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THE EFFECT OF REVERBERATION ON THE PHONEME DISCRIMINATION OF CHILDREN: A DEVELOPMENTAL STUDY

by

ARLENE CECELIA NEUMAN

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

1982

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

April 2, 1982
date

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Abstract

THE EFFECT OF REVERBERATION ON THE PHONEME DISCRIMINATION OF CHILDREN: A DEVELOPMENTAL STUDY

by

Arlene Cecelia Neuman

Adviser: Professor Irving Hochberg

The effect of reverberation on the phoneme discrimination ability of normal-hearing children, aged 5, 7, 9, 11, and 13, and a group of adults was determined by measuring discrimination of 114 VCV nonsense disyllables under three conditions of reverberation (0, 0.4, and 0.6-sec reverberation times). Experimental recordings were made through KEMAR and an associated Killion filter in an anechoic room and in a reverberation room. Testing was done via headphones in the binaural mode (non-reverberant, 0.4, and 0.6-sec condition) and the monaural mode (0.6-sec condition).

Analysis of variance techniques were used to determine the contribution of the factors of age and reverberation and of age and mode of presentation. Confusion matrices were also analyzed to determine patterns of errors for the children and adults.

The analyses revealed that the 0.4 and 0.6-sec reverberation times caused significant decreases in phoneme discrimination of all subjects.

Phoneme discrimination scores for the reverberant conditions improved with increasing age. Age differences were statistically significant.

Binaural listening was superior to monaural listening for all age groups. The monaural/binaural difference was statistically significant.

The pattern of phoneme errors obtained in the reverberant conditions was similar to that reported by other investigators. Place and manner errors were most common, while voicing and nasality errors were rare. The majority of the manner errors involved confusions between stops and fricatives.

In general, the children made the same type of errors as the adults, but made more errors. However, the younger children (5, 7, and 9-year-olds) did make some substitutions which differed from those of older children and adults. These errors included the features of voicing, affrication, and the consonantal feature.

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Reverberant recordings were made at the Auditory Department, United States Naval Submarine Medical Research Laboratory. I am grateful to Dr. John Kerivan for making the facilities available.

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CHAPTER I

INTRODUCTION

The importance of reverberation as a factor in determining speech intelligibility has been the focus of recent attention, especially with respect to special populations, i.e., the hearing impaired (e.g., Nabelek and Mason, 1981), the aged (e.g., Duquesnoy and Plomp, 1980; Nabelek and Jennings, 1981), and children (e.g., Finitzo-Hieber and Tillman, 1978). While several studies have demonstrated that reverberation-in-quiet has little effect on the speech discrimination abilities of adults until reverberation time exceeds 1 second (e.g., Crum and Tillman, 1973), other studies have demonstrated significant decreases in discrimination in normal-hearing adults at shorter reverberation times (e.g., Millin, 1968; Moncur and Dirks, 1967). Differences in the experimental design including the size of the room, distance between the speaker and listener, and the speech material used may have contributed to the discrepancies among studies.

Increasingly, investigators have questioned the assertion that reverberation times in excess of .5 sec allow optimal understanding of speech for normal-hearing or hearing-impaired listeners in quiet or in noise (e.g., Finitzo-Hieber and Tillman, 1978; Ross, 1978; Nabelek and Jennings, 1981; Nabelek and Mason, 1981). For example, Nabelek and Jennings (1981) demonstrated that discrimination of 10-year-old children and of adults older than 64 years significantly decreased when reverberation time in quiet conditions exceeded .5 sec.

Another factor to be considered is that the addition of noise to reverberation degrades speech intelligibility more than would be expected on the basis of speech-in-noise or speech-in-reverberation alone. For example, Finitzo-Hieber and Tillman (1978) demonstrated that the combination of a +6 signal-to-noise ratio and a .4-sec reverberation time caused a 23.2% decrease in discrimination from the quiet anechoic condition, while the predicted decrease (decrease due to .4-sec reverberation + decrease due to noise) was only 16.8%.

Despite the recognition that classroom accoustics are important (e.g., Ross, 1978; Olsen, 1977), relatively little attention has been focused on the ability of normal-hearing children to discriminate reverberant speech. This, despite the fact that the child is expected to function in classrooms where reverberation times average between .6 sec to well over 1 sec (McCroskey and Devens, 1975). Reverberation times of the latter magnitude are sufficient to interfere with speech discrimination scores of adults. However, the paucity of knowledge about the discrimination abilities of young, normal-hearing children does not justify the assumption that reverberation times of the former magnitude allow optimum discrimination of speech by children in the classroom.

In general, children function more poorly than adults in difficult listening situations. Developmental effects, such as an increase in ability with increase in age, have been demonstrated for difficult listening tasks such as discrimination of speech-in-noise (e.g., Elliott, et al., 1979), of dichotic messages (e.g., Mirabile, et al., 1978), and of time-compressed speech (e.g., Beasley, et al., 1976). Since reverberation degrades the speech signal by causing a temporal form of masking (Houtgast and Steeneken, 1973; Lochner and Burger, 1961), it seems likely that developmental changes in performance will occur for reverberant speech materials as it has for other degraded speech tasks. While Nabelek and Jennings (1981) have demonstrated that perception of reverberant speech by 10-year-olds is inferior to that of young adults, the change of discrimination ability in children was not investigated. When does the discrimination ability of children become similar to that of an adult? The development of the ability to discriminate phonemes under reverberation will be investigated in this study.

Another variable which has been investigated as a factor affecting discrimination of speech under reverberant conditions is mode of presentation (monaural versus binaural). A binaural advantage has been demonstrated for both normal-hearing and hearing-impaired adult listeners under certain conditions of reverberation (e.g., Moncur and Dirks, 1967; Nabelek and Pickett, 1974a,b; Gelfand and Hochberg, 1976). However, the effect of this variable has not been studied in children.

