.6 dB for the final vowel. The difference in relative peak amplitude between the vowel and the consonant was 20.25 dB in the first syllable and 25.5 dB for the second syllable. These two values were similar to the 28 dB difference between the most intense vowel /ɔ/ and the softest consonant /θ/ in the English language (Fletcher, 1953).

The wideband spectrograms of the 10 items and a chart of the measured values appear in Appendix C. This information was obtained to provide possible explanation, if necessary, for results.

Measurement of Reverberation Time and Ambient Noise level

Reverberation Time

All experimental testing occurred in the same lecture hall which had a volume of 415 m3. A cap pistol was fired and tape recorded several times within the room from two different positions. The first position involved

firing the cap pistol from one corner of the room with the microphone of a high quality portable reel-to-reel tape recorder (Sony, Model No. APR-2003) located in the opposite diagonal corner. The second position involved firing the pistol at the 15 m testing position toward the microphone of the tape recorder located at the sound source.

For analysis of reverberation time, the output of the reel-to-reel tape recorder was connected to the input of the SUVAG Lingua for filtering through 1/3 octave bands. The output of the SUVAG Lingua was connected to the input of a graphic level recorder (Bruel & Kjaer, Type No. 2203). Three pistol shots from each recording position were filtered through one-third octave bands with the octave center frequencies 250 through 8000 Hz. The intensity of the pistol shots were plotted as a function of time by the graphic level recorder.

Reverberation time is defined as the time it takes for the root mean square SPL of a sound to decrease 60 dB after cessation (Beranek, 1984; Nabelek & Nabelek, 1985) A special measuring disk was used to estimate the reverberation time of the lecture hall through each 1/3 octave band. An example of one of the printouts from the graphic level recorder is displayed in Appendix D. Figure 2 depicts the reverberation times of the lecture hall through the 1/3

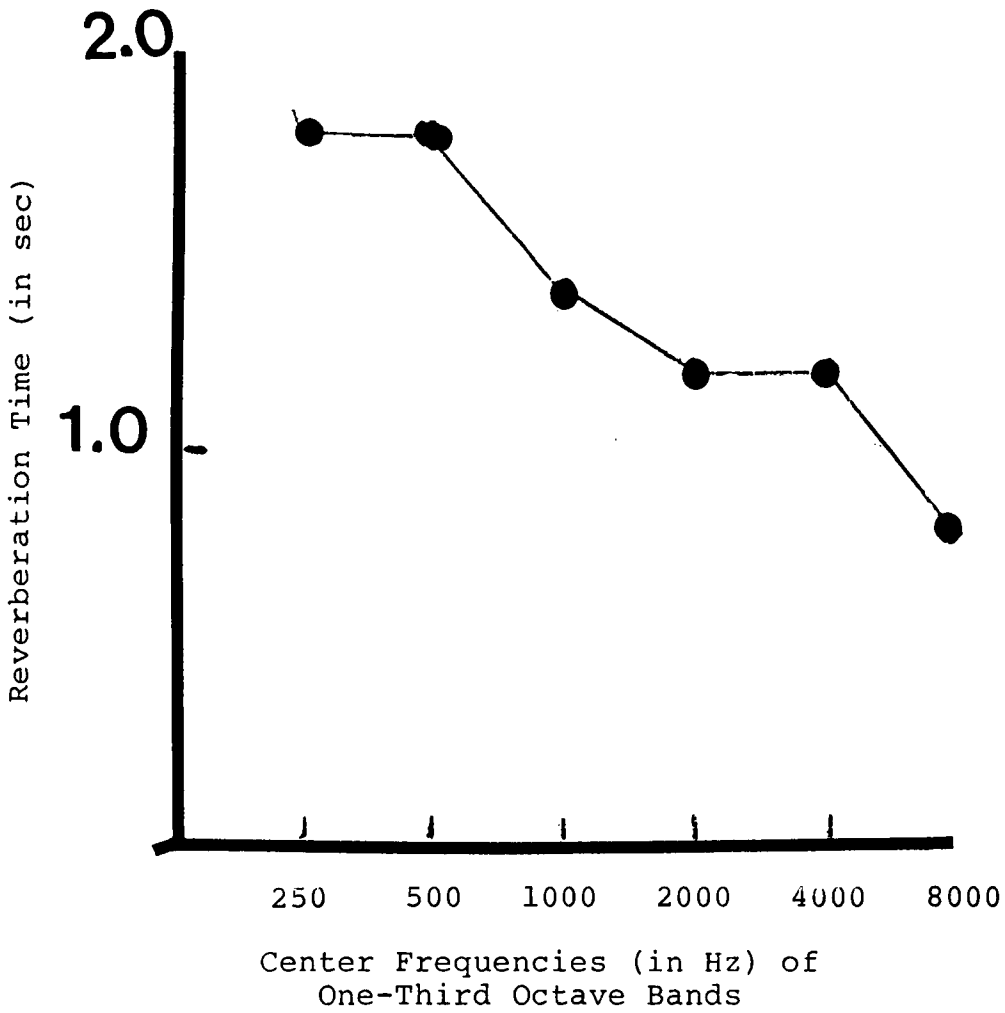


Figure 2. Reverberation time for the lecture hall.

octave bands. An overall reverberation time was calculated by averaging the values obtained for the 500, 1000, and 2000 Hz 1/3 octave bands resulting in a T of 1.5 s.

A range was calculated for the critical distance of the lecture hall. Assuming a reflective room, the critical distance was 1.0 m using the equation $Dc = (0.06 \sqrt{V/T})$. Assuming a highly absorptive room, the critical distance was 3.3 m using the equation $Dc = 0.2 \sqrt{V/T}$. The V in the equations was the volume of the lecture hall in cubic meters and the T is its reverberation time in seconds. Thus, the critical distance of the lecture hall was between 1.0 and 3.3 m. The measurement of A-weighted speech levels indicated a decrease in level up to 4 m. If the critical distance of the room was 1.0 m, then speech levels would not have decreased much beyond this distance. Thus, the critical distance was probably much closer to 3.3 m, than 1.0 m.

Ambient Noise

The ambient noise level of the lecture hall was measured each morning, prior to experimental testing, using a calibrated precision sound level meter (Bruel & Kjaer, Model No. 2203) The ambient noise levels were measured using a slow meter setting at the 1, 8, and 15 m

test positions to verify the uniformity of the ambient noise levels with distance. The 1/2 inch condenser microphone (Bruel & Kjaer, Model No. 8033) was positioned in the area of the listeners' right ear. Measurements were made for A-weighted levels and for the 1/3-octave bands at the octave center frequencies 250 through 8000 Hz. The mean ambient A-weighted noise level was 45 dB for the lecture hall. The mean measurements made for the three test positions appear in Appendix E. There was less than a +/- 2 dB variations in these measurements across test conditions.

Instrumentation

Figure 3 depicts the block diagram of instruments used for presenting the speech stimuli to subjects. The Auditec of St. Louis Recording of the randomizations of NST List A was played on a stereo cassette tape recorder (Toshiba, Model No. PC-X12). The output of the stereo cassette tape deck was connected to an amplifier (SUVAG Lingua). The output of the amplifier was connected to a high quality loudspeaker (Advent, Model Name Spectra).

The multi-talker babble from the Speech Perception in Noise Test (SPIN) (Kalikow, Stevens, & Elliot, 1977) was played from a second stereo cassette tape recorder

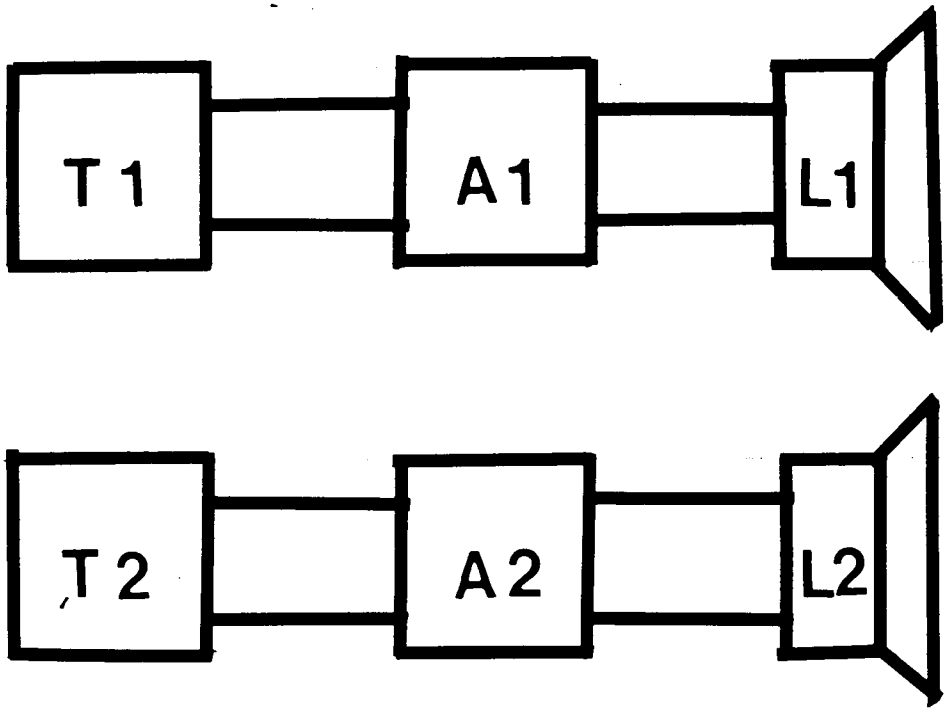


Figure 3. Block diagram for presenting speech stimuli and multi-talker babble to listeners.

Legend
T1--Stereo Cassette Tape Deck 1 (Toshiba, Model No. PC-X12)
T2--Stereo Cassette Tape Deck 2 (Toshiba, Model No. PC-X12)
A1--Amplifier 1 (SUVAG Lingua)
A2--Amplifier 2 (SUVAGII)
L1--Loudspeaker 1 (Advent, Model Name Spectra)
L2--Loudspeaker 2 (Advent, Model Name Spectra)

(Toshiba, Model No. PC-X12). The output of the stereo cassette tape deck was connected to an amplifier (SUVAG II). The SUVAG Lingua and SUVAG II have similar electroacoustic characteristics with regard to frequency response for the wide band setting (Asp, 1986). The output of the amplifier was connected to a high quality loudspeaker (Advent, Model Name Spectra).

Speech Levels and Signal-to Noise Ratios

Loudspeaker and Test Chair Arrangement

The two loudspeakers were placed at the front of the lecture hall in the area used by individuals for lecturing. The loudspeakers were placed side-by-side on a table so that the outer rims of their diaphragms were approximately 10 cm apart. The center of the diaphragms of the loudspeaker were approximately at the same level as the heads of subjects when seated for testing.

A tape measure was used to measure loudspeaker-to-listener distances. Markings were placed on the floor at 1, 2, 4, 8, and 15 m from the sound source. Chairs were placed such that subjects' ears were in alignment with the marks on the floor. The chairs were placed so that the subjects would be at 0 degree azimuth to the separation of the two speakers. In other words, the sagittal plane of

the subject's head was in alignment with the separation point between the two speakers. Figure 4 illustrates the loudspeaker-to-listener chair arrangement.

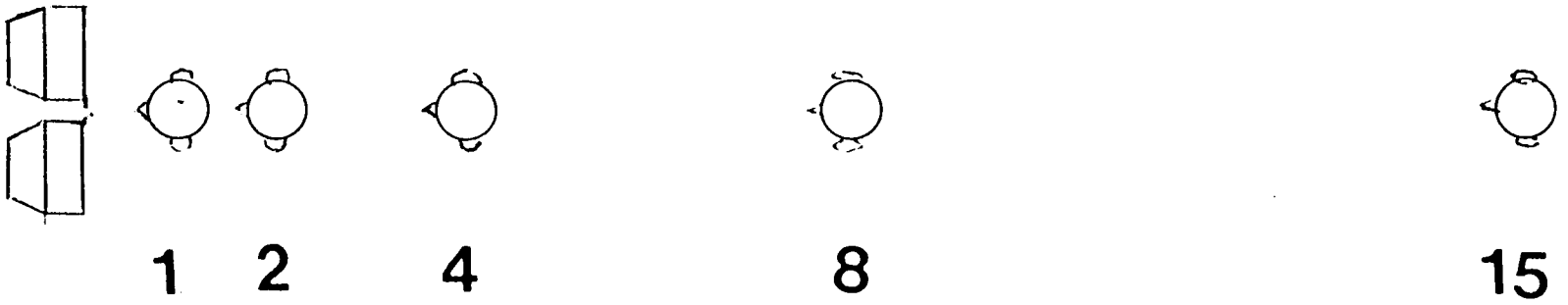
Speech Levels

The level of the speech was adjusted such that the vowels of the NST peaked at an average A-weighted level of 77 dB at 1 m. This level is similar to that used by male speakers using a loud voice for lecturing (Pearsons, Bennett, & Fiddell, 1977).

The A-weighted level of speech was measured at each of the distances using a precision sound level meter (Bruel & Kjaer, Model No. 2203) using the slow meter setting. The 1/2 condenser microphone (Bruel & Kjaer, Model No. 8033) was placed approximately at the location of the subject's right ear. The A-weighted levels of the speech were 77 dB at 1 m, 73 dB at 2 m, 70 dB at 4 m, 69.5 dB at 8 m, and 68 dB at 15 m.

Signal-to-Noise Ratio

There were two S/N conditions used in this experiment. The first was the "varied" condition in which the S/N decreased with distance. The second was the "fixed" S/N condition in which the level of a multi-talker



(m)

Loudspeaker-to-Listener Distance

Figure 4. Loudspeaker-to-chair arrangement for five distances.

noise was adjusted to maintain a constant S/N at each distance.

Varied S/N

The A-weighted ambient noise level of the lecture hall was 45 dB. Thus, the S/N ratio between the level of the speech and the ambient noise was +32 dB at 1 m. Since the level of the speech decreased with distance, so did the S/N. The S/N was +28 dB at 2 m, +25 dB at 4 m, +24.5 dB at 8 m, and +23 dB at 15 m. These values appear in Table 2.

Fixed S/N

The multi-talker babble from the SPIN test was played through the other loudspeaker. The A-weighted level of the babble was measured at each of the distances with a precision sound level meter (Bruel & Kjaer, Model No. 2203) positioned on the slow meter setting with the 1/2 inch condenser microphone (Bruel & Kjaer, Model No. 8033) placed at the location of the subject's right ear.

The A-weighted level of the noise was to adjusted to 62 dB at 1 m. Thus, at 1 m, the S/N between the A-weighted level of the speech and the multi-talker babble was +15 dB. The levels of the babble were 58 dB at 2 m, 55 dB at 4 m, 54.5 dB at 8 m, and 53 dB at 15 m. The level of the babble decreased proportionately to the speech level with

Table 2

A-Weighted Levels of Speech, S/N Conditions, and Multi-Talker Babble (in parenthesis) in Decibels as a Function of Distance (in m) from the Loudspeaker

Distance (m)	Speech Level (dB)	S/N Conditions (dB)	
		Fixed	Varied
1	77.0	+15 (62.0)	+32.0
2	73.0	+15 (58.0)	+28.0
4	70.0	+15 (55.0)	+25.0
8	69.5	+15 (54.5)	+24.5
15	68.0	+15 (53.0)	+23.0

distance. Thus, a +15 dB S/N was maintained at each distance. Those values appear along with the A-weighted speech levels measured at each of the five distances on Table 2.

The +15 dB S/N was selected for several reasons. First, +15 dB S/N is within the range of minimum levels recommended for rooms used by the hearing-impaired (Crum & Matkin, 1976; Finitzo-Hieber & Tillman, 1978; Gengel, 1971; Sanders, 1965). Second, Pearsons et al. (1977) reported that teachers try to maintain a +15 dB S/N between the level of their voice and the ambient noise of the classroom. Third, Danhauer, Doyle, and Lucks (1985) advised that the NST was so difficult that the addition of background noise may make the test too difficult even for normal-hearing listeners. Considering that the study involved hearing-impaired listeners and reverberation, +15 dB S/N was selected to provide a compromise between "realistic" listening conditions, difficulty of the NST, and the limited auditory capabilities of the subjects.

Procedures

Subjects were tested individually without hearing aids within the lecture hall. All subjects read the same instructions which appear in Appendix F. They were reminded

that they would be presented with a speech test of nonsense (meaningless) syllables through a loudspeaker while seated in one of five chairs at varying distances from the sound source. They were asked to verbally repeat each consonant and vowel of the test item and were encouraged to guess if they were not sure what they heard. Subjects were played three practice items from NST List B. Subjects were told that, from time to time, they would have noise played through the other loudspeaker along with the nonsense syllables.

Each subject received a randomized presentation of NST List A at each of the five distances in both noise conditions. The order of distances in both noise conditions in which subjects were tested was counterbalanced across subjects. Edgerton, Danhauer, and Rizzo (1981) found no practice effects for multiple presentations for NST List A. Therefore, no practice effects were expected in the present experiment. Percent of correct identification of both vowels and consonants were obtained for each distance in both noise conditions. The raw data for each subject at each distance in both noise conditions appear in Appendix G.

An experimenter trained in phonetic transcription sat 2 m from and perpendicular to each subject and phonemically transcribed each subjects' responses. A

reliability judge, also trained in phonetic transcription, independently transcribed the responses of a randomly selected subject during experimental testing. Inter-judge reliability was 96% using the following formula (Agreements/(Agreement + Disagreements)) x 100. The inter-judge reliability was determined to be adequate for the purposes of the study.

CHAPTER IV

RESULTS

Reliability

Intrasubject Reliability

Three subjects, two normal-hearing (No. 1 and 3) and one hearing-impaired (No. 16) were retested in three randomly selected experimental conditions two to three weeks after initial testing. Percent of intrasubject agreement between responses in the test and retest conditions was calculated.

Each subjects' initial test responses were compared with retest responses. Each consonant and each vowel on the test was compared for exact agreement for test and retest conditions. The test items were considered "agreements" if the phonemes were either correct or incorrect for both test and retest conditions, but as "disagreements" if a phoneme, for example, was correctly identified for the test, but then missed in the retest condition. For example, if a listener responded "/pitI/" for "/pitI/" for the test condition, but "/bitI/" for "/piti/" in the retest condition, then there would be three

agreements and one disagreement between test and retest conditions. Using the formula (Agreements/(Agreements + Disagreements)) x 100, percent of intrasubject agreement was calculated for each condition.

Table 3 displays the subjects, the conditions, and the percent of intrasubject agreement. For the three subjects, Numbers 1, 4, and 16, overall intrasubject agreement was 77.3%, 77.3%, and 72.6%, respectively. Percent of intrasubject agreement ranged between 68% and 92%. The overall mean percent of intrasubject reliability was 75.7%.

At first glance, 75.7% of test-retest intrasubject agreement may seem only "fair". The overall agreement suggested the subjects had the same items correct or incorrect 76% of the time. However, the phoneme-by-phoneme check is a very stringent measure. For example, a 100% test-retest agreement would indicate that subjects would correctly or incorrectly identify the same phonemes each time they took the test. A certain degree of variability in subjects' response patterns was expected. The agreements were similar for the different distances, so the farthest distance (i.e., 15 m) did not produce less agreement than distances nearer the source. The hearing-impaired subject had lower (i.e., 4.7%) agreement scores than did the normal-hearing subjects. Overall, it was assumed that the

Table 3

Percent (%) of Intrasubject Agreement for Three Subjects (No. 1, 4, and 16) in Three Test Conditions

Subject Number	Condition Retested	% Agreement	Overall % Agreement
1	1 m (Varied S/N)	92	
	4 m (Fixed S/N)	72	77.3
	15 m (Varied S/N)	68	
4	1 m (Fixed S/N)	70	
	2 m (Varied S/N)	82	77.3
	4 m (Varied S/N)	80	
16	1 m (Fixed S/N)	70	
	2 m (Varied S/N)	72	72.6
	15 m (Varied S/N)	76	
		M = 75.7	M = 75.7

intrasubject agreement was within acceptable limits for the purposes of this study.

Results

Consonant and vowel data were each submitted to a separate Three-Way 2 x 5 x 2 Analysis of Variance (i.e., two listener groups--normal and hearing-impaired, five distances--1, 2, 4, 8, and 15 m, and 2 two S/N conditions--varied and fixed) with one between factor (i.e., groups) and two within factors (i.e., distances and S/N conditions) (Lindquist, 1953; Winer, 1984; Bruning & Kintz, 1987) to test the experimental questions. For reporting the data, the symbol "M" will be used for the mean scores. Data for nonsignificant statistical tests appear in Appendix H.

Consonant Identification

Table 4 illustrates the ANOVA Summary Table for the statistical analyses completed on the consonant data.

Experimental Question 1

Is there a significant difference between consonant identification scores for adults with normal and high frequency hearing loss?

Table 4

Summary Table for 3-Way 2 x 5 x 2 ANOVA for Repeated Measures on Two Factors-Consonant Scores

Total	SS	df	ms	F	p <
	91,750.0	239	-	-	
Between subjects	78,824.0	23	-	-	
Groups	53,103.7	1	53,103.7	45.42	0.0001
Error	25,720.2	22	1,169.1	-	-
Within subjects	12,926.0	216			
S/N	4,250.4	1	4,250.4	140.3	0.0001
Distance	2,715.9	4	679.0	24.9	0.0001
GxN	138.0	1	138.0	4.5	0.05
GxD	105.3	4	26.3	.96	NS
NxD	41.6	4	10.4	.36	NS
GxNxD	76.6	4	19.1	.67	NS
Error (Noise/GxN)	667.2	22	30.3	-	-
Error (Dist./GxD)	2,402.8	88	27.3	-	-
Error (NxD/GxNxD)	2,528.2	88	28.7	-	-

Results

A significant difference ($F(1,22) = 45.42$; $p < 0.0001$) was found for consonant identification scores for normal and hearing-impaired listeners. The mean score for normal--hearing listeners (M, 79.0%) was significantly higher (i.e., +29.7%) than that of the hearing-impaired (M,49.3%). Figure 5 shows the mean consonant identification scores and the standard deviations for both listener groups.

Experimental Question 2

Is there a significant difference among consonant identification scores obtained at the loudspeaker-to-listener distances of 1, 2, 4, 8, or 15 m?

Results

A significant difference ($F(4,88) = 24.9$; $p < 0.0001$) was found among consonant identification scores obtained at the five distances. Mean consonant identification scores and standard deviations are listed in Table 5 and are displayed in Figure 6. Mean consonant identification scores were: 68.8% at 1 m, 67.0% at 2 m, 63.9% at 4 m, 61.2% at 8 m, and 59.9% at 15 m. Duncan's New Multiple Range post-hoc test (Duncan, 1955) indicated the following significant differences (i.e., $p < .05$): 1 m vs. 4 m; 1 m vs. 8 m; 1 m vs. 15 m; 2 m vs. 8 m; 2 m vs. 15 m. The

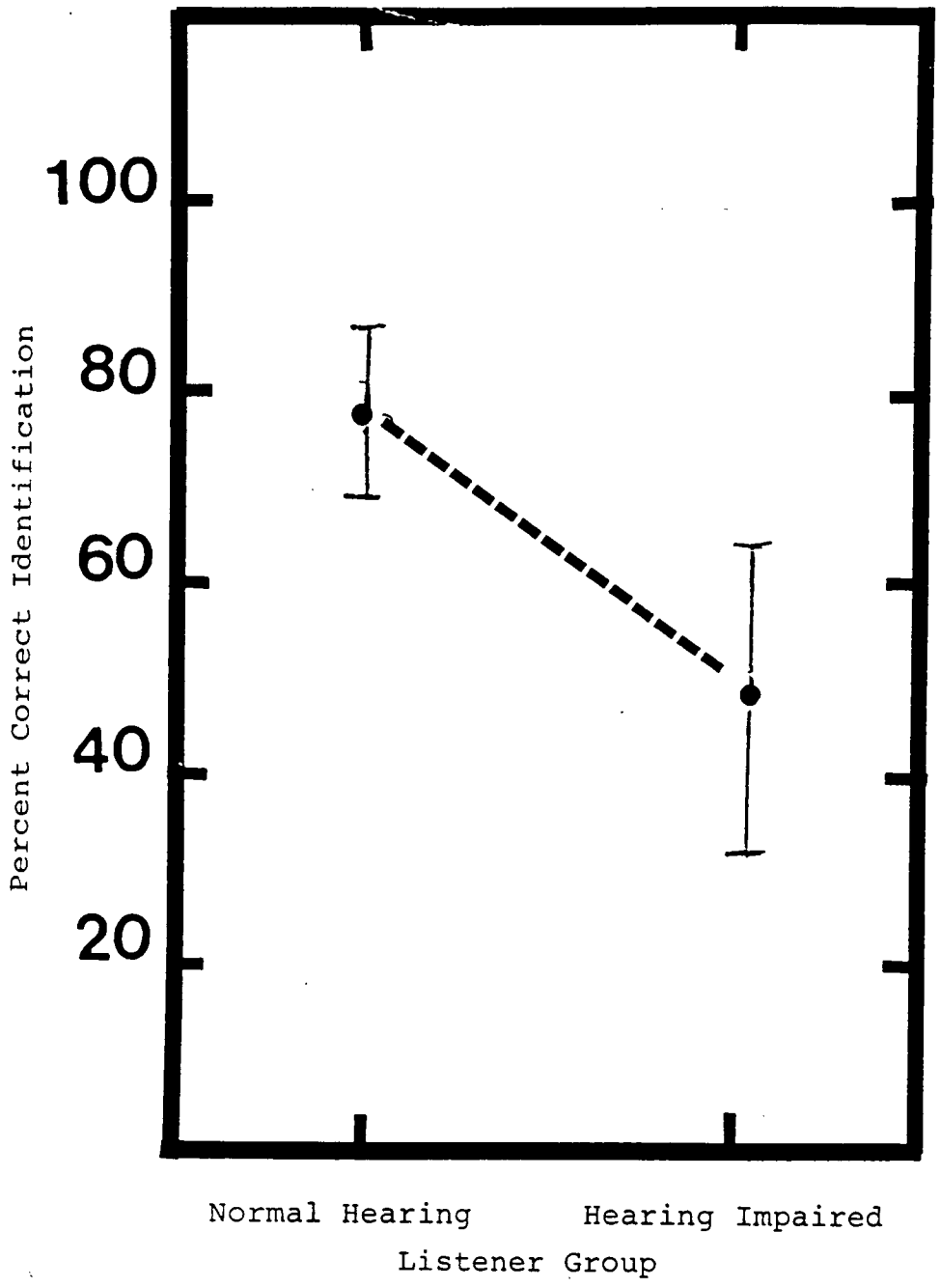


Figure 5. Mean consonant identification scores and standard deviations for normal-hearing and hearing-impaired adults.

Table 5

Mean (M) Consonant Identification Scores and Standard Deviations (SD), in Percent, for Listeners at Five Distances

	Distances (m)				
	1	2	4	8	15
M =	68.8	67.0	63.9	61.2	59.9
SD =	18.3	18.8	19.1	20.1	19.1

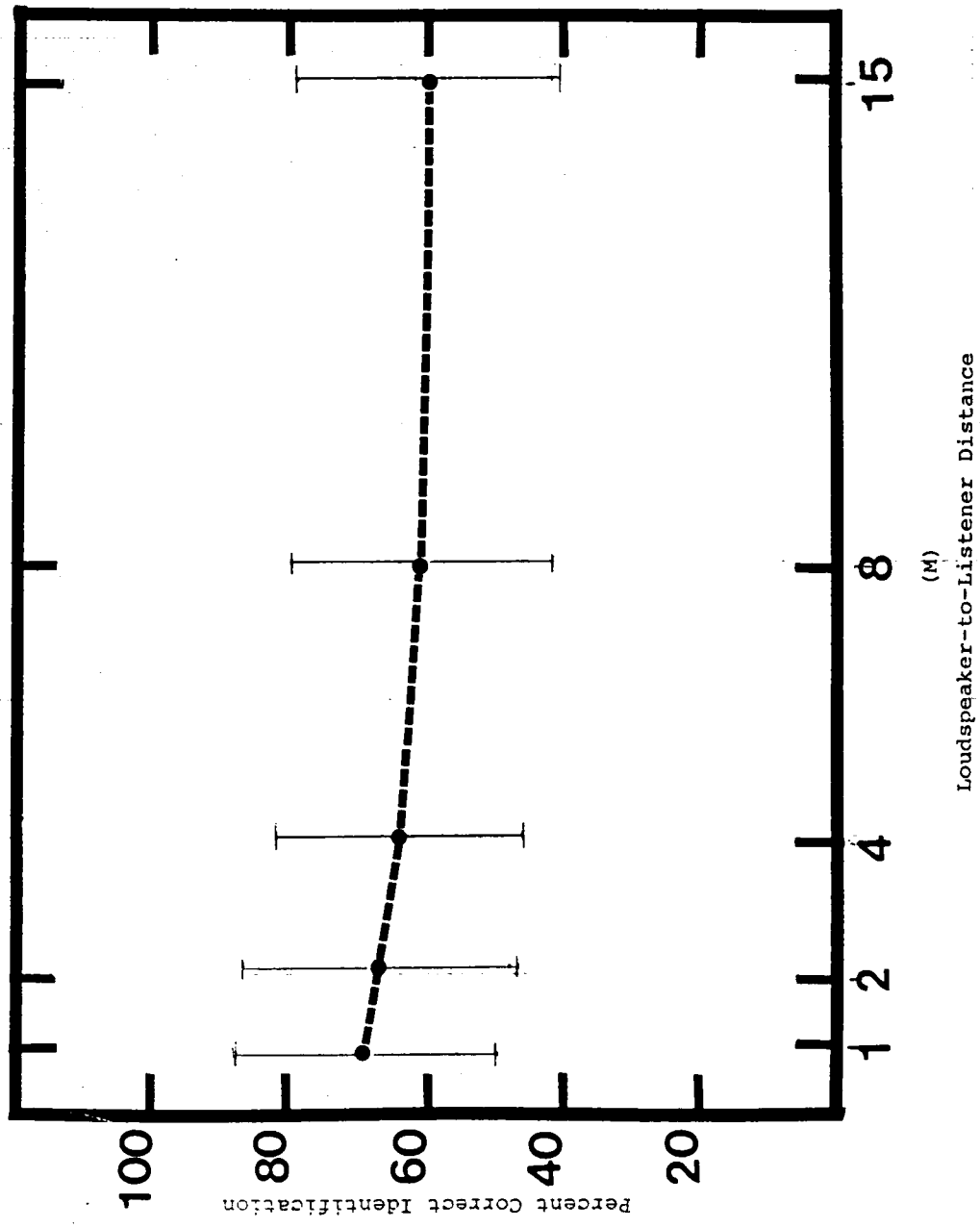


Figure 6. Mean consonant identification scores for listeners at five loudspeaker-to-listener distances.

scores obtained inside (i.e., 1 and 2 m) the critical distance were different from scores outside (i.e., 8 and 15 m). However, scores at 4 m, which is considered to be outside the critical distance, were not significantly different from scores at 2 m, which was inside the critical distance. None of the distances within nor those outside the critical distance were significantly different from each other. For example, the scores for 1 m were not different from 2 m, and 8 m was not different from 15 m.

Experimental Question 3

Is there a significant difference between consonant identification scores obtained in the varied (i.e., +32 dB to +23 dB) vs. fixed (i.e., +15 dB) S/N conditions?

Results

A significant difference ($F(1,22) = 140.3$; $p < 0.0001$) was found between consonant identification scores obtained in the fixed and varied S/N conditions. The mean consonant score (M, 68.4%) for the varied condition was significantly higher (i.e., + 8.5%) than that for the fixed condition (M, 59.9%). Figure 7 depicts the means for these two conditions and standard deviations.

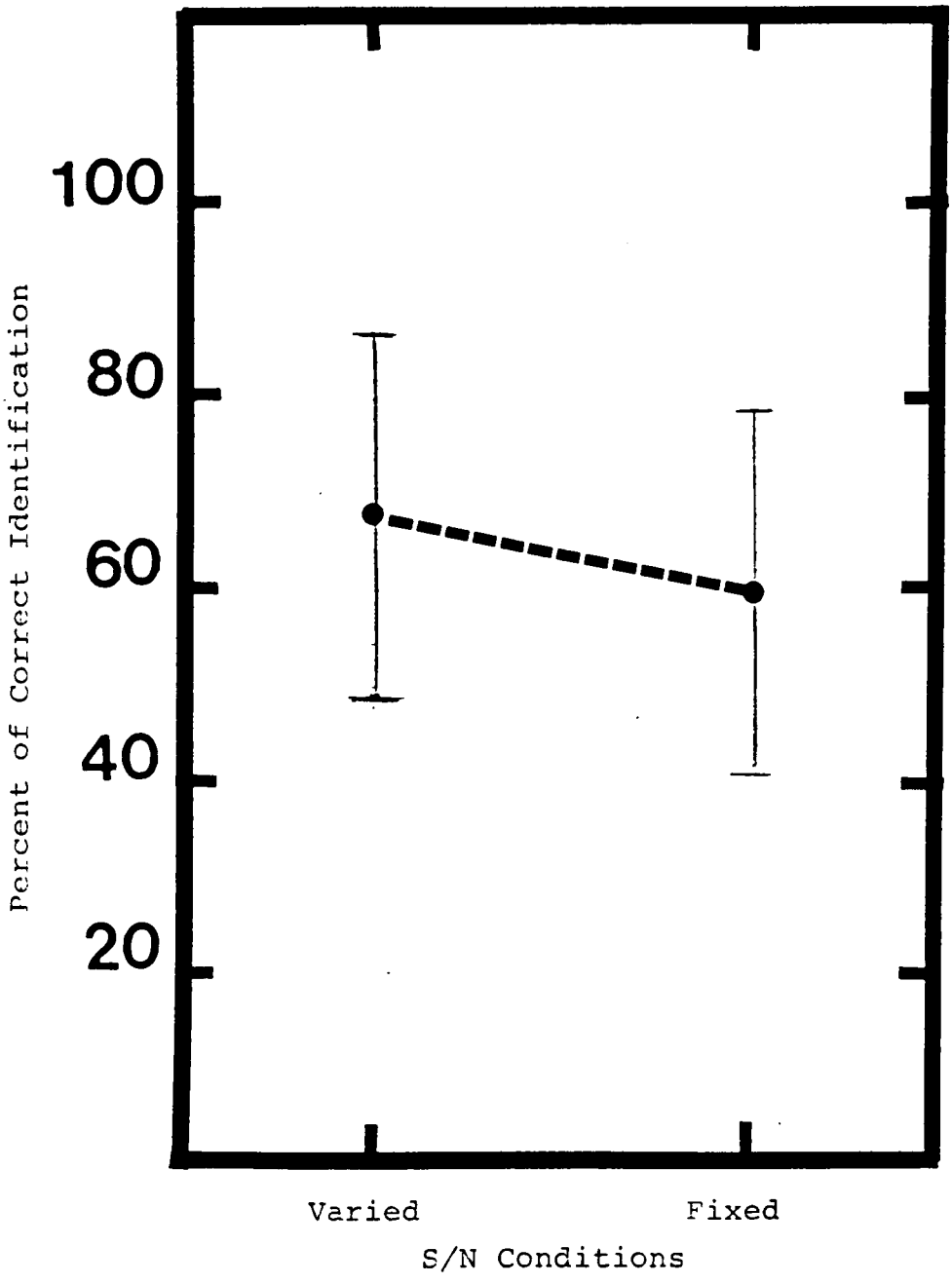


Figure 7. Mean consonant identification scores and standard deviations for the varied and fixed S/N conditions.