Finitzo-Hieber and Tillman (1978) found that the monaural speech discrimination scores of a group of normal-hearing children, aged 8 to 13, were poorer than the binaural speech discrimination scores of adults obtained by Crum (1974) under the same reverberant conditions. Since the mode of presentation differed, as well as age, it is difficult to ascertain which of these two factors caused the difference in performance. Studies with children using dichotic input have shown immmature performance by young children and approximations of adult performance by age 13 (e.g., Willeford, 1978; Plakke, 1979). It is possible that the binaural advantage which has been found in adults may not be found in children. A direct assessment of children's performance on reverberant speech materials with monaural and binaural presentation is therefore necessary to ascertain whether or not children of different ages benefit from binaural listening under reverberant conditions.

The fact that introducing reverberation and/or noise degrades speech discrimination is an important consideration in architectural design. Examination of patterns of errors, however, will lead to a better understanding of the masking effect of reverberation. While analysis of errors made by adults has been undertaken for auditoria (e.g., Knudsen, 1929; Steinberg, 1929) and for small rooms (e.g., Nabelek and Pickett, 1974a,b; Gelfand and Silman, 1979), this sort of analysis has not been performed on errors made by children. A comparison of the type of errors made by children and adults will be included in this study.

In summary, the present study is designed to determine: (1) If short reverberation times typical of modern classrooms affect the phoneme discrimination ability of school-age children, (2) If the phoneme discrimination ability of children changes as a function of age under these short reverberant conditions, (3) If there is an increase in the phoneme discrimination performance under binaural listening conditions as compared with monaural listening, and (4) If the pattern of errors made by children under reverberant conditions changes as a function of age.

CHAPTER II

REVIEW OF THE LITERATURE

The following review of the literature is divided into two major sections: studies pertinent to the developmental aspects of children's performance on psychoacoustic, speech perception, phoneme discrimination, and phoneme production tasks; and studies on reverberation and its effects on speech discrimination in normal-hearing adults and children. The review of the literature on children is limited to studies in which behavioral measurements were obtained.

DEVELOPMENTAL STUDIES

Developmental studies are difficult to interpret for the same reasons that complicate their design. Because more than one age group of subjects is studied, the experimental method should be appropriate for all subjects tested. But children of different ages differ in cognitive ability, as well as in attention span and in motivation.

If different experimental methods are used for younger than older children, procedural differences may underlie differences in performance. However, if the same method is used for all subjects, differences in the ability of subjects of different ages to function on the experimental procedure may affect the validity of the measurement. For example, a discrimination task which requires that the subject make a quality judgment (same/different, higher/lower, louder/softer) should not be administered to children younger than age 5 or 6 since these concepts are not usually known to younger children (Piaget, 1968; Carter, et al., 1972; Bangs, 1975). Thus, when performance changes as a function of age, it is difficult to determine the underlying cause for the change in performance because both perceptual and cognitive abilities are factors.

Psychoacoustic Tasks

The classic study of threshold in children is the Pittsburgh study (Eagles, et al., 1967). A total of 5748 children, aged 5 to 14, were studied over a period of eight years. Of these children, 1191 participated in the study for five to six years. For the children with hearing better than 5 dB HL (re. ASA 1951), an improvement in threshold was found over the five to six years of participation in this longitudinal study. The investigators offered two possible explanations for this improvement in threshold with increased age: (1) the decrease in occurrence of otitis media in the older children, and (2) an increase in familiarity with the test procedure on the part of the older children. The second explanation does not seem likely, since other studies which have been cross-sectional rather than longitudinal in design have also found better thresholds in older than younger children.

Roche, et al. (1978) have also done a longitudinal study on the thresholds of children ranging in age from 4 to 18 years. Because the age range of subjects extended through age 18, asymptotic performance could be examined. The study revealed that better thresholds were obtained on the 12 to 17-year-olds than on the younger children. The finding of asymptotic performance around age 12 is consistent with results of studies on some auditory discrimination tasks where adult-like performance was exhibited by children aged 12 or 13.

The findings of Kennedy (1957) are similar. Subjects in this study ranged from age 3 to age 18. A group of subjects ages 18 to 23 were included in order to obtain normative data. Again, improvements in threshold were found in subjects younger than age 15. Because the subjects were ages 3, 4, 5, 6, 7, 8, 10, 12, 15 and 18, it is diffficult to determine at which age adult-like performance was attained. It is possible that asymptotic performance occurred between the ages of 12 and 15.

Lenihan, et al. (1971) obtained thresholds for pure tones on children ages 5, 9, and 14 (886 normal ears). Again, thresholds improved from age 5 to age 14. Because only three age groups were included in the study, it is difficult to get a clear picture of the magnitude of change as the children grow older.

Maxon (1977) obtained pure tone thresholds on children ages 4, 6, 8, 10, and 12. The thresholds decreased systematically with increasing age at all frequencies (250 through 8000 Hz). The thresholds of the 12-year-olds were close to the thresholds of adults.

Elliott and Katz (1980) reported that the thresholds of 10-year-old children were obtained at lower sound pressure levels than those of 6-year-olds when a three-alternative, forced-choice adaptive procedure was used to obtain threshold at 500 and 2000 Hz. The thresholds obtained on a group of adults using the same experimental procedure were at even lower sound pressure levels.

All of the studies cited have shown a change in absolute threshold as a function of age. Elliott and Katz (1980) point out that change in threshold may be due to several factors: attention effects, learning effects, earphone leakage, differences in the size of the ear canal of subjects of different ages, middle-ear disorders in children, the experimental method, and differences in sensitivity. It is possible that some or all of these factors might account for the findings of the previously mentioned studies.

Many of the psychoacoustic studies on differential thresholds of children have concentrated on the measurement of frequency discrimination. Several studies of frequency discrimination have demonstrated an improvement in discrimination as a function of age. Endovitskaya (1959) conditioned 40 subjects, ages 4 to 7, to discriminate between two frequencies. While children 4 years and older were able to learn this discrimination, younger children could not perform the task.

Repina (1961) tested the ability of 42 children, ages 3 to 7 years, to detect a frequency change of 30 Hz. Children younger than 5 years were unable to make the discrimination, while the older children could. In a second study, 3 to 5-year-old children were taught to label three different pure tones of 250, 400, and 1500 Hz. The younger children were able to label only the highest and lowest tones, while the older children learned to label all three. Again, better identification ability was demonstrated with increasing age. Because these studies were done in Russia and the results were reported in a secondary source, little detail is available regarding the experimental design of these experiments. The results, however, are consistent with the studies of Soderquist and Moore (1970) and of Duell and Anderson (1967).

Soderquist and Moore (1970) used a method of constant stimuli to obtain difference limens for frequency on 54 childen, ages 5, 7, and 9. Test tones were presented binaurally through headphones at a loudness of 77 phons. It should be noted that the younger children were first taught the concept of "higher/lower" while the older children already knew the concept. The difference limen for the 5-year-olds was found to be much larger than for the 7-year-olds, while there was no difference between the 7 and 9-year-olds. With training on the discrimination task, the difference limen decreased for all age groups. The younger children still exhibited larger difference limens than the older children. It is likely that cognitive differences, rather than differences in sensory abilities, underlie the differences in performance by older and younger children.

Duell and Anderson (1967) also studied frequency discrimination in first, second, and third-grade students. They demonstrated changes in performance as a function of grade. The experimenters asked the children to make a same/different judgment for each tone pair. The standard tone was low in frequency (ranging between 390 and 440 Hz) and the two tones differed by standard musical intervals (ranging from a third of a half step to a major sixth). Because the experimenters were interested in pitch discrimination information for purposes of music training, the choice of musical intervals is an understandable one. The difference limen was taken as the smallest interval on which three of four discriminations were correct. Analysis of variance showed a significant difference in performance between grades with better performance by children in the higher grades.

In this study, extremely large difference limens were obtained. The experimental procedure may have contributed to these findings.

The children were tested in a classroom through a loudspeaker. Differences in subject location could affect the level of the tone, due to standing waves and the failure to control distance of the listener from the sound source. As Shower and Biddulph point out (1931), intensity cues may confound the measurement of frequency discrimination. Further, since grade level was the criterion for subject selection, the age of the subjects was not controlled adequately. And since large groups of subjects were tested in one experimental session, it was impossible to control subject motivation and attention. Although a developmental difference was found in this study, the underlying cause of the grade level difference is unclear.

Another study of discrimination ability in children is that of Eguchi (1976) who examined the difference limen for formant frequencies of synthesized vowels. Ninety children, ages 7 to 15, and ten adults served as subjects. An ABX method was used to obtain the difference limen. A decrease in the size of the difference limen was seen between ages 7 and 11, at which time performance was equivalent to adult performance. A complication in interpreting the results of this study is the possibility that use of an ABX procedure may not be suitable for young children. Pisoni and Lazarus (1974) point out that the ABX procedure places a load on the memory of adults. This factor could have even more effect on experimentation with children.

Abromovitz (1971) tested the ability of children ranging from age 5 to 10 to recognize environmental sounds, discriminate speech intonation, identify simultaneous environmental sounds, and discriminate tone pairs varying in duration, pitch, interval, and loudness. All subjects could be expected to have some familiarity with the test stimuli with the exception of the fourth task. A significant difference was found between the youngest and oldest subjects, although differences between adjacent age groups were not statistically significant.

This increase in auditory perceptual abilities with age is again reported by Fior (1972). Performance of seventy subjects, aged 3 to 13, was measured for a variety of psychoacoustic and speech discrimination tasks which included measurement of pure tone threshold, pure tone adaptation, auditory fatigue, masked pure tone detection, difference limens for intensity, and speech discrimination in quiet and in noise. While the results did not reveal developmental differences in performance on all tasks; the pure tone thresholds, detection of pure tones in noise, and the speech discrimination scores all showed improvement with age. Fior concluded that maturation occurs gradually, with maximum acuity reached by age 13.

Unfortunately, complete data were not provided in Fior's paper. Moreover, since a statistical analysis was not done, the reader is unsure of the significance of the observed age differences. Another factor which makes interpretation of this study difficult is the lack of information on the test procedures used. There is no indication that test procedures were modified in any way for the younger subjects, other than throughthe use of different word lists for that group. It is therefore possible that some of the differences found between age groups may be due to cognitive differences, i.e., differences in the abilities of the children to perform a particular experimental task.

Another study which points to a trend of improvement in performance with age is that of Siegenthaler (1969) who tested normal-hearing children aged 3 to 12. Changes in performance as a function of age were demonstrated for pure tone thresholds, localization, reaction time to a tone, speech reception thresholds, speech-in-noise thresholds, and perception of interrupted speech. For some of the tasks, improvement in performance was seen only in the younger children. Performance on pure tone threshold, speech reception threshold, and speech discrimination did not improve past age 8. Improvement in performance did continue to age 11 for the speech-in-noise task and to age 12 for the reaction time task.

Two aspects of the research design complicate interpretation of Siegenthaler's study. Sub-tests were not administered to all age groups. Furthermore, adult norms are unavailable for the specific test procedures. Nevertheless, these findings would suggest that the more complex the task, the older the child must be before maximum performance is attained.