Experimental Question 4

Is there a significant interaction for consonant identification scores between:

a. Listener groups and distances

Results. The listener groups and distances interaction (G x D) was not significant ($F(1,88) = 0.96$; $p = 0.43$). The mean consonant identification scores and standard deviations are listed in Table H-1 in Appendix H for both groups at each of the five distances.

b. Listener groups and S/N conditions

Results. A significant interaction ($F(1,22) = 4.5$; $p < 0.05$) was found between the listener groups and S/N conditions. The difference in mean consonant identification scores between the varied and fixed condition was greater [i.e., 84.0% (varied) - 74.1% (fixed) = 9.9%] for the normal-hearing listeners than for the hearing-impaired listeners [i.e., 52.7% (varied) - 45.8% (fixed) = 6.9%]. The mean consonant identification scores and the standard deviations are depicted in Figure 8 for both groups in both S/N conditions.

c. Distances and S/N conditions

Results. The distances and S/N conditions interaction (N x D) was not significant ($F(4,88) = 0.36$; $p = 0.16$). The mean consonant identification scores and standard deviations are listed in Table H-2 in Appendix H for both S/N conditions at each of the distances.

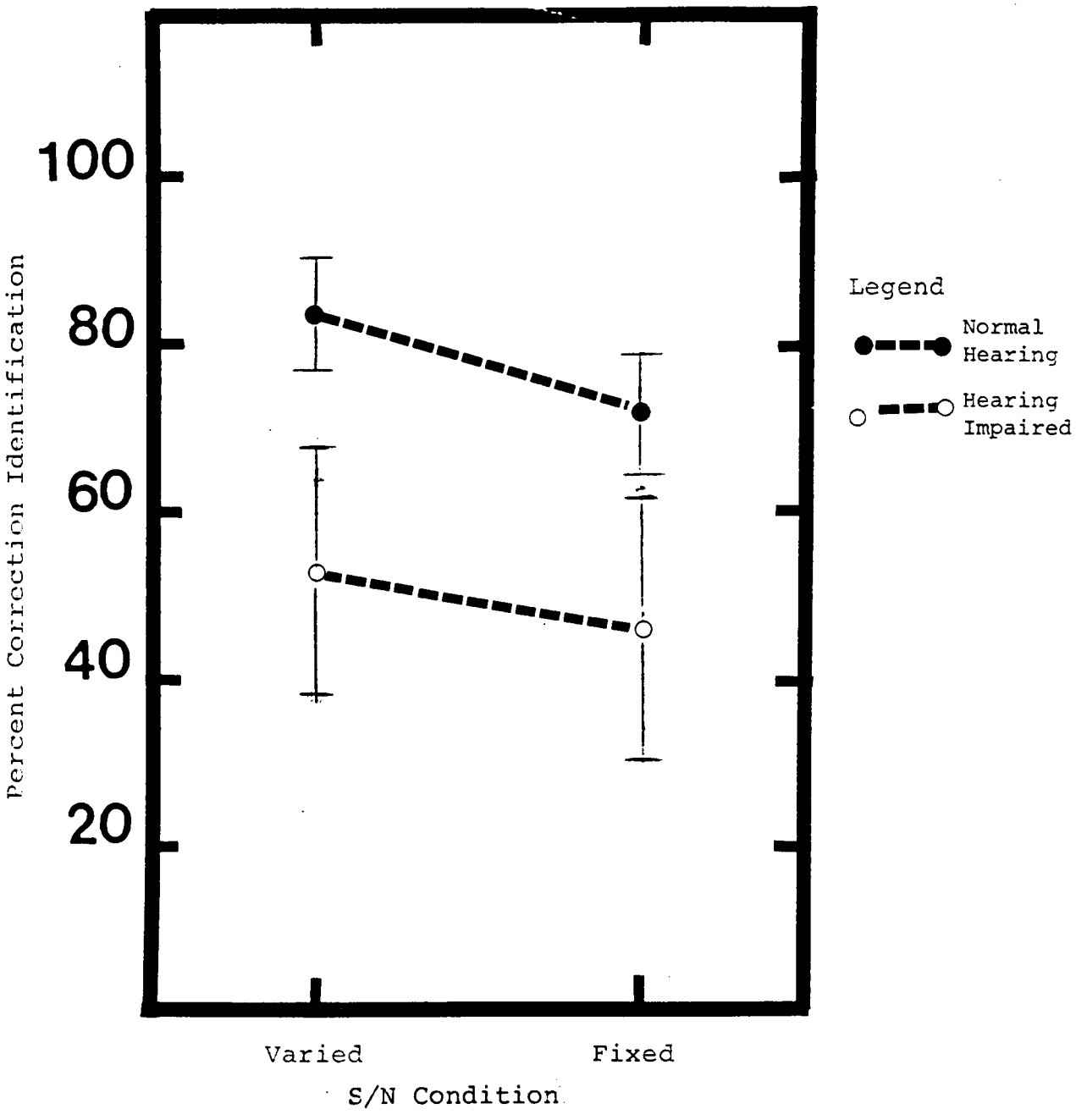


Figure 8. Mean consonant identification scores and standard deviations for normal-hearing and hearing-impaired listeners in two S/N conditions.

d. Listener groups, distances, and S/N conditions

Results. The listener groups, distances, and S/N conditions interaction (G x D x N) was not significant ($F(4,88) = 0.67$; $p = 0.38$). The mean consonant identification scores and standard deviations are listed in Table H-3 in Appendix H for both listener groups, in both S/N conditions, at each of the distances.

Vowel Identification

Table 6 illustrates the ANOVA Summary Table for the statistical analyses completed on the vowel data.

Experimental Question 1

Is there a significant difference between vowel identification scores for adults with normal and high frequency hearing loss?

Results

A significant difference ($F(1,22) = 14.82$; $p < 0.02$) was found for vowel identification scores for normal and hearing-impaired listeners. The mean score for normal-hearing listeners (M, 89.9%) was significantly higher (i.e., +11.4%) than that of the hearing-impaired (M, 78.5%). Figure 9 shows the mean vowel identification scores and the standard deviations for both listener groups.

Table 6

Summary Table for 3-Way 2 x 5 x 2 ANOVA for Repeated Measures on Two Factors-Vowel Scores

Source	SS	df	ms	F	p <
Total	23,164.7	239	-	-	
Between subjects	19,145.7	23	-	-	-
Groups	7,706.6	1	7,706.6	14.82	0.002
Error	11,439.1	22	519.9	-	-
Within subjects	4,019.0	216			
S/N	224.2	1	224.2	20.37	0.0004
Distance	250.1	4	62.5	3.28	0.02
GxN	29.4	1	29.4	2.66	NS
GxD	108.4	4	27.1	1.42	NS
NxD	9.7	4	2.4	0.15	NS
GxNxD	89.4	4	22.3	1.41	NS
Error (Noise/GxN)	242.1	22	11.0	-	-
Error (Dist./GxD)	1,672.6	88	19.0	-	-
Error (NxD/GxNxD)	1,393.1	88	15.8	-	-

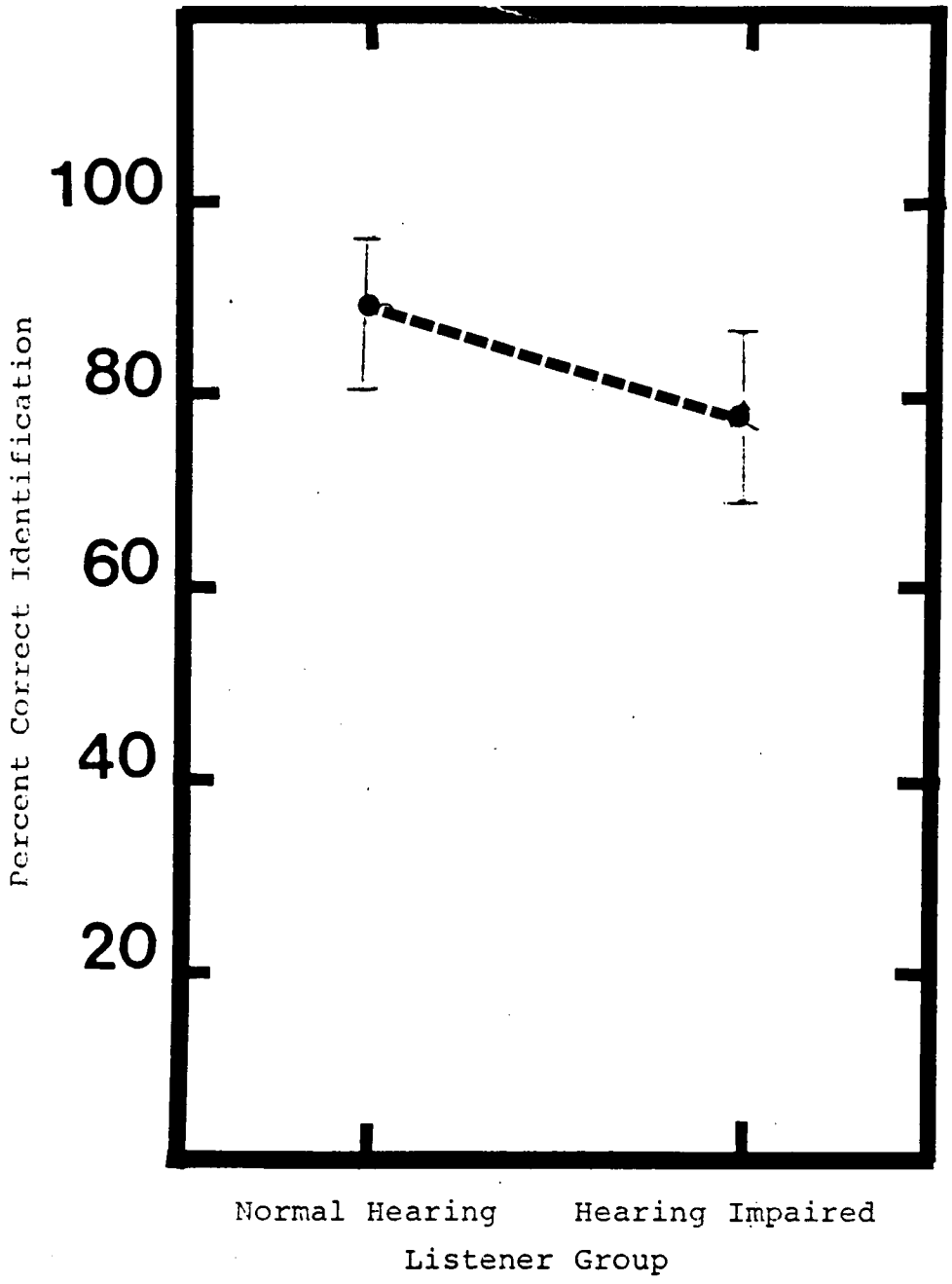


Figure 9. Mean vowel identification scores and standard deviations for normal-hearing and hearing-impaired adults.

Experimental Question 2

Is there a significant difference among vowel identification scores obtained at the loudspeaker-to-distances of 1, 2, 4, 8, and 15 m?

Results

A significant difference ($F(4,88) = 3.28$ $p < 0.02$) was found among vowel identification scores obtained at the five distances. Mean vowel identification scores and standard deviations are listed in Table 7 and are displayed in Figure 10. Mean vowel identification scores were: 85.6% at 1 m; 84.9% at 2 m; 83.4% at 4 m; 84.2% at 8 m; and 82.8% at 15 m. Duncan's New Range Multiple post-hoc test (Duncan, 1955) indicated a significant difference (i.e., $p < 0.05$) only between mean vowel identification scores obtained at 1 (M, 85.6%) and 15 m (M, 82.8%).

Experimental Question 3

Is there a significant difference between vowel identification scores obtained in the varied (i.e., +32 dB to +23 dB) vs. fixed (i.e., +15 dB) S/N conditions?

Results

A significant difference ($F(1,22) = 20.37$; $p < 0.0004$) was found between vowel identification scores obtained in

Table 7

Mean (M) Vowel Identification Scores and Standard Deviations (SD), in Percent, for Listeners at Five Distances

	Distances (m)				
	1	2	4	8	15
M =	85.6	84.9	83.4	84.2	82.8
SD =	8.1	9.5	9.8	9.9	10.2

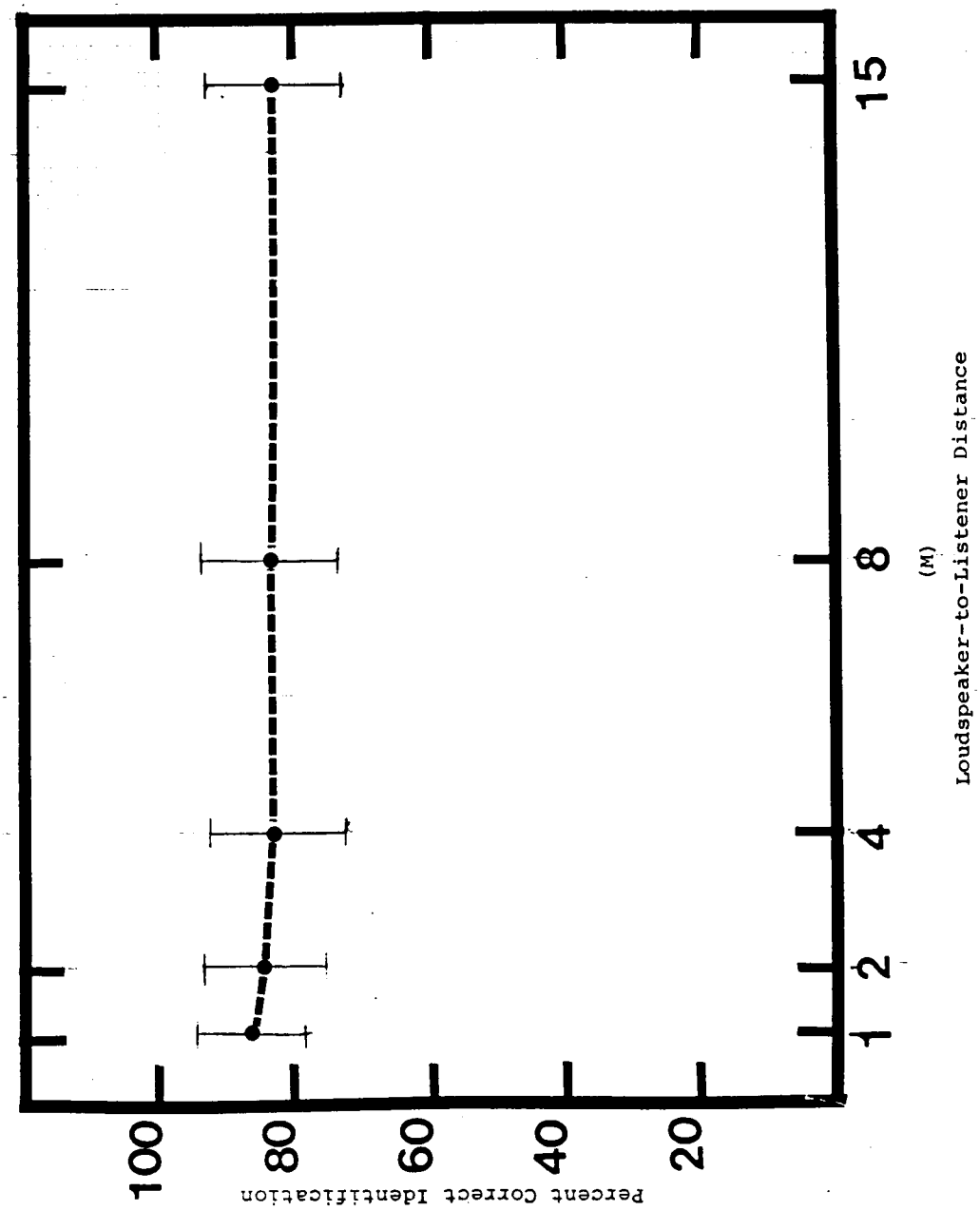


Figure 10. Mean vowel identification scores and standard deviations for listeners at five loudspeaker-to-listener distances.

the varied and fixed S/N condition. The mean vowel score (M, 85.2%) for the varied condition was significantly higher (i.e., +2.0%) than that for the fixed condition (M, 83.2%) Figure 11 depicts the means for these two conditions and standard deviations.