Maxon (1977) measured pure tone thresholds, as well as difference limens for intensity and frequency and temporal integration of loudness abilities of children ages 4 to 12. The four tasks were chosen to represent progressively more difficult psychoacoustic tasks. Special care was taken to assure that test methods were appropriate to all subjects. For the pure tone threshold and temporal integration tasks, the 4 and 6-year-olds were tested using a play audiometry procedure, while the older children raised their hands to indicate that a stimulus had been heard. A standard audiometric procedure was used to obtain threshold, while a method of limits was used to obtain threshold for 25 through 800 msec. durations at 500, 1000, 2000, and

4000 Hz. A method of constant stimuli requiring a same/different response was used for both difference limen procedures. Differential thresholds for frequency and intensity were obtained at 500, 1000, 2000, and 4000 Hz. The difference limen for frequency was obtained at only one level (standard at 40 dB SL), while the difference limen for intensity was obtained at 10, 20, 40, and 60 dB SL. A fixed schedule of reinforcement was used to maintain subject attention throughout testing.

Once again, the results of the study reveal an improvement in performance with increasing age. Findings include a significant decrease in the size of the difference limens for intensity and for frequency, and a significant decrease in temporal integration thresholds as a function of age ($p < .001$).

Thus, as the child grows older his performance on psychoacoustic tasks becomes more and more similar to that of an adult. It is difficult to pinpoint the exact age when the children's performance on auditory tasks approximates adult performance. Lack of uniformity of the ages of subjects included in developmental studies precludes direct comparisons between studies. Differences in the measurement procedures also make comparison of studies difficult. An adult control group is rarely included to facilitate comparisons between the performance of children and adults. Despite these methodological shortcomings, many investigators have found that children's performance on psychoacoustic tasks becomes similar to that of adults at the age of 12 or 13.

Speech Perception Tasks

It has long been recognized that speech intelligibility is dependent on a number of factors -- the speaker, the test material, the test environment, and the listener. When the listener is a child, special care must be taken to insure that test procedures, test materials, and response mode are appropriate to his cognitive and motoric abilities. Furthermore, control over attentional factors must be exercised in order to insure reliable test results. While many different test materials are available for adults, the choice of materials for children is somewhat limited. Keaster (1947) recommended a procedure for finding speech reception thresholds on young children. She suggested that common nouns be used in sentences directing the child to do something. The child was provided with pictures representing the key nouns and was asked to follow certain directions, e.g., "Give mother the dog." The lowest level at which the child could follow three directions was taken as the threshold. A similar procedure in which a child was asked to point to pictures or objects from an array of such pictures or objects representing spondaic words has also been recommended (Siegenthaler, Pearson, and Lezak, 1954; Sortini and Flake, 1953). A picture test in which the child is asked to choose the picture representing the test word (monosyllable) from a closed set of two words per test item is also available (Threshold by the Identification of Pictures, Siegenthaler and Haspiel, 1966), as is a spondee word list which has been modified for use with children (Newby, 1958).

Materials and procedures have also been developed in order to test speech discrimination abilities of children. The Phonetically

Balanced Kindergarten List (Haskins, 1949), the Word Intelligibility by Picture Identification test (Ross and Lerman, 1970), the Discrimination by Picture test (Siegenthaler and Haspiel, 1966), and the Northwestern University Children's Perception of Speech Test (Elliott and Katz, 1980) are some of the materials presently available for clinical use. While these tests are more likely to be suitable for younger children in terms of appropriateness of vocabulary, all subjects will not necessarily know all the vocabulary items. Older children may thus perform better than younger children on these word tests due to cognitive, rather than perceptual, differences.

Sanderson-Leepa and Rintelmann (1976) compared performance by children ranging in age from 3½ to 11½ years on the WIPI, the PBK's, and the NU-6, CNC (Northwestern University Consonant-Nucleus-Consonant lists) test, a speech discrimination test for adults. The children's discrimination scores were highest on the WIPI, followed by the PBK's, and then the NU-6. The WIPI was judged to be most appropriate for the 3½-year-olds, not only because they obtained better mean scores on this test, but also because there was less variability in their scores. Both the WIPI and the PBK lists were judged to be age appropriate for children ages 5½ and older based on percentage correct and variability of scores. Performance of the 11½-year-olds was essentially at adult level, i.e., they exhibited good ability to discriminate words and homogeneous test scores on both measures. Differences in word familiarity of the vocabulary of the NU-6 lists and the PBK lists were thought to be the source of the differences in performance by the younger children on these materials.

Differences in performance on the WIPI and the PBK materials might be due to differences in the design of the tests. The WIPI is a closed-response set test, i.e., the child indicates his answer from a finite set of choices, while the PBK is an open-set test. Word familiarity effects and other factors may also contribute to the differences in performance.

Hodgson (1973) compared the performance of children aged 5 to 9 on the WIPI used as an open-set test and as a closed-set test. The first method required that the subject repeat the stimulus word, while in the second method the subject pointed to the picture representing the stimulus word from an array of six pictures. The subjects were also tested with PBK lists. Both the WIPI and PBK lists were recorded and low-pass filtered (1560 Hz setting) before presentation in order to avoid ceiling effects. The older children scored better than the younger children on the WIPI test in both closed and open conditions. Approximately 10% difference was found between these two conditions for each of the groups of children. Significant differences were obtained ($p < .01$) between scores as a function of age and test condition (open vs. closed set).

Hodgson found the WIPI words and PBK words to be of equal difficulty; the mean scores for the younger children on the WIPI (open set) was 68.7% (s.d. = 9.7%) and on the PBK was 68.8% (s.d. = 10%). For the older children the WIPI mean score (open set) was 76.3% (s.d. = 5.3%) and on the PBK was 75.5% (s.d. = 5.8%).

As noted, older children performed better on both the WIPI and PBK tests. Other studies also provide data demonstrating changes in speech perception with age. Siegenthaler (1969) reported a decrease in the speech reception threshold as a function of age. Boothroyd (1968) found an increase in speech discrimination scores on monosyllabic words between ages 6 and 9½. Marsh (1973) mixed spondees with wideband noise and tested children ages 5 to 9. Performance improved as a function of age. Goldman, Fristoe, and Woodcock (1970) similarly reported an increase in speech discrimination ability in noise as a part of the normative data for their discrimination test.

Elliott, et al. (1979) recently studied speech perception abilities of children in quiet and in noise on a closed-response test consisting of monosyllabic nouns that had been standardized on inner-city children, aged 3. An adaptive testing procedure was used to obtain threshold (71% level) in quiet and noise. Four groups of subjects were tested: normal children age 5 to 10, 5 to 10-year-old children with articulation problems, children of the same age with learning problems, and a group of adults. A developmental change in speech thresholds was found for the quiet condition, with the 10-year-olds performing similarly to adults. No age-related trend in performance was evident for speech-in-noise (twelve-voice babble or speech spectrum noise). Children with learning problems performed more poorly than those who were at grade level.

This study clearly demonstrates developmental changes in speech reception abilities in children. The failure to find an age-related difference in performance for the speech-in-noise is somewhat surprising in view of the results of other studies. The finding of poorer performance of children with learning problems may be attributed to cognitive differences between groups.

In another study, Elliott (1979) examined the performance of children ages 9 to 17 on the SPIN (Speech Perception in Noise) test. This test differs from other speech discrimination tests already discussed because the test materials are sentences in which a keyword must be reported. Half of the test words are in high probability sentences, while the other half are in low probability sentences. The test could be expected to be strongly influenced by cognitive factors, since semantic and syntactic knowledge can affect performance. A developmental approach toward adult performance for the high probability sentences was found under the difficult listening condition of 0 dB S/N. This change in maximum score as a function of age was attributed to growing knowledge of the language rules by the younger subjects. It is interesting that in this study developmental changes were found only in the noise condition, while in the threshold study changes were found only in the quiet condition. The threshold procedure involved a closed-set test. It is possible that in quiet, differences in word familiarity could affect the measure. Once the test situation was made more difficult by adding noise, degradation of the acoustic cues could minimize the word familiarity effect. Because the test was at threshold, the task then became a recognition task in noise and performance was similar acros age groups. In the SPIN test situation, addition of noise served to accentuate inter-subject differences. Thus, if the older children have greater knowledge of language, they will utilize that information better in a more difficult environment. Utilization of such knowledge may be less crucial in quiet where the redundance of the acoustic signal and contextual cues allow asymptotic performance for all subjects.

Boothroyd (1970) in an analysis of developmental factors in speech discrimination presented a model of a speech reception task whereby an incoming stimulus is analyzed and categorized. Once a decision of word category is made, a response is given. He proposed that the younger child may have an underdeveloped phoneme or word category or that he may have an inadequately developed "decision process," i.e., the ability to use context or knowledge of probability of word occurrence. An assessment of this latter factor was done by having 7-year-old children recognize monosyllabic words which had been high or low-pass filtered. Children's scores were more depressed on the filtered speech materials than were adult's scores. This is similar to Elliott's findings on the speech-in-noise task. Boothroyd recommended the use of phoneme scoring as a way of minimizing the age effect on speech discrimination tasks.

Other studies have demonstrated that developmental changes will be evident when the speech signal is degraded, whether by introducing a competing signal (Berlin, et al., 1973; Mirabile, et al., 1978) or by temporal distortion (Beasley, et al., 1976). The findings on speech-in-noise tasks and on filtering have already been mentioned. These age-related changes may reflect the need of the younger child for a redundant acoustic signal.

Berlin, et al. (1973) tested 150 right-handed children ages 5, 7, 9, 11, and 13 on a dichotic listening task. The stimuli used were CV nonsense syllables. All children had normal speech and language and were able to correctly identify the CV stimuli monaurally (100%).

The test results were scored in order to obtain information about double correct, single correct and double error responses.

An important finding of the study was the change in total accuracy, phonetic content and in the nature of errors as a function of age. While the right-ear advantage for dichotic listening was evident even in the 5-year-olds, older children were better able to identify both stimuli and made phonetic errors more similar to those of adults. This would seem to indicate an increasing capacity to process simultaneous stimuli as a function of age.

Another interesting dichotic measure was described by Mirabile, et al. (1978) who investigated the dichotic lag effect in 150 children, ages 7 to 15. Stop CV syllables were presented with onset asynchronies of 0, 15, 30, 60, and 90 msec. Analysis of the data involved the factors of age, sex, lag time, and lag ear.

Results showed an improvement in double correct performance with age, through age 11. The lag effect (better performance for the lagging message) was seen for all ages and each ear. Identification of the leading item increased in older subjects as the time between the stimuli increased. Female subjects performed better than male subjects in all age groups.

A model of temporal efficiency of processing was proposed in which younger children made phonetic decisions more slowly than older children. This would account for the fact that for the young subjects there were fewer double correct scores until long asynchronies, and the rate of growth of double correct scores was slow, whereas the older subjects began to get more double correct scores at small asynchronies and got many more double correct as asynchrony increased.

Beasley, et al. (1976) used time-compressed recordings of the WIPI and the PBK tests in order to study the effects of age, test material, and level of presentation. Subjects ranged in age from 3½ to 8½. Compression times of 0, 30% and 60% were presented at 16 dB and 32 dB SL.

The study revealed that as time compression increased, discrimination decreased; as sensation level increased, discrimination increased; and as age increased, discrimination increased. The improvement in performance as a function of age was greater on the PBK lists which are more difficult.