Experimental Question 4

Is there a significant interaction for vowel identification scores between:

a. Listener groups and distances

Results. The listener groups and distances interaction (G x D) was not significant ($F(1,88) = 1.42$; $p = 0.23$). The mean vowel identification scores and standard deviations are listed in Table H-4 in Appendix H for both groups at each of the distances.

b. Listener groups and S/N conditions

Results. The listener groups and S/N conditions interaction (G x N) was not significant ($F(1,22) = 2.66$; $p = .11$). The mean vowel identification scores and standard deviations are listed in Table H-5 in Appendix H for both listener groups in both S/N conditions..

c. Distances and S/N conditions

Results. The distances and S/N conditions interaction (D x N) was not significant ($F(1,88) = 0.15$; $p > 0.41$). The mean vowel identification scores and standard deviations are

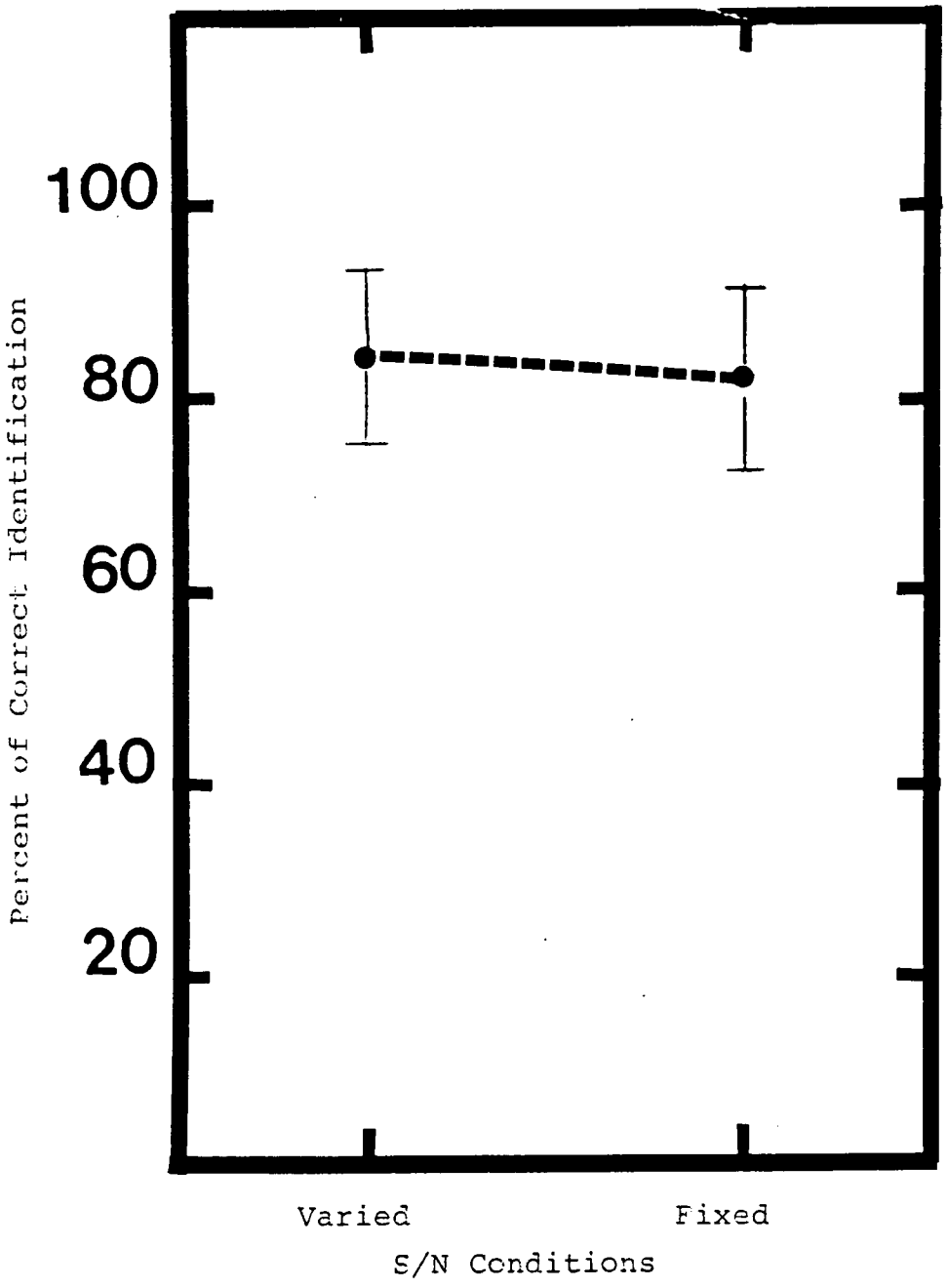


Figure 11. Mean vowel identification scores and standard deviations for the varied and fixed S/N conditions.

listed in Table H-6 in Appendix H for both S/N conditions at each of the distances.

d. Groups, distances, and S/N conditions

Results. The listener groups, distances, and S/N conditions interaction (G x D x N) was not significant ($F(4,88) = 1.41$; $p = 0.23$). The mean vowel identification scores and standard deviations are listed in Table H-7 in Appendix H for both listener groups, in both S/N conditions at each of the distances.

CHAPTER V

DISCUSSION

The findings of this study are discussed in relation to listener group differences, loudspeaker-to-listener distances, speech-to-noise ratio (i.e., S/N) conditions, and practical applications.

Normal Hearing and Hearing-Impaired Listeners

Consonant and vowel identification scores were significantly better (i.e., +29.7% and +11.4%, respectively) for the adults with normal hearing than for adults with high frequency hearing loss. These results are discussed in relation to previous research on the NST, differences in hearing threshold levels, and differences in age between the two groups.

Previous Studies Utilizing the NST

Edgerton and Danhauer (1979) and Danhauer, Hiller, and Edgerton (1982) using the NST reported that consonant and vowel scores were significantly better for adults with normal-hearing than for adults with sensori-neural hearing losses of varying degree and configuration. In those two

studies, scores were obtained at various sensation levels (re: SRT) under earphones in an audiometric test booth. In the current study, scores were obtained with reverberation, noise, and loudspeaker-to-listener distance as factors. It appears that the NST is sensitive to a variety of hearing losses in both quiet and more realistic testing conditions.

Differences in Hearing Threshold Levels

Consonant Identification Scores

In the current study, the hearing-impaired adults had had mean pure tone detection thresholds within normal limits (i.e., HTL less than 25 dB) for frequencies of 1000 Hz and below, but had a mean thresholds (i.e., hearing loss) of 36.9, 55.6, and 63.2 dB at 2000, 4000, and 8000 Hz, respectively. Average SRTs were 17.3 dB compared with 0.42 dB for the adults with normal-hearing (See Table 1). In quiet audiometric testing, the mean word recognition score was 86.5% (Median was 96%) for the hearing-impaired adults and it was 99.5% (Median was 100%) for the normal-hearing adults. The between-group mean difference of 13.0% for word recognition scores in quiet was much smaller than the 29.7% difference for the consonant identification scores in the current study.

For individual subjects' data (See Appendix A), normal-hearing subject, Number 4, had SRTs of 0 and 5 dB at the right and left ear, respectively, with 100% word recognition scores, bilaterally. Hearing-impaired subject, Number 18, had an SRTs of 10 and 15 dB, and word recognition scores of 92% and 96% at the right and left ears, respectively. For the experimental conditions (See Appendix G), the normal-hearing subject (i.e., No. 4) obtained a 29.2% higher mean consonant score (i.e., obtained by averaging scores at all five distances in both S/N conditions) of 75.2% compared to 46% for the hearing-impaired subject (i.e., No. 18). Thus, an adult with high frequency hearing loss who exhibited normal low frequency hearing sensitivity, normal SRTs, and good speech recognition scores in quiet was affected more by reverberation, noise, and loudspeaker-to-listener distance than a normal-hearing listener.

Vowel Identification Scores

Nabelek (1988) investigated the effects of hearing loss and age on listeners' identification of vowels in quiet, reverberation, and noise. She reported a strong significant positive correlation between degree of hearing loss, particularly at 4 k Hz, and the number of identification errors for vowels masked by multi-talker babble or presented in a reverberation time of 1.2 s. Her finding is

consistent with the results of the present study since the adults with high frequency hearing loss had difficulty identifying vowels in reverberation and noise (i.e., M, 78.5%), whereas the normal hearing listeners had a higher mean score (M, 89.9%) in those conditions.

Leek, Dorman, and Summerfield (1987) reported that hearing-impaired listeners who exhibit the broadening of the auditory filters in the peripheral auditory system with hearing loss (e.g., Glasberg & Moore, 1986) may need as much as a 6 to 8 dB peak-to-trough difference for vowel identification far exceeding the 2 dB difference needed by normal-hearing listeners. The 6 to 8 dB peak-to-trough difference may not be present in vowels degraded by noise and reverberation making their identification difficult for hearing-impaired listeners. Further, adults with high frequency hearing loss may have difficulty identifying vowels with high frequency formants that are below their thresholds of detection (Nabelek, 1988). Thus, it appears that high frequency hearing loss may have contributed to the difference in vowel identification scores between the two listener groups.

Differences in Age

The adults with high frequency hearing loss had a mean age of 62 years (range 44 to 71 years), as compared to the

35.4 years (range 22 to 61) for the normal-hearing adults. This 26.6 year difference in the ages of the groups possibly contributed to the hearing-impaired adults having significantly poorer consonant and vowel identification scores than the normal-hearing listeners.

Consonant Identification Scores

For individual subjects, two normal-hearing subjects, Numbers 2 and 3, were 23 and 44 years of age with mean consonant scores of 81.6% and 72.2%, respectively (See Appendix A and G). Thus, the younger normal-hearing subject had a 9.4% higher mean score than the older normal-hearing subject. Also, normal-hearing subject, Number 5, who was 25 achieved among the highest consonant scores in the group. On the other hand, subject Number 6, who was only 23 years of age, had scores similar to subjects who were between 30 and 40 years of age. Although there were several examples where higher consonant identification scores were achieved by the younger subjects, this trend was not consistent in every situation.

The effects of age on speech recognition have been well documented in the literature. For example, Nabelek and Robinson (1982) compared the monaural and binaural speech recognition abilities of listeners of various ages in 0.4, 0.8, and 1.2 s of reverberation time. They found that young

adult listeners (M, 27 years) had significantly higher scores in reverberation than either children (M, 10 years), or elderly adults (M, 65 to 72 years). Nabelek and Robinson's (1982) results agree with other studies that reported lower speech recognition scores as age increased in realistic listening conditions. These conditions included reverberation (Bergman, Blumenfield, Cascardo, Dash, Levitt, & Marguiles, 1976; Duquesnoy & Plomp, 1980), traffic noise (Mayer, Levitt, & Bergman, 1976), rapid presentation of speech, filtering, competing speakers (Bergman et al., 1976), and time-compressed speech (Jerger, 1973).

Vowel Identification Scores

Nabelek (1988) reported a significant positive correlation between subjects' age and the number of identification errors for vowels masked by multi-talker babble or presented in a reverberation time of 1.2 s. Elderly hearing-impaired listeners may have difficulty identifying vowels in these conditions because auditory filters in the peripheral auditory mechanism also broaden with age (Patterson, Nimmo-Smith, Weber, & Milroy, 1982; Tyler, Hall, Glasberg, Moore, & Patterson, 1984). Thus, in the current study, aging may have contributed to the difference in vowel identification scores between the two listener groups.

Differences in Performance Due to Loudspeaker-to-Listener Distance

Consonant Identification Scores

Generally, consonant identification scores were significantly better within the critical distance of the lecture hall, than outside the critical distance. The only exception to this finding was that scores at 2 m (i.e., inside the critical distance) were not significantly different from scores obtained at 4 (i.e., outside the critical distance). Thus, there was no clear separation between scores within and outside the critical distance of 3.3 m. The 4 m distance appeared to have been a "transition area" from inside to outside the critical distance. Nevertheless, scores did not significantly decrease as loudspeaker-to-listener distance increased in the reverberant field.

Significantly better consonant scores within vs. outside the critical distance may have been affected by the greater speech levels within the critical distance. The A-weighted speech level was 77 dB at 1 m and it was was 73 dB at 2 m. Outside the critical distance, speech levels were 70, 69.5, and 68 dB at 4, 8, and 15 m, respectively. It appears that the higher levels within the critical distance may have contributed to better consonant

identification scores. However, the lowest level of 68 dB at 15 m should have been sufficient for eliciting maximum performance for the subjects used in this study. Therefore, the decrease in the relative level of the direct to reflected energy of the speech with loudspeaker-to-listener distance probably had a greater effect on performance than the overall A-weighted level of the speech.

Within the critical distance, both the direct and reflected energy of the speech signal were present (See Figure 1). For the proposed model, the relative level of the direct sound energy, represented by line "a", decreases as a function of distance from the loudspeaker. The level of the reflected sound, represented by line "b", is the same throughout the lecture hall. The total speech energy in the lecture hall is the sum of the direct and reflected sounds and is represented by curve "c".

The ratio of direct to reflected energy decreases until lines "a" and "b" intersect at point "d", the critical distance, at which the direct and reflected energy are equal. Outside the critical distance, the energy of the direct sound is negligible and the reflected sound predominates. When the reverberation time of a room is sufficient to degrade speech recognition, such as 1.5 s for the lecture hall in this study, performance decreases as loudspeaker-to-listener increases until the critical

distance. Outside of the critical distance, only reflected energy is available and the full effect of masking by reverberation occurs and remains constant (Beranek, 1984; Nabelek & Nabelek, 1985; Peutz, 1971). Therefore, outside the critical distance consonant scores did not decrease with increasing loudspeaker-to-listener in the reverberant field.

Listener Groups and Distances

The nonsignificant interaction between listener groups and distances indicated that adults with normal-hearing and adults with a high frequency hearing loss did not significantly differ in their trends of performance as a function of loudspeaker-to-listener distance. This trend in performance for normal-hearing listeners is consistent with previous investigations (Crum & Tillman, 1973; Johnson et al., 1988; Peutz, 1971). Similarly, the results for hearing-impaired listeners is consistent with previous research that reported significantly higher scores nearer the source than at distances farther away (Borrild, 1986; Fisher, 1964; Miller & Niemoeller, 1967; Ross & Giolas, 1971; Ross et al., 1973; Watson, 1964). However, most of the aforementioned studies did not report the volume and the reverberation times of the room(s) making it impossible to calculate the respective critical distances. Thus, the current study was the first to demonstrate that the

consonant scores of adults with normal-hearing and adults with a high frequency hearing loss were affected by loudspeaker-to-listener distance in a similar way within and outside the critical distance of a lecture hall.

Vowel Identification Scores

Vowel identification scores were 2.8% better at 1 m (M, 85.6%) than at 15 m (M, 82.8%). Other than these extreme distances, the vowel scores were not significantly affected by distance. If listeners' vowel scores had been significantly affected by reverberation, perhaps performance would have followed a pattern similar to consonants. However, listeners' vowel identification abilities were affected by some additional factors since scores were not 100%. This point will be discussed later.

Listener Groups and Distances

The nonsignificant interaction between listener groups and distances indicated that the groups did not significantly differ in their trends of performance as a function of loudspeaker-to-listener distance. That is, neither the vowel scores of adults with normal hearing or adults with high frequency hearing loss were affected by distance. Johnson et al. (1988) reported that vowel scores of normal-hearing listeners were not affected by distance.

Testing occurred in the same lecture hall used in the present study before it was remodeled. However, at that time, the reverberation time of the hall was 1.9 s and performance was only assessed at 1, 4, and 8 m.

The present study is the first to demonstrate that vowel scores of hearing-impaired listeners were unaffected by distance. It is interesting that their scores were significantly lower than that of normals, but followed the same trend in performance. It is unusual, for example, to have the same low vowel score both near and far away from the speech source. Hearing-impaired subject, Number 15, achieved a 72% vowel score at both 2 m and 15 m in the varied S/N condition. An error analysis of the subject's errors revealed similar errors for both the 2 m and 15 m distances (See Table I-1 in Appendix I). Thus, the errors could have been caused by subjects' perceptual preferences, due to such factors as dialect, rather than the experimental treatments. Nabelek (1988) reported that some subjects consistently make the same vowel identification errors regardless of the listening conditions. She referred to these as labelling errors which are particular to a listener and were not dependent on factors such as noise and reverberation.

Differences in Performance for the S/N Conditions

Consonant Identification Scores

Consonant identification scores were significantly better (i.e., +8.5%) in the varied (i.e., +32 dB to +23 dB) than in the fixed (i.e., +15 dB) S/N condition. The varied S/N condition was a more favorable listening situation than the fixed. The least favorable varied S/N was +23 dB at 15 m. However, it was 8 dB better than the +15 dB S/N of the fixed S/N condition. These differences were apparently responsible for the lower scores in the fixed condition. An additional factor was the difference in the spectra between the ambient noise of the lecture hall and the multi-talker babble. The multi-talker babble probably created more masking than the ambient noise of the lecture hall.

Young, Parker, and Carhart (1975) reported that use of multi-talker babble played forward resulted in poorer number recognition scores for normal-hearing listeners than did other maskers such as multi-talker "backward" babble and modulated noise. However, Danhauer, Doyle, and Lucks (1986) reported a contradictory finding in that better scores on the NST were obtained with multi-talker babble than with white noise and amplitude modulated white noise. Danhauer et al. (1986) explained that their subjects complained about the white noise and amplitude modulated white noise maskers

being very irritating and distracting. Thus, significantly higher scores were obtained with the less irritating multi-talker babble as compared to the white noise and amplitude modulated white noise. Danhauer and his colleagues are currently investigating the discrepancy between their results and those of Young et al. (1975).

Based on the analysis of the spectra of the NST, the ambient noise level, and the multi-talker babble, it seems that the greatest overlap was between the NST items and the multi-talker babble, especially above 1000 Hz. Thus, the multi-talker babble appeared to have a greater masking effect than the ambient noise level of the lecture hall. The levels and spectra of the NST, multi-talker babble, and ambient noise in the lecture hall are displayed in Appendix J.

The S/Ns of the varied and the fixed conditions were both within the recommended range of background noise (i.e., +15 to 20 dB) for rooms used by the hearing-impaired (Crum & Matkin, 1976; Finitzo-Hieber & Tillman, 1978; Gengel, 1971; Sanders, 1971). However, mean consonant identification scores of 68.4% and 59.9% were low for both the varied and the fixed S/N conditions, respectively. The A-weighted levels of the NST items were measured as syllables peaked on the sound level meter. The level of each syllable probably reflected the peak amplitude of the vowel rather

than the consonant. The spectrographic analyses on ten randomly selected NST items showed that the vowels had a mean peak amplitude that was 23 dB greater than the amplitude of the consonants. Thus, the overall +32 dB to +23 dB S/N would be +9 dB to 0 dB for consonants in the varied S/N condition; the overall +15 dB S/N would be -8 dB for consonants in the fixed S/N condition. The poorer S/N for consonants resulted in low consonant identification scores.

Listener Groups and S/N Conditions Interaction

The significant interaction between listener groups and S/N conditions indicated the normal-hearing and hearing-impaired adults significantly differed in the way which their scores changed from the varied to the fixed S/N condition. The scores of the normal-hearing listeners were significantly more affected (i.e., -9.9%) from the varied to the fixed S/N condition than the high frequency hearing loss group (i.e.-6.9%) (See Figure 8).

The consonant scores for the hearing-impaired adults reflected poor performance (M, 52.7%) in the varied S/N condition and, so the fixed condition resulted in only a marginal decrease in performance (M, 45.8%). However, for normal-hearing listeners, the difference between the two S/N conditions may have been between an "easy" listening

situation (M, 84.0%) and a very "difficult one" (M, 74.1%), respectively.

Vowel Identification Scores

Vowel identification scores were significantly higher (i.e., +2.0%) in the varied S/N condition (M, 85.2%) (i.e., +32 dB to +23 dB) than the fixed S/N condition (M, 83.2%) (i.e., +15 dB), but the mean difference was rather small and may not be a meaningful difference.