As has been pointed out, familiarity with vocabulary has been shown to be an important variable in speech testing. In fact, it has usually been a confounding variable in the measurement of children's speech discrimination ability (Elliott, et al., 1979). Elliott recently hypothesized that even when vocabulary familiar to 3-year-old children is used to test older children, the cumulative frequency of usage may be advantageous to older children. The use of nonsense syllables could nullify any advantage that older children have with meaningful stimuli. Nonsense syllables are less subject to memory effects than real words. They also allow more accurate analysis of errors (Fletcher and Steinberg, 1929; Miller and Nicely, 1955).

Meaningful stimuli have been widely used clinically for both adults and children. However, nonsense syllables have been used in the evaluation of communication systems (Campbell, 1910; Fletcher, 1922; Fletcher and Steinberg, 1929), for experimental evaluation of phoneme perception by normal-hearing and hearing-impaired adults (Miller and

Nicely, 1955; Singh, Woods and Becker, 1972; Wang and Bilger, 1973; Walden and Montgomery, 1973; Resnick, et al., 1975; etc.), and for phoneme perception and production studies on children (Graham and House, 1971; McGarr , Stromberg, and Hochberg, 1977; Templin, 1957; Shvachkin, 1973). In general, the primary advantage of nonsense syllables is that it allows separation of the phonetic aspect of speech discrimination from the lexical aspect. This separation can be especially useful in the design of a developmental study.

Phoneme Discrimination Tasks

In addition to the studies which have dealt with the question of developmental changes in speech discrimination abilities, there are studies concerned with developmental changes in phoneme perception and production abilities. Unfortunately, most of the studies dealing with phoneme perception abilities do not cover a full range of ages, perhaps because it has been assumed that development of phoneme perception occurs at relatively young ages, i.e., prior to age 3 (Winitz, 1969). Shvachkin (1973), Garnica (1973), and Edwards (1974) have all shown a gradual acquisition of phonemic perception. The oldest children tested in the Shvachkin and Garnica studies were younger than 2-years-old; and 3 years, 11 months was the oldest age included in the Edwards' study. Templin (1957) studied speech sound discrimination abilities of a large group of children over a wide range of ages (3 to 8). Findings included developmental increases in discrimination scores up to age 8, although very little change in score was evident after approximately age 5.

Studies of discrimination ability also point to differences in performance as a function of age, although there is no agreement as to when performance is equivalent to that of an adult. Graham and House (1971) employed a two-alternative, forced-choice (same/different) paradigm to test perception of phonemes. Sixteen consonants were embedded in a polysyllabic nonsense word. Thirty subjects, ages 3 to 4½, with normal speech and hearing were asked to make a total of 672 judgments after undergoing a training period. Errors were analyzed for those pairs with error rates greater than 20%. Errors were made on pairs differing by only one distinctive feature and associated with the features coronal, anterior, continuant, and voiced. The children made errors similar to those of adults, but more often. Because older children were not tested, changes in perception with increasing age could not be ascertained.

Tikofsky and McInish (1968) also used a same/different paradigm to test phoneme discrimination of four subjects, age 7. Fifteen different initial consonants were compared in word-word, word-nonsense syllable, and nonsense syllable-nonsense syllable pair environments. Although the children made very few errors (2%), it is of interest that the errors involved contrasts differing by only one distinctive feature (place of articulation or voicing). Most frequent confusions were between /f/ and /θ/, /v/ and /ð/. It would have been interesting to look at the performance of younger subjects, although adjustment of the experimental design might have been required to accommodate them.

Stewart, Singh, and Hayden (1979) measured Choice Reaction Time

(CRT), rather than correct identification of phonemes. A total of 33 children ages 5, 6, and 7 were tested. In order to be included in the study, subjects were required to exhibit normal articulation, normal hearing, and an understanding of the concept of same/different. The study revealed a change in CRT as a function of age. The CRT for the 5-year-olds was much higher than for the older children, although their response strategy was the same. The CRT decreased in all age groups as the contrasts differed in number of features, i.e., judgments took longer between two phonemes differing by only one distinctive feature than between phonemes which differed by two to five features. Clearly the children were able to discriminate between the phonemes in question, however, the differences in reaction time as a function of age point to cognitive differences between age groups. The task was more difficult for the younger than the older subjects. Increasing the difficulty of a discrimination task by reducing the redundancy of the signal could be expected to cause poorer discrimination performance by the younger subjects, reflecting poorer cognitive abilities in a similar way.

Phoneme Production Tasks

The developmental aspect of speech production ability has also been examined. Children younger than 2-years-old have been studied, however the data are specific to each child (Leopold, 1947; Moskowitz, 1970; Velten, 1943). Wellman, et al. (1931) tested children ages 2 to 6; Poole (1934) tested 2½ to 8-year-olds; Templin (1957) tested 3 to 8-year-olds; and Prather, et al. (1975) tested 2 to 4-year-olds. While the studies are in general agreement as to the order of acquisition of phonemes, there are discrepancies on the age of acquisition (percentage of children producing the phoneme correctly).

Templin (1957) demonstrated that most consonants were produced correctly by 75% of her subjects by age 6, and all consonants by age 7. Poole (1934) used a higher criterion (100% correct production by subjects) and thus showed slightly higher age ranges. Prather, et al. (1975) found 75% correct production at earlier ages than did the other researchers. There are, of course, individual differences. Often children younger than age 7 are able to correctly produce all phonemes.

In summary, a review of the literature reveals developmental changes in children's performance on psychoacoustic tasks, speech perception tasks, phoneme discrimination tasks, and phoneme production tasks. The nature and complexity of the experimental situation, as well as the properties of the test stimulus all play a role in determining the age when asymptotic performance will be obtained.