Practical Implications for Hearing-Impaired Listeners

Recommendations for Seating in Lecture Halls

The finding that the phoneme recognition scores of both the adults with normal-hearing and with high frequency hearing loss did not decrease as loudspeaker-to-listener distance increased in the reverberant field has practical applications with regard to seating. Audiologists usually recommend that hearing-impaired people sit as close to the speaker as possible. The results of the present study suggested that both normal and hearing-impaired listeners can benefit by moving closer to the sound source and within the critical distance. For an average size room, it is necessary to move within 3 m of the source (Nabelek & Nabelek, 1985). However, if the closest seat is outside of

the critical distance, moving closer would not help. This is especially true when the speech level and S/N are adequate for recognition throughout the room.

When listening to a live speaker in a room, moving closer to the speaker may help speech recognition because visual cues and concentration are improved. In a room, other sources of background noise (e.g., talking, foot shuffling, etc.) contributes to a reduced S/N especially when the speaker has a soft voice or is far away. In this case, moving closer to the speaker can be advantageous.

Recommendations for Assistive Listening Devices and Hearing Aids

Even though the hearing-impaired adults had a high frequency (i.e., above 2000 Hz) hearing loss, these subjects had normal hearing threshold levels (i.e., less than 25 dB) at 1000 Hz and below, normal SRTs, and good speech recognition scores. The hearing-impaired listeners performed much worse than the normal-hearing listeners in noise, reverberation, and at various loudspeaker-to-listener distances.

Some hearing-impaired listeners in this study could be considered as having "minimal hearing loss" as defined by Bess (1986). Those with minimal hearing loss are often considered borderline candidates for amplification yet may

experience difficulty in noise and/or reverberation. Sher and Owens (1974) reported that persons with high frequency hearing impairment usually scored between 90 to 100% on speech recognition tasks in quiet and nonreverberant conditions. These patients are surprised when an audiologist informs them that they have "normal" speech recognition and may not benefit from a hearing aid. This information conflicts with the difficulty they encounter in "real life" listening situations involving reverberation, noise, and distance (Sher & Owens, 1974). These patients may consider using assistive listening devices or hearing aids. Marked improvements in speech recognition of hearing-impaired listeners using assistive listening devices in classrooms has been recently documented in the literature (Nabelek, Donahue, & Letowski, 1986). Only 42% (i.e., 5 of 12) of the hearing-impaired adults used a hearing aid for their daily communication situations. It was not clear if the five hearing aid wearers would benefit from wearing their hearing aids in this study. It is possible that some of their scores would not have improved.

Recommendations for Auditory Training

Based on the results of this study, audiologists should not conclude that adults with high frequency hearing loss and good word recognition scores would not benefit from

using hearing aids. Speech audiometry should include speech recognition measures outside the test booth that include noise, reverberation, and distance from the speech source for a more comprehensive assessment of a patient's auditory ability. This has been recommended in the literature (Nabelek & Robinette, 1978), but this advice has not been heeded by most audiologists.

Finitzo-Hieber and Tillman (1978) reported speech contaminated by noise and reverberation is made even more unintelligible when filtered through a patient's hearing aid. If the patient has been identified as having speech recognition problems in reverberation, noise, and at distances from the source, the client should receive extensive auditory training prior to the placement of a hearing aid. This notion of "prehearing aid" treatment was developed at the SUVAG Speech and Hearing Center (Krapez, 1985) in Zagreb, Yugoslavia, and at the University of Tennessee at Knoxville (Asp & Guberina, 1981). Both programs use the Verbotonal Method of aural habilitation and rehabilitation. Prehearing aid treatment involves training a patient's auditory perception in a variety of listening conditions including unaided listening at considerable distances from a sound source. In therapy, a patient can be trained to improve their speech recognition in listening conditions resembling real life. If speech recognition is

improved prior to fitting a hearing aid, patients should be more successful in their use of amplification.

CHAPTER VI

CONCLUSIONS

Based on the results of this study. the following conclusions were formulated:

1. Vowel and consonant identification scores of the normal-hearing adults were significantly better than of the adults with a high frequency hearing loss.

2. Consonant scores were generally better within the critical distance than outside the critical distance, with no decrease in performance as loudspeaker-to-listener distance increased in the reverberant field.

3. Vowel scores were unaffected by distance except in the extreme conditions with scores at 1 m being significantly better than at 15 m.

4. Both consonant and vowel scores were significantly better in the varied than in the fixed S/N condition.

5. For both consonant and vowel scores, the Groups x Distances and S/N Conditions x Distances interactions were not significant suggesting similar trends in performance with distance for these factors.

6. Unless a listener moves to <u>within</u> the critical distance of a speech source, decreasing loudspeaker-to-

listener distance from one point to another in the reverberant field may not improve aural phoneme recognition.

Limitations of the Study

The following limitations should be considered in reading this study:

1. The disparity in age between the two listener groups made it difficult to attribute the differences in between-group performance solely to hearing threshold levels.

2. The acoustic conditions of each lecture hall are related to its geometric shape, volume, and properties of the materials on the floor, ceiling, and walls. Thus, these results cannot be generalized to all rooms.

3. The speech stimuli used in this study were nonsense syllables so it is difficult to predict listeners' performance on other test material using words, sentences, or connected discourse.

4. The effects of distance on person-to-person communication cannot be determined without including the visual component of the message.

5. The loudspeakers were placed side-by-side, rather than stacked vertically. Thus, in the fixed S/N condition, the nonsense syllables and multi-talker babble were

presented more in a dichotic, than diotic mode. Some hearing-impaired listeners may have been affected at the 1 and 2 m distances.

6. The raw data that were used in the data analysis produced a large intra- and intergroup variability. A conversions to proportion P and then to φ by the equation:

$$\varphi = 2\arcsin\sqrt{P}$$

(Walker & Lev, 1953) to stabilize error variance may have provided some insights for data interpretation.

7. The effects of listener and experimenter dialect were not controlled or assessed.

Suggestions for Future Research

Some possible directions for future research are:

1. The effects of loudspeaker-to-listener distance on the aided and unaided phoneme identification abilities of hearing-impaired listeners would provide valuable information on the benefits derived from the use of amplification and could be used to monitor progress in therapy.

2. The effects of loudspeaker-to-listener distance on phoneme recognition should be assessed using hearing-impaired listeners with various degrees and configurations

of hearing loss, poorer S/Ns, and different rooms of varying acoustic properties.

3. An error analysis of subjects' responses would determine if significant differences in perceptual features for consonants exist between listener groups, loudspeaker-to-listener distances, and S/N conditions.

4. Videotaped presentations providing a visual component to the speech stimuli may determine if there is a critical distance for vision.

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APPENDICES

APPENDIX A

SUBJECTS' SEX, AGE, AND AUDIOMETRIC DATA

Table A-1

Subjects' Sex, Age, and Audiometric Data (Normal-Hearing Subjects)

						Audiometric Data (KHz)								
No.	Sex	Age	Ear	SRT	SRS	.25	.5	1	1.5	2	3	4	6	8
S1	F	35	R	0	100	15	10	10		10		5		20
			L	0	100	15	10	5		10		10		5
S2	F	23	R	0	100	5	-5	0		-5		0		-10
			L	0	100	5	-5	0		-5		0		-10
S3	F	44	R	0	100	5	0	5		5		0		0
			L	0	100	5	0	0		0		-5		5
S4	F	61	R	0	100	15	10	10		5		20		25
			L	5	100	15	10	5		-5		20		25
S5	F	25	R	0	100	0	-5	0		-5		-5		0
			L	0	100	-5	-5	0		5		0		0
S6	F	23	R	0	100	10	10	5		0		-5		5
			L	0	100	10	10	0		5		-5		0
S7	F	45	R	10	100	10	10	10		0		-5		5
			L	10	100	15	20	15		5		10		15
S8	F	34	R	0	100	10	0	0		-5		5		10
			L	0	100	10	5	0		0		5		10
S9	F	31	R	0	100	5	5	5		-5		0		-10
			L	0	96	0	0	5		-5		0		10
S10	F	37	R	-5	100	15	0	0		-5		5		-5
			L	0	100	15	5	5		0		5		-5
S11	F	36	R	0	96	15	15	10		10		5		0
			L	-10	100	10	0	-10		-5		0		10
S12	M	31	R	0	100	5	5	10		0		10		25
			L	0	96	5	10	5		-5		10		20
Mean		35.4		0.42	99.5	8.7	4.8	3.9		0.2		3.5		6.2

Table A-2

Subjects' Sex, Age, and Audiometric Data (Hearing-Impaired Subjects)

					Audiometric Data (KHz)								
No.	Sex	Age	Ear	SRT	SRS	.25	.5	1	1.5	2	3	4	6	8
S13	F	63	R	15	100	10	20	15	20	25	45	60	70	85
			L	20	88	10	15	20	25	30	55	80	100	NR
S14	M	60	R	0	56	5	0	15	50	75	75	70	75	60
			L	5	84	5	0	5	5	25	60	60	60	50
S15	M	61	R	25	76	25	25	25	65	95	90	85	90	85
			L	35	72	30	25	25	40	55	75	65	105	70
S16	M	61	R	15	92	25	30	25	25	20	40	35	60	60
			L	10	96	20	25	25	25	20	35	45	60	60
S17	F	63	R	25	96	30	20	20	35	50	55	50	55	55
			L	30	92	20	25	20	30	45	50	45	50	50
S18	M	68	R	10	92	15	15	20	25	35	55	65	70	65
			L	15	96	15	20	25	25	50	75	70	85	60
S19	F	44	R	20	88	15	15	25	40	40	30	30	40	55
			L	5	96	20	10	20	30	30	25	20	30	55
S20	M	71	R	10	88	25	15	15	10	15	30	40	75	70
			L	20	80	25	20	20	10	10	30	60	60	60
S21	F	66	R	25	84	25	35	30	20	20	35	35	30	80
			L	25	96	25	30	25	20	15	20	35	50	60
S22	M	68	R	5	52	10	5	10	30	60	-	70	-	65
			L	5	80	5	5	5	30	55	-	60	-	50
S23	M	58	R	15	96	25	20	15	25	20	45	55	55	65
			L	20	100	10	10	20	20	15	40	55	45	60
S24	M	61	R	35	88	15	20	30	-	40	55	75	75	70
			L	25	88	10	20	25	-	40	70	70	65	65
Mean		62.0		17.3	86.5	17.5	17.7	20.0		36.9		55.6		63.2

APPENDIX B

FREQUENCY OF OCCURRENCE FOR PHONEMES AND RANDOMIZATIONS OF NST LIST A

Table B-1

Frequency of Occurrence for Phonemes on NST List A

Phoneme	Position C1	V1	C2	V2
Consonant				
p	2		0	
b	2		0	
t	0		1	
d	1		0	
k	0		0	
g	1		0	
f	2		3	
v	1		1	
θ	1		6	
ð	6		6	
s	1		1	
z	1		1	
ʃ	3		0	
h	1		1	
t	1		1	
d	2		0	
m	0		2	
n	1		1	
l	0		1	
w	0		1	
j	0		1	
r	0		0	
Vowels				
i		4		0
I		4		5
e		1		1
ɛ		1		1
æ		2		6
a		4		5
o		1		4
ʊ		2		2
u		2		1
ʌ		4		0

Table B-2

The Six Randomizations of the NST List A

	Bisyllable List Forms 1–6					
	#1	#2	#3	#4	#5	#6
1.	ðɪjo	dʒʌðʊ	ðæwo	ðɑnɑ	giðo	ðɑnɑ
2.	giðo	ɵʌfɪ	nɪɵʊ	ʃitʃɑ	ʃeɵɑ	ʃitʃɑ
3.	ðæwo	dʒɑfe	ðumɑ	dʒʌðʊ	sɛfɛ	fisæ
4.	fuɵɪ	bʌðɪ	ʃitʃɑ	nɪɵʊ	ðumɑ	dʒʌðʊ
5.	ʃɪɵæ	bæðæ	fuɵɪ	ðʊmæ	dʒɑfe	bæðæ
6.	fisæ	pʌðu	dɑɵɑ	fuɵɪ	ʃitʃɑ	ðumɑ
7.	vʊvɪ	fisæ	dʒɑfe	dʒɑfe	pitɪ	pitɪ
8.	dʒɑfe	ðɑnɑ	pʌðu	dɑɵɑ	bʌðɪ	hɑðo
9.	ðumɑ	ðʊmæ	ðɪlæ	fisæ	tʃoɵæ	ðɪjo
10.	sɛfɛ	ðɪjo	bʌðɪ	pʌðu	ðæwo	giðo
11.	ʃeɵɑ	ðumɑ	dʒʌðʊ	hɑðo	fuɵɪ	ðɪlæ
12.	ðɪlæ	nɪɵʊ	tʃoɵæ	vʊvɪ	hɑðo	sɛfɛ
13.	bʌðɪ	ðæwo	ðʊmæ	pitɪ	pʌðu	pʌðu
14.	ðɑnɑ	dɑɵɑ	ʃɪɵæ	sɛfɛ	dɑɵɑ	ɵʌfɪ
15.	bæðæ	ʃɪɵæ	vʊvɪ	ʃeɵɑ	dʒʌðʊ	tʃoɵæ
16.	ðʊmæ	sɛfɛ	ðɪjo	ɵʌfɪ	nɪɵʊ	ðæwo
17.	ʃitʃɑ	hɑðo	ðɑnɑ	ðæwo	vʊvɪ	ðʊmæ
18.	pʌðu	fuɵɪ	bæðæ	tʃoɵæ	ʃɪɵæ	ʃeɵɑ
19.	tʃoɵæ	tʃoɵæ	ɵʌfɪ	bʌðɪ	ðʊmæ	nɪɵʊ
20.	pitɪ	giðo	pitɪ	ðumɑ	ðɪlæ	dɑɵɑ
21.	dʒʌðʊ	ðɪlæ	ʃeɵɑ	ðɪlæ	ðɑnɑ	ʃɪɵæ
22.	ɵʌfɪ	ʃeɵɑ	sɛfɛ	bæðæ	ðɪjo	fuɵɪ
23.	hɑðo	vʊvɪ	fisæ	giðo	fisæ	vʊvɪ
24.	dɑɵɑ	pitɪ	giðo	ðɪjo	ɵʌfɪ	dʒɑfe
25.	nɪɵʊ	ʃitʃɑ	hɑðo	ʃɪɵæ	bæðæ	bʌðɪ

APPENDIX C

SPECTROGRAPHIC INFORMATION ON THE NST

Table C-1

Relative Peak Amplitudes (in dB) Phonemes of Ten NST List A Items

Item	Phoneme			
	C1	V1	C2	V2
1. /ɹIlɚ/	-27	-5	-33	-5
2. /bɚɹɑ/	-28	-5	-27.5	-5
3. /bʌɹI/	-30	-7.5	-26	-3.5
4. /ɹuma/	-27	-5	-30	-7
5. /vʊvI/	-25	-4.5	-27.5	-4.5
6. /sɛfɛ/	-12	-5	-40	-6
7. /ɹana/	-18.5	-3.5	-20	-3.5
8. /ʃəə/a/	-12	-4.5	-43	-4.5
9. /dʒafe/	-33	-5	-44	-3
10. /fisɹ/	-40	-5	-10	-4
M =	-25.25	-5	-30.1	-4.6

Table C-2

Duration (in Ms) of Phonemes of Ten NST List A Items

Item	Phoneme			
	C1	V1	C2	V2
1. /ðIlɚ/	200	255	150	380
2. /bɹðɚ/	160	340	140	370
3. /bʌðI/	145	275	130	270
4. /ðuma/	120	320	118	352
5. /vʊvI/	175	255	135	320
6. /sɛfɛ/	165	300	125	345
7. /ðana/	120	320	130	370
8. /ʃeθa/	150	360	95	335
9. /dʒafe/	150	390	140	395
10. /fisɹ/	135	395	150	345
M =	152	321	131.3	348.2

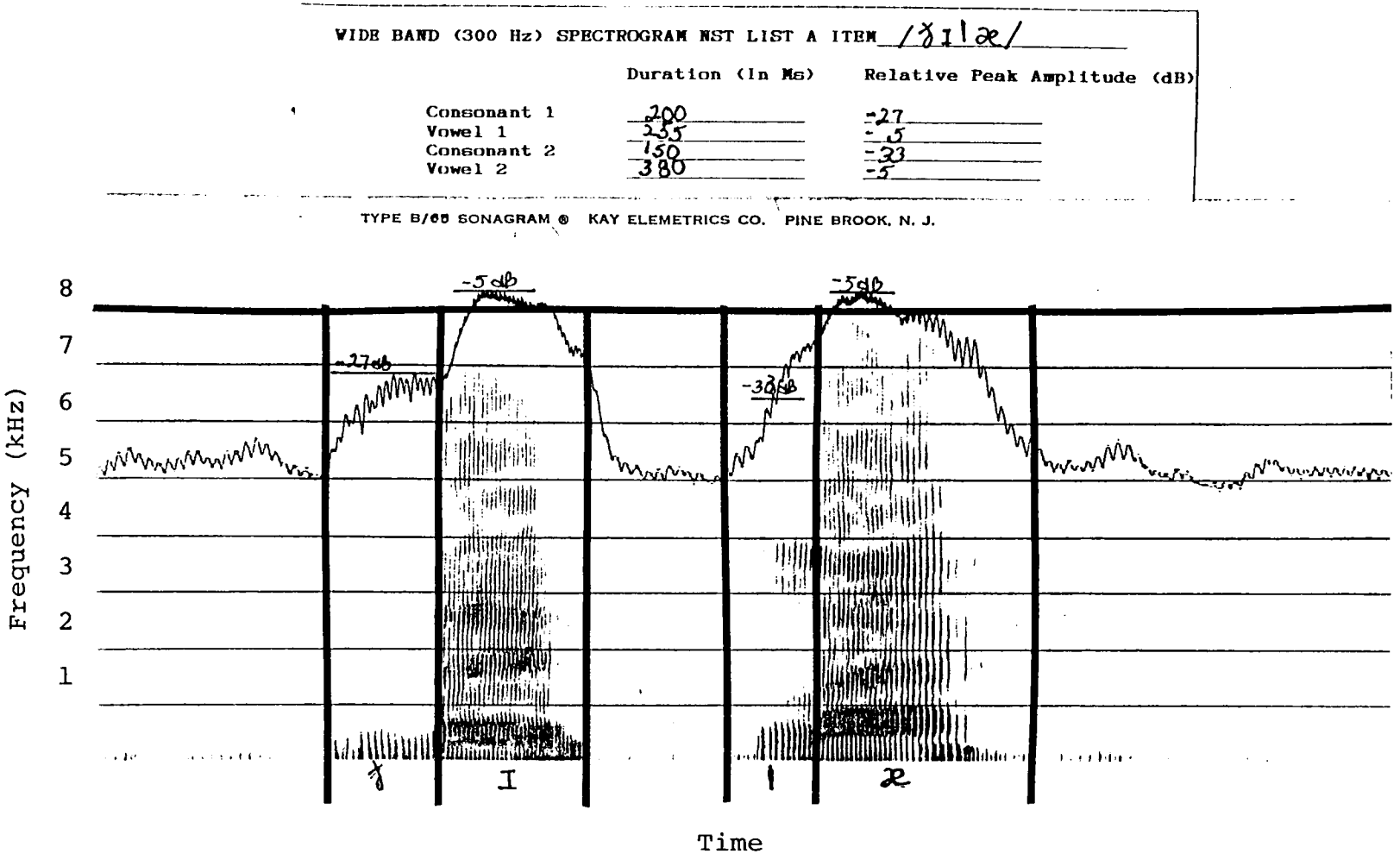


Figure C-1. Wide band (300 Hz) spectrogram NST List A Item /ɣɪlɜ/.

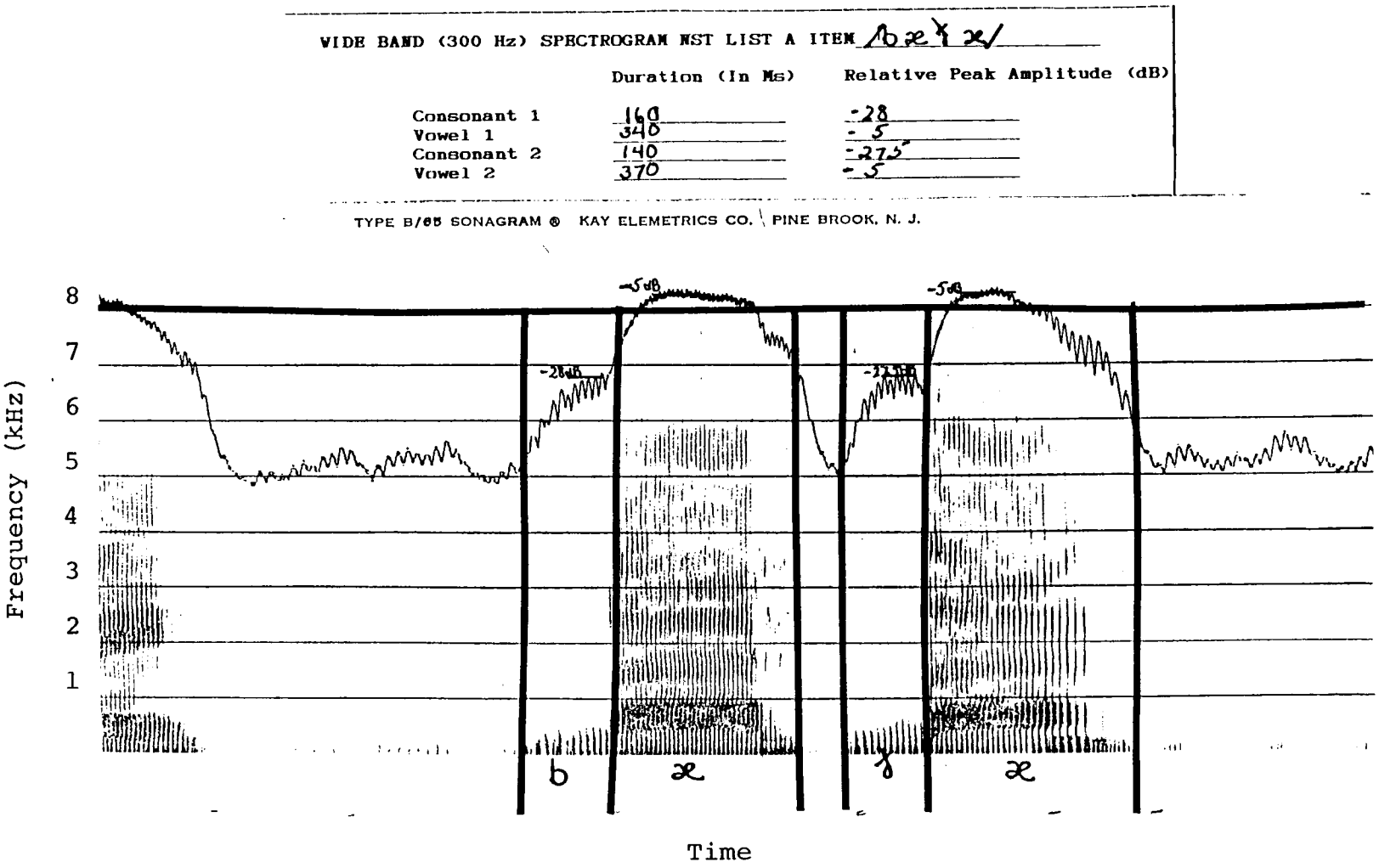


Figure C-2. Wide band (300 Hz) spectrogram NST List A Item /bædæ/.

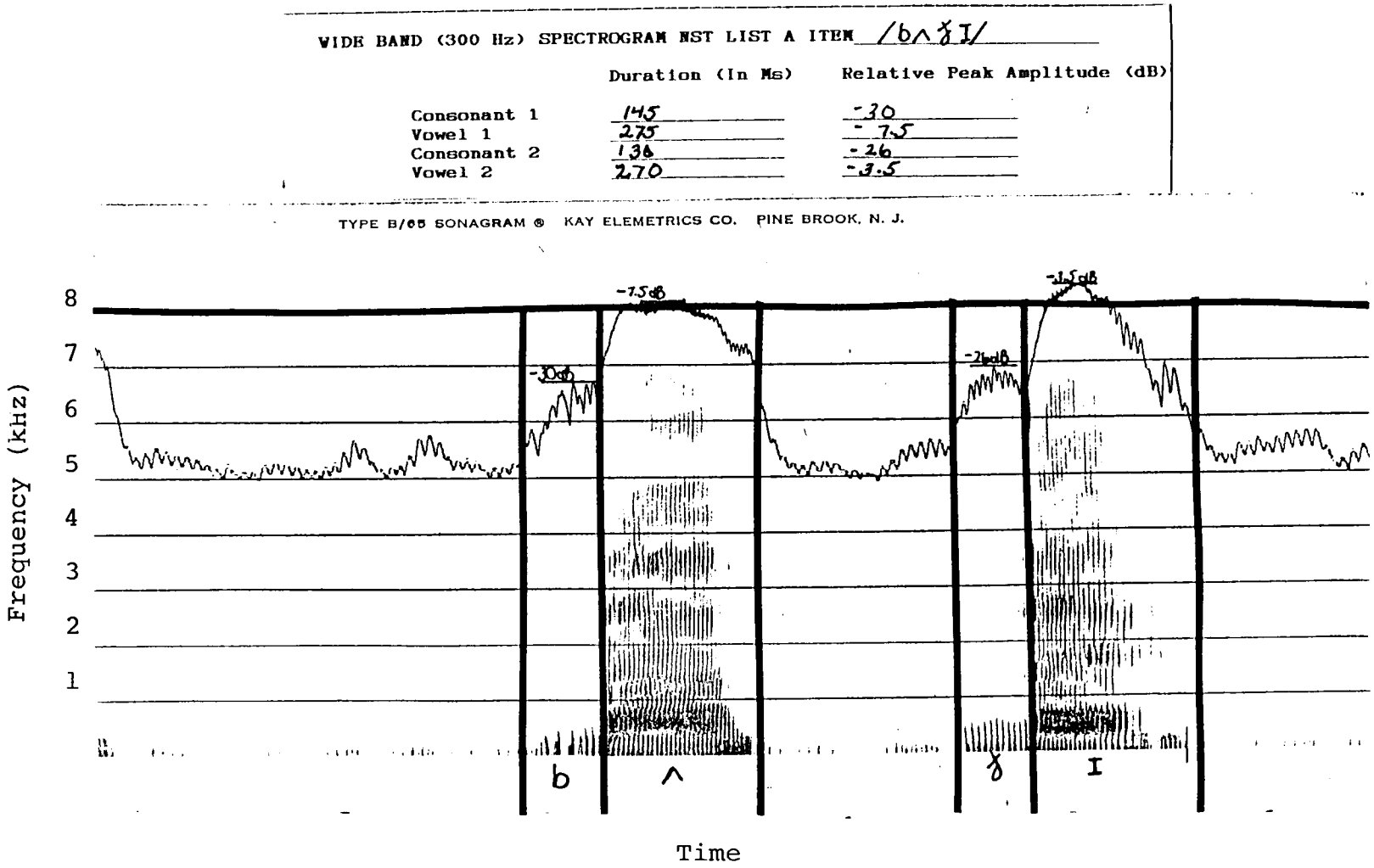


Figure C-3. Wide band (300 Hz) spectrogram NST List A Item /bʌðI/.

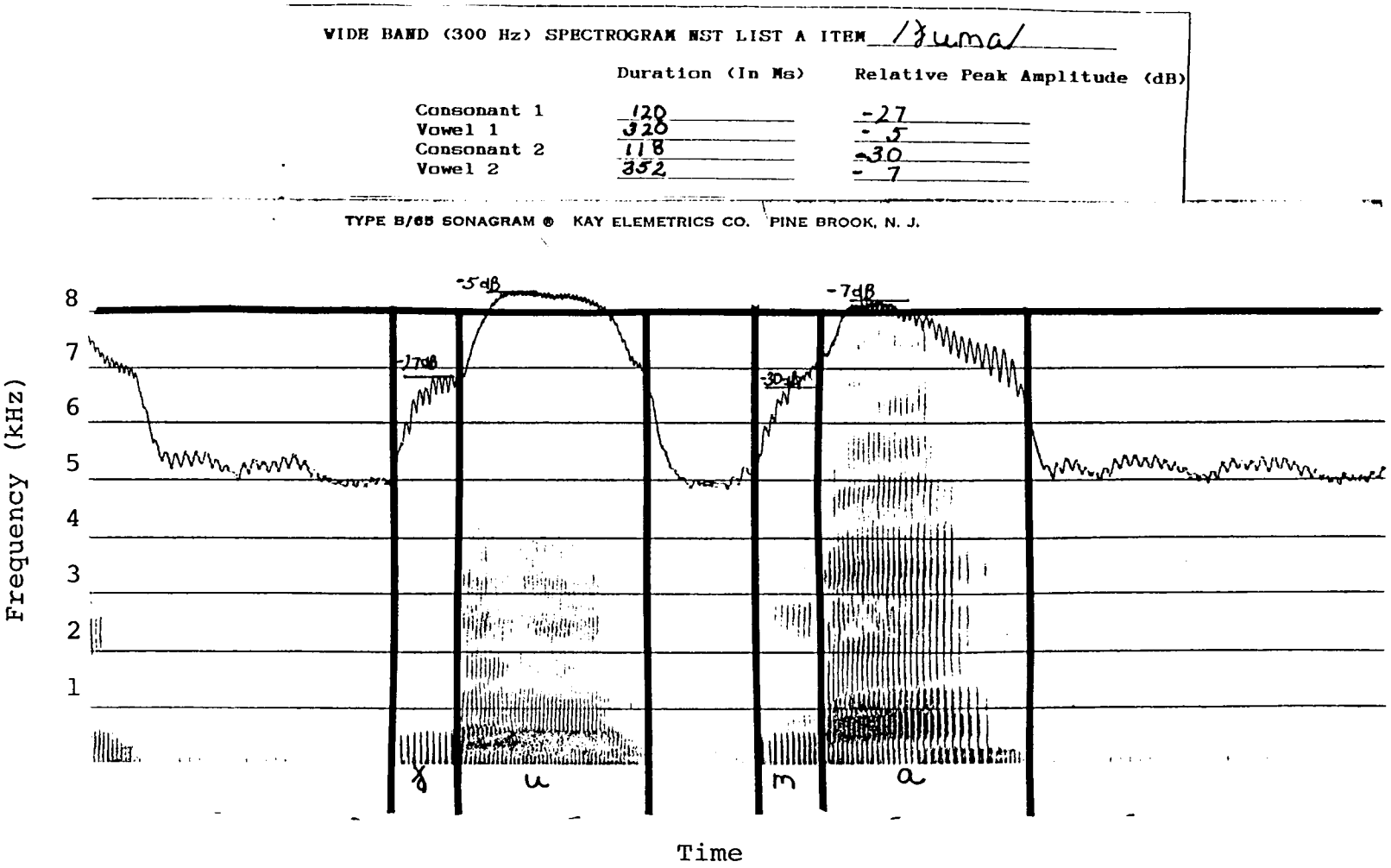


Figure C-4. Wide band (300 Hz) spectrogram NST List A Item /ðuma/.

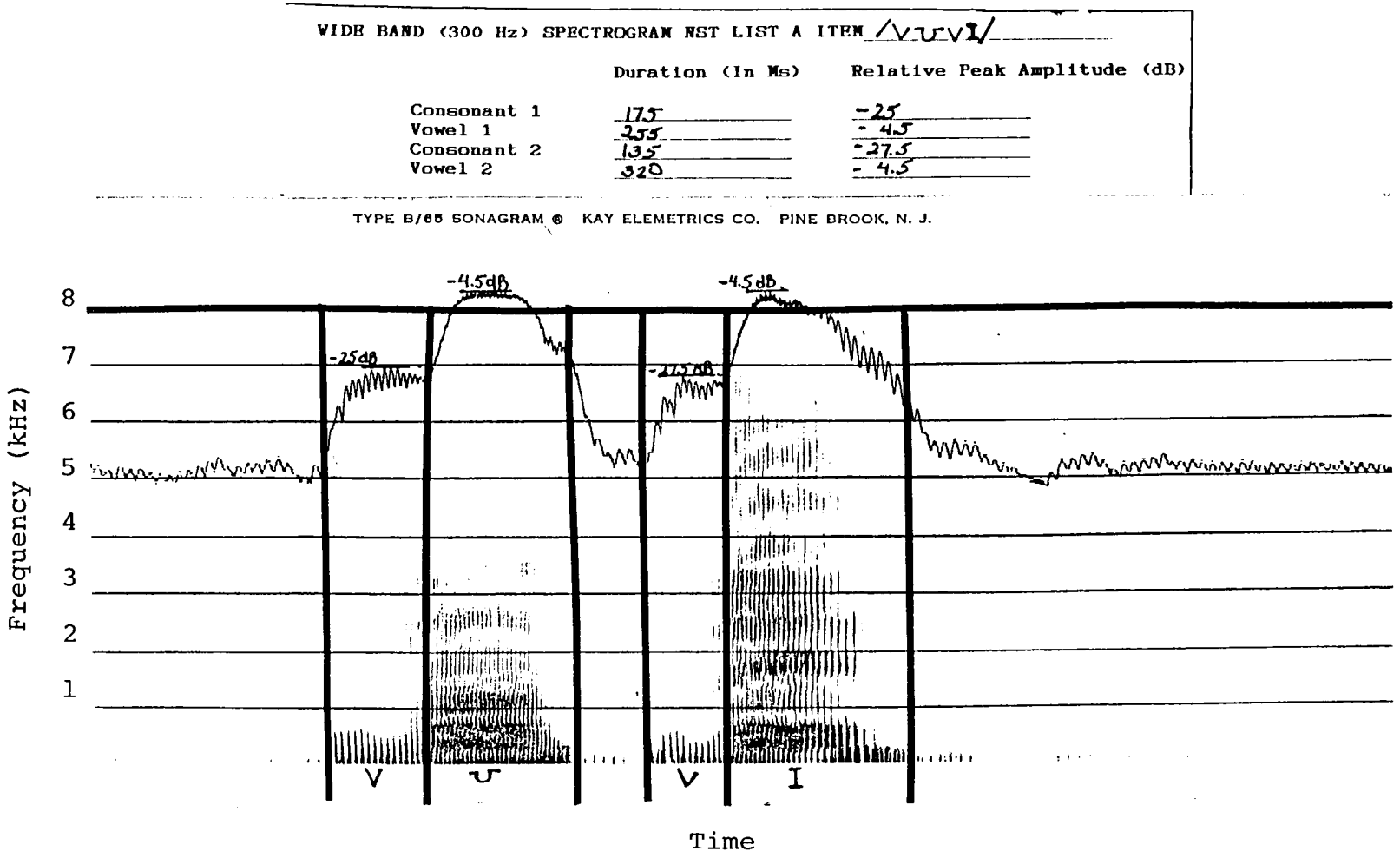


Figure C-5. Wide band (300 Hz) spectrogram NST List A Item /vuvI/.