Knowledge of developmental changes in auditory abilities of children is important because of the crucial role of hearing in the acquisition of language and speech. If children need an auditory signal which is of greater intensity and clarity than that required by adults, that need should be carefully considered in the educational setting. In the classroom a speech signal may be heard incorrectly by a child for various reasons: the signal may be of insufficient intensity, there may be too much competing noise in the environment, there may be excessive reverberation in the environment, or all of these factors may act in combination to affect discrimination ability. The literature on reverberation, its measurement, and its effect on speech intelligibility will be reviewed in the next sections.

REVERBERATION STUDIES

Reverberation and its Effects

When a signal is generated in a room, the sound wave travels outwards from the source until it hits the wall, floor, or ceiling of the enclosure; at which point, part of the signal is absorbed and part of the signal is reflected back into the room at an angle equal to the angle of incidence. These reflected waves will in turn be reflected. The effect of the enclosure, then, is to sustain intensity and to modify the original signal. The early reflections give rise to the perceptual effect of coloration which have an effect on the quality of the received signal (Berkley, 1980). These early echoes will also reinforce the direct signal (Lochner and Burger, 1961). Later reflections are perceived as echoes and affect the intelligibility of the perceived signal (Berkley, 1980). The prolongation of sound and modification of the signal caused by the reflections is reverberation.

Reverberation has been described by Nabelek and Jennings (1981) as the most pervasive contaminator of speech and by Lochner and Burger (1964) as the most important factor in shaping the acoustic character of a room. Whereas in the free field, sound decreases by 6 dB SPL for every doubling of distance from the source; the volume of the room, type of reflective surfaces in the room, and the distance between the signal source and the listener all affect the intensity of the sound in a room. The traditional parameter which has been studied in evaluating the effect of room acoustics on speech perception is reverberation time, which is defined as the time necessary for the original signal to decay by 60 dB once the sound is terminated. Reverberation time of a particular room may be calculated or may be measured (Knudsen and Harris, 1950). Since calculations are most appropriate only when the room in question is large and the sound field is diffuse (i.e., reverberation is equal in all parts of the room), actual measurement of reverberation time over a range of frequencies is advisable (Knudsen and Harris, 1950). Fletcher (1965) has recommended that the average of the reverberation time at 500, 1000, and 2000 Hz be used as the single number to characterize the reverberation time of a room being used for speech.

The impedance of the materials used in the construction of the room will, to a large extent, determine the reverberation time of a room at different frequencies. Knudsen and Harris (1950) provide information on the absorption characteristics of different materials. The less sound that a particular material absorbs, the longer will be the reverberation time. Another factor to be considered is that different materials will absorb different amounts of sound energy at different frequencies, thus the need for reverberation measures at various frequencies.

Equal reverberation time does not necessarily have an equal effect on the perception of a speech signal. According to Lochner and Burger (1964), the amplitude of the reflections as well as the pattern of reflections will determine how reverberation will affect a speech signal. Thus equal reverberation time will have a greater effect on speech discrimination in a smaller room than in a larger room because the distribution of reflections in the two rooms will differ (Nabelek and Robinette, 1978b).

The distance between the speaker and the listener will also affect the person's perception of speech in a reverberant environment. If the distance between the speaker and the listener is small, the direct sound will predominate. If the distance between the speaker and listener exceeds a certain critical distance, the reverberant energy predominates (Peutz, 1971). The critical distance is defined as the point where the intensity of the direct sound is equal to that of the reflected sound. Once the critical distance has been exceeded, the speech threshold should remain relatively constant, regardless of the distance between the speaker and listener. This is in contrast to the direct field where signal-to-noise ratio decreases as distance between the speaker and the listener increases (Nabelek, 1980).

There are a number of ways to measure reverberation time. All methods include the introduction of an intense sound into a room, abrupt termination of the sound, and measurement of the amount of time which it takes for the sound level to decay by 60 dB from its original level. The sound source may be wideband (e.g., a gunshot or white noise) or narrowband (e.g., narrowband noise or a frequency modulated tone). The analysis of the reverberation time may be done on site at the time of the measurement by reading the output from the measuring instrument into a graphic level recorder and using a special protractor to read out reverberation time, or it may be done by recording the reverberation on tape and analyzing the recording later in the laboratory (Broch and Jensen, 1966; Kingsbury, 1972).

The reverberation effect has been treated by most investigators as a form of masking. Bolt and MacDonald (1949) formulated a statistical theory in which speech is seen as a series of pulses with a 30 dB intensity range in any frequency band. Using rate and durational values obtained from spectrograms, the authors calculated an articulation index as a function of reverberation time. Predicted scores were in good agreement with actual data from real rooms.

Lochner and Burger (1961) approached the masking effect of reverberation differently. They took impulse measurements of a room in order to obtain information about the reflection patterns of that particular room and the signal-to-noise ratios in the room. A weighting scale was derived to be used to make predictions about speech discrimination. Only echoes occurring 95 msec. after termination of a sound would cause interference with the intelligibility of a speech signal. Predictions were in good agreement with actual measurements in three different rooms.

Santon (1976) also attributed the interference of reverberation with speech intelligibility to the late reflections, but he emphasized the need to consider the direction of the reflections generated in the room as well as their pattern. The masking effect of reverberant energy is assumed to be similar to that of noise and the direction of the energy will affect the amount of interference that will occur. Santon found that his predictions were in agreement with measured scores.

Houtgast and Steeneken (1973) proposed a very different way of looking at room acoustics. They treated the effect of the room as a low-pass filter which caused a "time smear." The modulation transfer function is proposed as a method which will account for reverberation and interfering noise factors. Quantification of this effect is obtained by looking at the decrease of the modulation depth of a sine wave modulated envelope which has been introduced into a room.