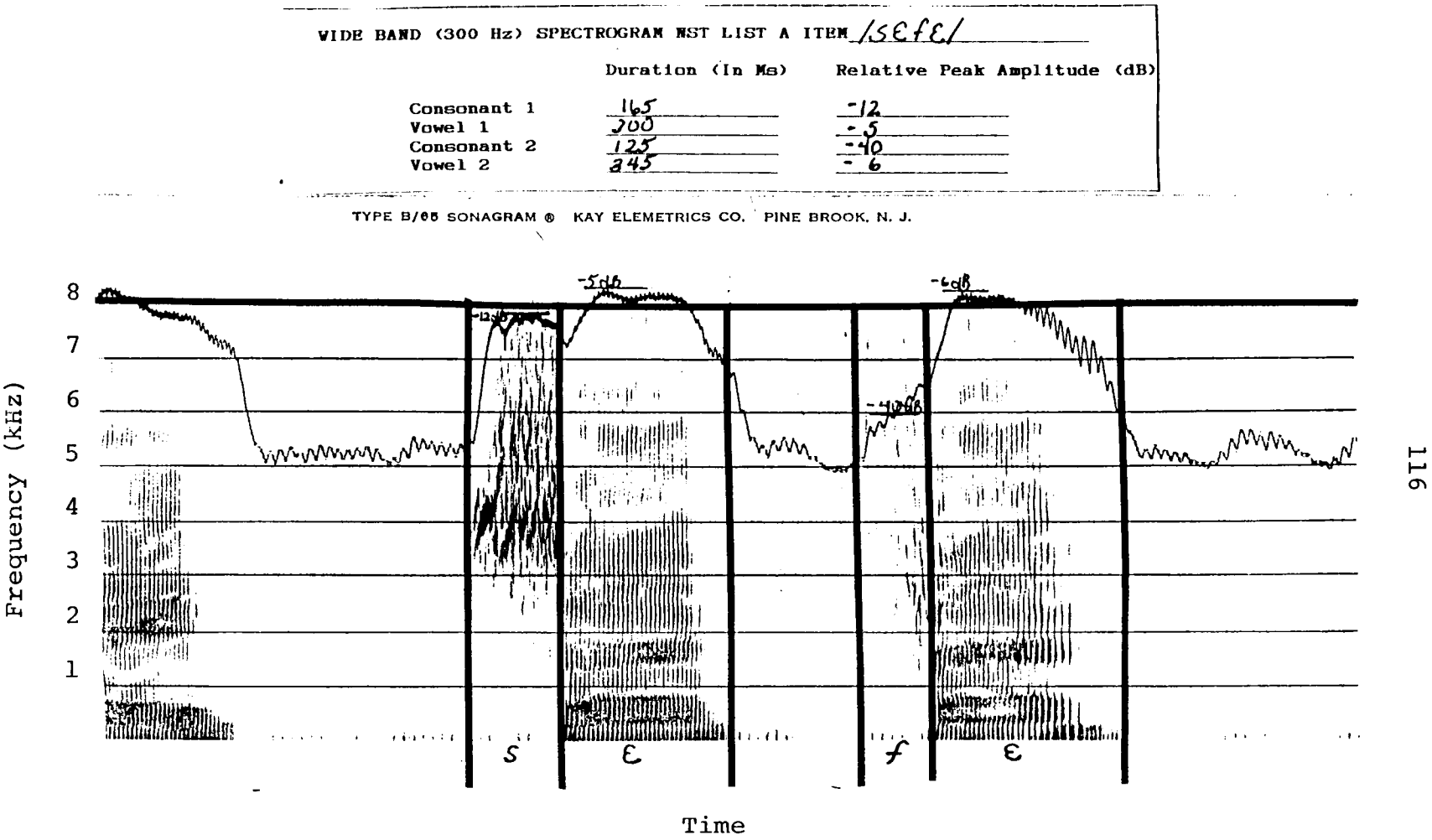


Figure C-6. Wide band (300 Hz) spectrogram NST List A Item /sɛfɛ/.

WIDE BAND (300 Hz) SPECTROGRAM NST LIST A ITEM /ðana/

	Duration (In Ms)	Relative Peak Amplitude (dB)
Consonant 1	120	-18.5
Vowel 1	320	-2.5
Consonant 2	130	-20
Vowel 2	370	-3.5

TYPE B/65 SONAGRAM ® KAY ELEMETRICS CO. PINE BROOK, N. J.

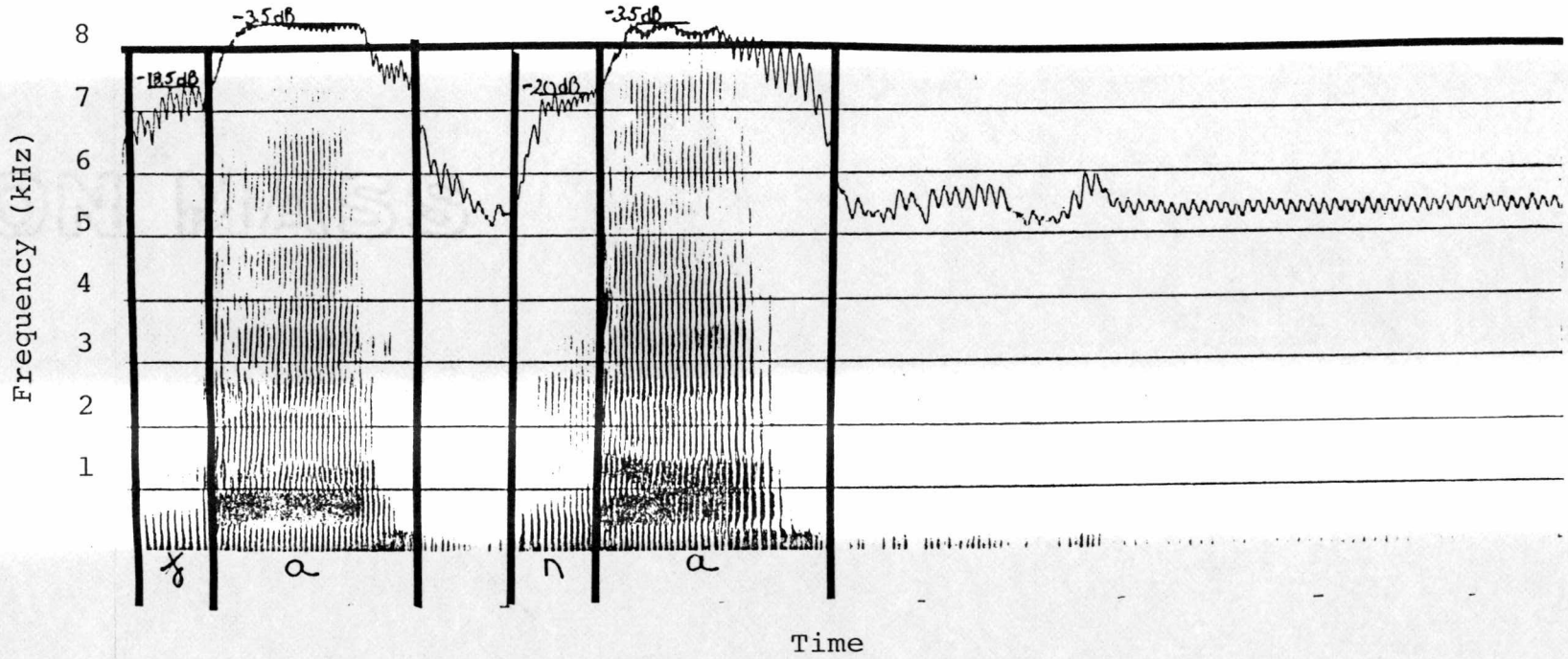


Figure C-7. Wide band (300 Hz) spectrogram NST List A Item /ðana/.

WIDE BAND (300 Hz) SPECTROGRAM NST LIST A ITEM /ʃeθa/

	Duration (In Ms)	Relative Peak Amplitude (dB)
Consonant 1	150	-12
Vowel 1	360	- 4.5
Consonant 2	95	-43
Vowel 2	335	- 4.5

TYPE B/66 SONAGRAM ® KAY ELEMETRICS CO. PINE BROOK, N. J.

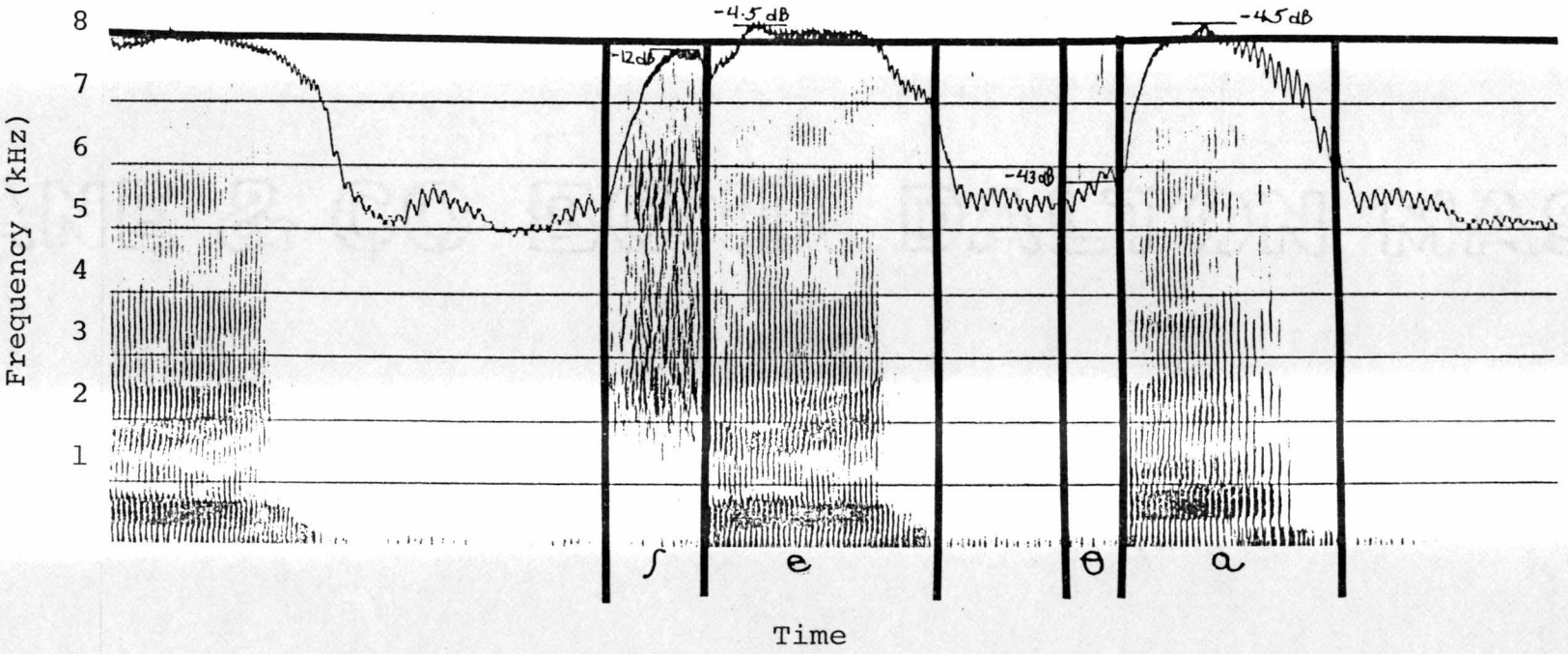


Figure C-8. Wide band (300 Hz) spectrogram NST List A Item /ʃeθa/.

WIDE BAND (300 Hz) SPECTROGRAM NST LIST A ITEM /ʤafe/

	Duration (In Ms)	Relative Peak Amplitude (dB)
Consonant 1	150	-33
Vowel 1	390	-5
Consonant 2	140	-44
Vowel 2	395	-3

TYPE B/65 SONAGRAM ® KAY ELEMETRICS CO. PINE BROOK, N. J.

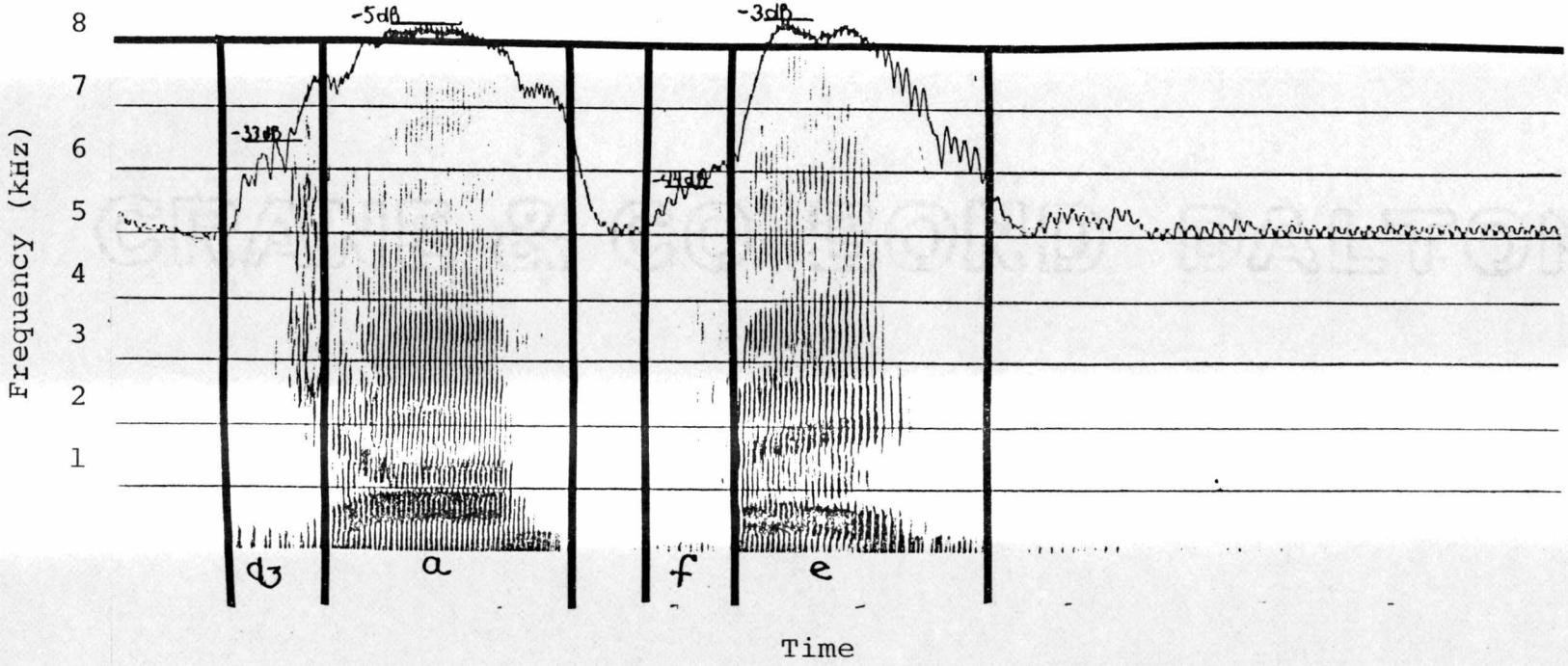


Figure C-9. Wide band (300 Hz) spectrogram NST List A Item /ʤafe/.

WIDE BAND (300 Hz) SPECTROGRAM NST LIST A ITEM /fiSɹ/

	Duration (In Ms)	Relative Peak Amplitude (dB)
Consonant 1	135	-40
Vowel 1	393	- 5
Consonant 2	130	-10
Vowel 2	345	- 4

TYPE B/65 SONAGRAM ® KAY ELEMETRICS CO. PINE BROOK, N. J.

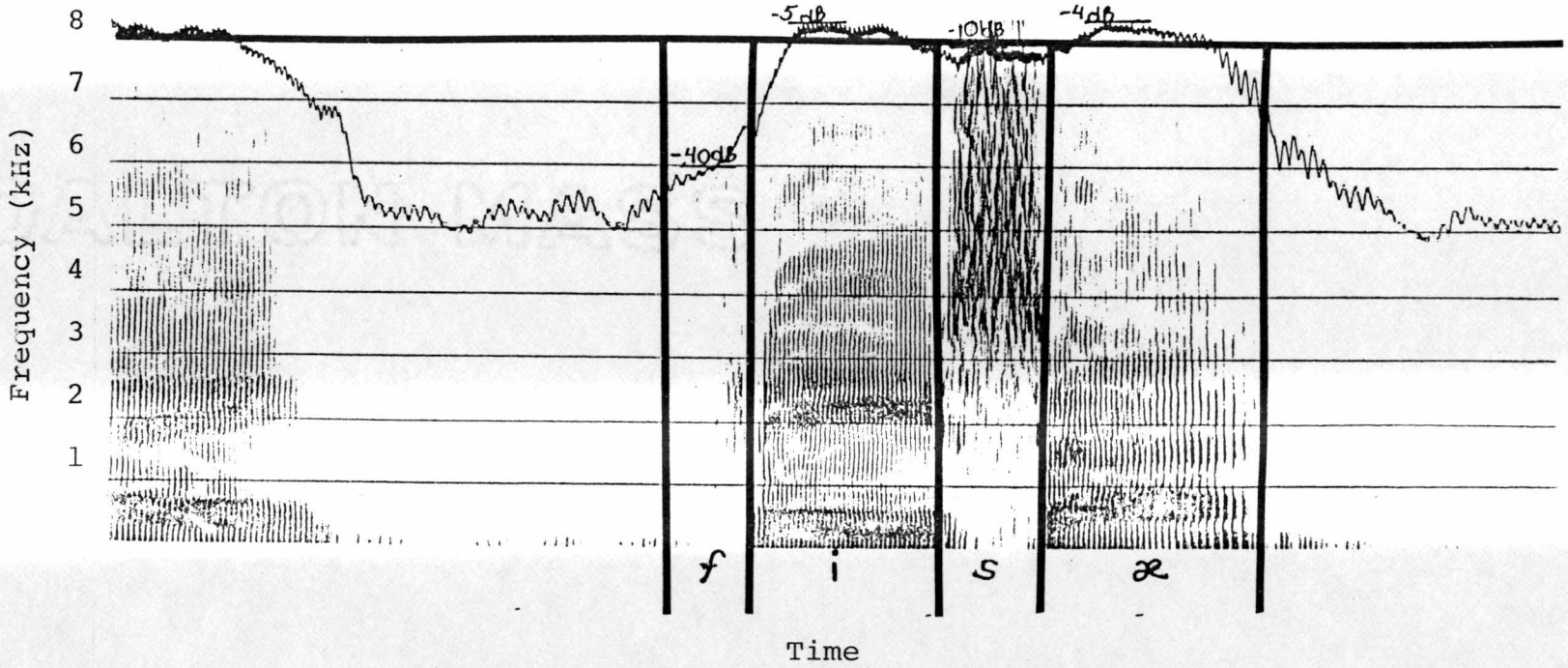


Figure C-10. Wide band (300 Hz) spectrogram NST List A Item /fiSɹ/.

APPENDIX D

PRINTOUT FROM GRAPHIC LEVEL RECORDER FOR ESTIMATING REVERBERATION TIME

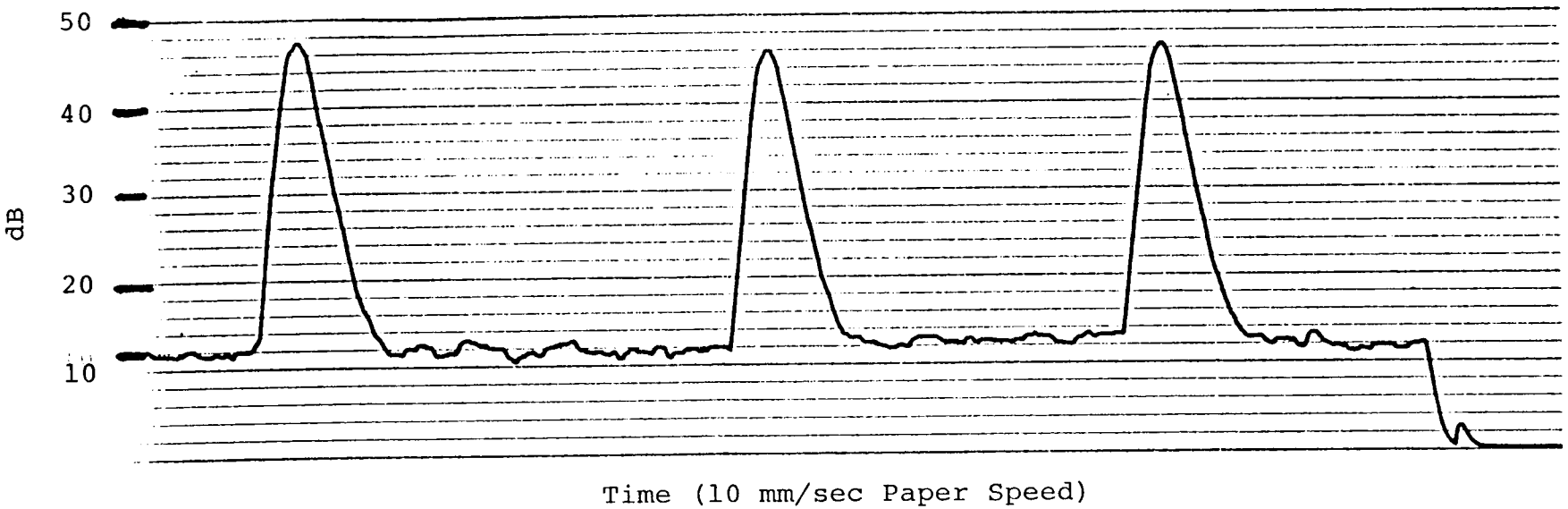


Figure D-1. Printout from graphic level recorder for estimation of reverberation time from a gunshot filtered through a 1000 Hz 1/3 octave band.

APPENDIX E

AMBIENT NOISE MEASUREMENTS

Table E-1

Mean Ambient Noise Levels of the Lecture Hall (in dB)

		1/3 Octave Band (c/F Hz)					
Position	A-Scale	250	500	1000	2000	4000	8000
1 m	45.0	46.0	44.0	34.5	28.0	21.5	21.0
8 m	44.5	47.0	42.5	33.0	28.0	23.5	21.0
15 m	45.0	46.0	40.5	33.0	27.5	22.5	21.0

APPENDIX F

INSTRUCTIONS ON SUBJECT CONSENT FORM

CONSENT FORM FOR PARTICIPATION IN THE STUDY OF PHONEME RECOGNITION AS A FUNCTION OF DISTANCE FROM THE SOUND SOURCE IN A LECTURE HALL

The purpose of this study is to investigate speech recognition as a function of distance from the sound source in a lecture hall. The reason why you have been selected as a listener is because you either have normal hearing or a high frequency hearing loss.

You will first be given a clinical audiometric test. then you will be taken to a lecture hall in which you will be seated alternately in five different chairs. The chairs will be placed at different distances from a loudspeaker. A speech perception test will be played through the loudspeaker. What you will hear are nonsense syllables composed of consonant-vowel-consonant-vowel (i.e., CVCV) combinations preceded by the word "Say." Your task is to listen to these items and repeat them. If you are not sure what the item was, take a guess. From time to time, you will hear background noise played at a soft level from another loudspeaker. The task takes about one hour.

You should not experience any discomfort nor will there be any health risk as a result of this testing.

The staff in this project will be glad to answer any questions you may have regarding this procedure.

-----*-----*-----*-----*-----*-----*-----*-----*-----*-----

I hereby volunteer to participate as a test subject in the investigation of speech understanding. This consent is voluntary and has been given under the circumstances in which I can exercise free power of choice. I may at any time revoke my consent and withdraw from the experiment without prejudice.

Date _____

Signature of Volunteer _____

APPENDIX G

RAW DATA

RAW DATA

Varied Signal-to-Noise Ratio

Distance		1 m	2 m	4 m	8 m	15 m
Normal-Hearing						
S1	V	94	96	90	92	82
	C	88	88	90	86	80
S2	V	98	98	92	96	86
	C	96	90	88	88	84
S3	V	96	94	94	100	92
	C	78	80	78	74	74
S4	V	76	78	78	80	76
	C	92	90	86	66	72
S5	V	98	90	98	96	98
	C	94	90	92	88	84
S6	V	74	80	80	78	78
	C	82	84	82	78	70
S7	V	90	86	80	88	84
	C	74	76	72	68	70
S8	V	96	96	96	96	94
	C	92	88	84	86	88
S9	V	98	98	98	98	98
	C	90	92	94	88	86
S10	V	90	96	92	94	92
	C	86	86	92	84	80
S11	V	94	96	96	94	88
	C	82	84	86	82	80
S12	V	88	86	88	94	88
	C	92	82	80	88	86

V = Vowel
C = Consonant

RAW DATA

Fixed Signal-to-Noise Ratio

Distance		1 m	2 m	4 m	8 m	15 m
Normal-Hearing						
S1	V	90	84	86	96	82
	C	84	70	74	68	78
S2	V	84	90	86	86	92
	C	78	88	66	66	72
S3	V	92	96	92	94	96
	C	68	76	66	68	60
S4	V	80	78	78	80	80
	C	66	74	76	66	64
S5	V	98	96	96	94	96
	C	90	80	82	82	74
S6	V	82	74	80	78	82
	C	74	68	72	66	64
S7	V	86	86	86	88	82
	C	74	74	70	60	58
S8	V	96	98	98	96	96
	C	86	82	80	74	80
S9	V	96	98	96	96	98
	C	80	76	76	82	78
S10	V	90	92	90	90	92
	C	82	76	78	76	76
S11	V	92	92	90	90	92
	C	78	70	78	64	68
S12	V	86	90	90	80	86
	C	82	88	72	68	78

V = Vowel
C = Consonant

RAW DATA

Varied Signal-to-Noise Ratio

Distance		1 m	2 m	4 m	8 m	15 m
Hearing-Impaired						
S13	V	92	94	92	86	90
	C	66	66	60	66	62
S14	V	80	84	82	84	74
	C	64	70	40	38	44
S15	V	80	72	72	66	72
	C	46	42	46	42	36
S16	V	82	82	78	74	84
	C	66	64	60	54	62
S17	V	86	92	70	84	84
	C	40	44	36	38	40
S18	V	86	78	84	86	78
	C	52	46	50	42	38
S19	V	70	66	74	76	78
	C	84	72	64	58	66
S20	V	84	82	76	76	72
	C	46	42	54	44	42
S21	V	88	92	88	88	88
	C	74	78	74	66	70
S22	V	82	70	66	62	66
	C	52	40	36	44	30
S23	V	88	90	94	94	92
	C	76	74	74	68	58
S24	V	72	62	70	68	70
	C	42	26	32	28	30

V = Vowel
C = Consonant

RAW DATA

Fixed Signal-to-Noise Ratio

Distance		1 m	2 m	4 m	8 m	15 m
Hearing-Impaired						
S13	V	96	76	88	92	92
	C	64	54	58	58	48
S14	V	68	82	80	68	74
	C	32	52	38	30	38
S15	V	80	70	64	78	68
	C	36	34	32	30	32
S16	V	74	80	72	84	72
	C	64	62	56	50	52
S17	V	84	86	64	74	80
	C	36	40	32	38	38
S18	V	84	86	78	78	78
	C	46	58	44	40	44
S19	V	72	70	76	64	68
	C	62	58	58	72	62
S20	V	76	82	78	78	72
	C	40	34	32	30	24
S21	V	90	86	84	84	88
	C	78	76	58	66	56
S22	V	74	72	72	70	56
	C	42	28	42	26	22
S23	V	88	90	88	92	90
	C	78	64	58	68	60
S24	V	72	66	64	62	60
	C	30	38	18	18	16

V = Vowel
C = Consonant

APPENDIX H

TABLES FOR NONSIGNIFICANT STATISTICAL RESULTS

Table H-1

Mean (M) Consonant Identification Scores and Standard Deviations (SD), in Percent, of Normal-Hearing and Hearing-Impaired Listeners at Five Distances

	Distances (m)				
Listener Group	1	2	4	8	15
Normal-Hearing					
M	82.8	81.3	79.7	76.1	75.2
SD	7.9	7.1	7.4	9.1	8.1
Hearing-Impaired					
M	54.8	52.6	48.1	46.4	44.6
SD	16.0	15.5	14.1	15.4	14.7

Table H-2

Mean (M) Consonant Identification Scores and Standard Deviations (SD), in Percent, in the Varied and Fixed S/N Conditions Five Distances

	Distances (m)				
S/N Condition	1	2	4	8	15
Varied					
M	73.1	70.6	68.7	65.6	63.8
SD	18.2	19.8	20.2	19.2	19.0
Fixed					
M	64.6	63.3	59.0	56.9	55.9
SD	19.3	17.4	18.5	18.7	19.5

Table H-3

Mean (M) Consonant Identification Scores and Standard Deviations (SD), in Percent, in Two S/N Conditions for Normal-Hearing and Hearing-Impaired Listeners at Five Distances

	Distances (m)				
	1	2	4	8	15
Normal-Hearing					
Varied S/N					
M	87.2	85.8	85.3	82.2	79.5
SD	6.8	4.6	6.5	7.7	6.5
Fixed S/N					
M	78.5	76.8	74.2	70.0	70.8
SD	7.0	6.6	5.1	7.0	7.7
Hearing-Impaired					
Varied S/N					
M	59.0	55.3	52.2	49.0	48.2
SD	14.6	17.0	14.6	13.0	14.5
Fixed S/N					
M	50.7	49.8	43.8	43.8	41.0
SD	17.6	16.8	13.7	18.4	15.3

Table H-4

Mean (M) Vowel Identification Scores and Standard Deviations (SD), in Percent, of Normal and Hearing-Impaired Listeners at Five Distances

	Distances (m)				
Listener Group	1	2	4	8	15
Normal-Hearing					
M	90.2	90.3	89.6	90.6	88.7
SD	6.8	7.1	6.4	6.7	6.7
Hearing-Impaired					
M	81.2	79.6	77.2	77.8	76.9
SD	7.4	9.1	8.7	9.5	9.8

Table H-5

Mean (M) Vowel Identification Scores and Standard Deviations (SD), in Percent, of Normal and Hearing-Impaired Listeners in Two S/N Conditions

	S/N Condition	
Listener Group	Varied	Fixed
Normal-Hearing		
M	90.5	89.3
SD	7.1	6.4
Hearing-Impaired		
M	79.9	77.2
SD	8.8	9.2

Table H-6

Mean (M) Vowel Identification Scores and Standard Deviations (SD), in Percent, in the Varied and Fixed S/N Conditions at Five Distances

	Distances (m)				
S/N Condition	1	2	4	8	15
Varied					
M	86.7	85.7	84.5	85.4	83.5
SD	8.6	9.4	10.0	10.3	11.8
Fixed					
M	84.5	84.2	82.3	83.0	82.2
SD	8.4	10.5	9.9	10.8	9.0

Table H-7

Mean (M) Vowel Identification Scores and Standard Deviations (SD), in Percent, in Two S/N Conditions for Normal-Hearing and Hearing-Impaired Listeners at Five Distances

Groups	Distances (m)				
S/N Condition	1	2	4	8	15
Normal-Hearing					
Varied					
M	91.0	91.2	90.2	92.2	88.0
SD	8.2	7.0	7.2	6.8	7.2
Fixed					
M	89.3	89.5	89.0	89.0	89.5
SD	5.8	7.7	6.2	6.7	6.7
Hearing-Impaired					
Varied					
M	82.5	80.3	78.8	78.7	79.0
SD	6.4	10.8	9.1	9.9	8.5
Fixed					
M	79.8	78.8	75.7	77.0	74.8
SD	8.6	7.8	8.7	9.9	11.4

APPENDIX I

VOWEL ERROR ANALYSIS FOR SUBJECT 15

Table I-1

Error Analysis of Vowels for Subject No. 15

Stimulus Vowels on Test	Response Conditions	Vowels on Test										Responses Not on Test
		i	I	e	ɛ	æ	ə	ɔ	ʊ	u	ʌ	X
i	2 m	2								2		
	15 m	4										
I	2 m	3	6									
	15 m	2	7									
e	2 m			2								
	15 m			2								
ɛ	2 m				0							2
	15 m				0							2
æ	2 m					5	2					1
	15 m					5	2					1
ə	2 m					1	8					
	15 m						9					
o	2 m							5				
	15 m							5				
ʊ	2 m						1		2	1		
	15 m			1				2	0	1		
u	2 m									3		
	15 m									3		
ʌ	2 m						1				3	
	15 m					1	1	1			1	

X = Omission

APPENDIX J

SPECTRA OF THE NST, MULTI-TALKER BABBLE, AND AMBIENT ROOM NOISE

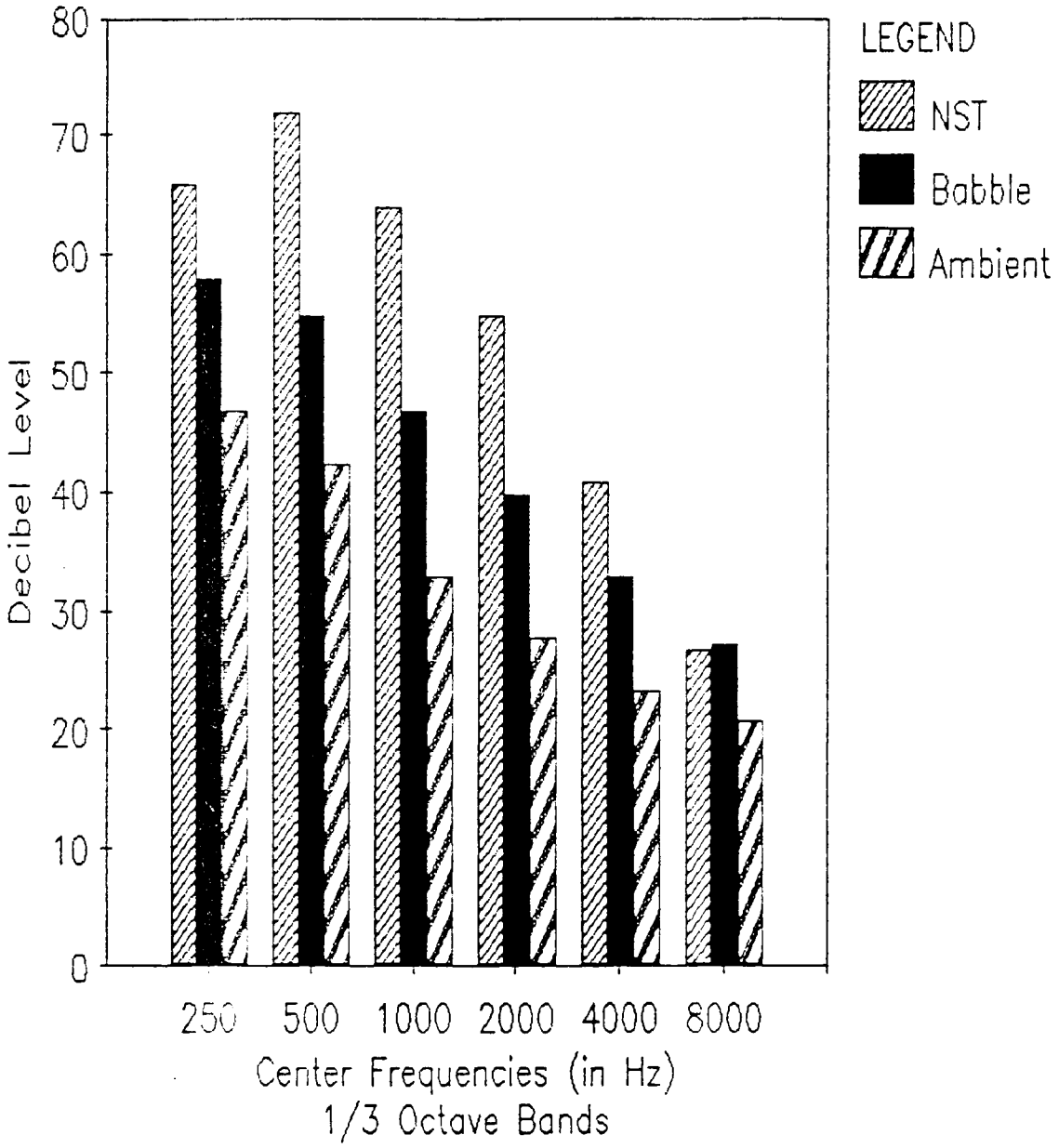


Figure J-1. Spectra of the NST, multi-talker babble, and ambient noise level of the lecture hall at the 8 m test position.

VITA

Carole E. Johnson was born in Oakland, California. She attended elementary and secondary schools in the San Francisco Bay Area. In June 1982, she received a Bachelor of Arts degree in Speech and Hearing Sciences and Psychology from the University of California, Santa Barbara. In June 1983, she entered the Graduate School of the University of Tennessee, Knoxville. In June 1986, she received her Master of Arts degree in Audiology. While at UTK, she served as a Graduate Assistant, Coordinator of the Verbotonal Research Lab, and completed her Clinical Fellowship Year in the Speech and Hearing Center. She has made 28 presentations at state, national, and international professional meetings and has published several articles. She completed her Doctor of Philosophy degree in Speech and Hearing Science in August 1989. She accepted a position as Assistant Professor in the Department of Communication Disorders at the University of Oklahoma Health Sciences Center in Oklahoma City, Oklahoma.