A further development of this approach has been detailed by Steeneken and Houtgast (1980). A Speech Transmission Index (STI) can be calculated to predict the articulation scores which will be obtained in a room. The modulation transfer function of the room is obtained for seven 2/3-octave noise bands. The STI is then calculated. Factors considered in the calculation include upward spread of masking, signal-to-noise ratios, frequency modulation, and the different octave bands included. Actual measures obtained on speech processed at reverberation times of 0.9, 1.4, 2.1, and 3.2 sec were in good agreement with predicted values.

The approach of Houtgast and Steeneken is an interesting one because it encompasses masking factors other than reverberation, *per se*. Neither the Modulation Transfer Function nor the Speech Transmission Index has been used to any great extent. Measured reverberation time, despite the admittedly limited information which it reveals, continues to be the major descriptor of room acoustic effects.

While reverberation effects have repeatedly been conceptualized as those of a masker (as described above), very few studies have compared the effect of reverberation to that of noise. While Knudsen (1929) and Fant (1973) reported differences in the errors made by listeners for speech-in-noise and speech-in-reverberation, Gelfand and Silman (1979) and Nabelek and Mason (1981) found no difference between errors made in noise and reverberation on a closed-set test (Modified Rhyme Test). It is possible that the differences reported by Knudsen and by Fant are applicable only to reverberation times typical of large enclosures. Another possibility is that use of the Modified Rhyme Test in the latter studies affected the error patterns causing the same pattern to occur for both noise and reverberation. Further attention should be given to this question.

Effect of Reverberation on Speech Perception

The preferred method of determining the effect of reverberation on speech intelligibility is to use real room reverberation (Nabelek and Robinette, 1978b). One way of doing this is to actually place a subject in a reverberant room and then measure speech intelligibility in that room (Steinberg, 1929; Nabelek and Pickett, 1974a,b; Finitzo-Hieber and Tillman, 1978; Millin, 1968). An alternative method is to record speech in a reverberant environment and then play back the speech through headphones (Nabelek and Jennings, 1981; Bergman, 1971; Moncur and Dirks, 1967; Gelfand and Silman, 1979). While simulation of reverberation is possible and, in fact, has been done in a number of studies, Nabelek and Robinette (1978b) have demonstrated that simulation techniques are unsuccessful in recreating the detail of real room reverberation, i.e., the distribution of reflections or the number of reflections necessary to create realistic reverberation. Various methods have been used to simulate reverberation and valuable information has been obtained about temporal masking, although none of these methods produced realistic reverberant conditions.

Lochner and Burger (1964) used a tape-delay system, as did Gelfand and Hochberg (1976). Nabelek and Robinette (1978a,b) used computer techniques to create the echoes used in an examination of the effects of a single echo and three different sets of reflections on speech discrimination. A filtering system was described by Houtgast and Steeneken (1973) to simulate real room effects. The results of discrimination tests for speech processed through their system were in agreement with data from real rooms (T=1.2, 2.4 sec). Schroeder (1970) used a computer to simulate room acoustics. However, speech discrimination testing was not done in the experiment reported. Allen and Berkley (1979) have also described a computer method for simulation of room acoustics. The thrust of their research has been to examine listener preference for various reverberant conditions. Speech intelligibility has not yet been examined with stimuli generated by this method.

Several studies have shown that reverberation degrades speech discrimination in normal-hearing adults (Knudsen, 1929; Steinberg, 1929; Moncur and Dirks, 1967; Millin, 1968; Gelfand and Hochberg, 1976; Gelfand and Silman, 1979; Nabelek and Pickett, 1974a,b; Nabelek and Robinette, 1978a; Nabelek and Jennings, 1981). In general, it has been found that speech discrimination is better for short reverberation time conditions than for long reverberation conditions, and for quiet than for noise. Equal reverberation times will have a greater effect (cause poorer speech discrimination) in a small room than in a larger room.

Knudsen (1929) examined the effect of reverberation on speech discrimination in large auditoria by measuring discrimination of nonsense syllables by listeners seated in various parts of the room. Each listener recorded his responses on an answer sheet. Articulation scores were calculated and an anaylsis of listener errors was done.

Because Knudsen was studying large rooms (volumes of 200,000 to 300,000 ft.^{3}), the reverberation times studied were quite long (1.0 to 9.0 sec). The study reveals a decrease in discrimination with increase in reverberation time. The pattern of errors made in the reverberant condition are similar to the errors which have been found in other studies.

Knudsen found a direct relationship between length of reverberation time and loudness, i.e., in large rooms, longer reverberation times were necessary for optimal listening. In smaller rooms where loudness of the direct sound was adequate, short reverberation times were optimal for listening. With a volume of 400,000 ft.^{3}, the optimal reverberation time was found to be 1.0 to 1.25 sec. Longer reverberation times caused deterioration of speech intelligibility. Vowels were least affected by reverberation and initial consonants were less affected than final consonants. Omissions and additions were noted, as well as substitutions.

Steinberg (1929) also investigated the perception of nonsense consonant-vowel-consonant (CVC) syllables under three reverberation conditions: 1.2, 2.2 and 4.0 sec. Each CVC was inserted in a carrier phrase. Thirty-two listeners participated in the study. The study revealed a decrease in speech intelligibility with increased reverberation. Nasals and stops were more affected by the reverberation than the fricatives. Steinberg felt that the temporal distortion of reverberation would be a major factor in perception of stop consonants.

Nabelek and Pickett (1974a) used the Modified Rhyme Test (MRT) to examine the effect of reverberation on speech discrimination in general and on phoneme perception in particular. All testing was done in a specially designed classroom in which reverberation time could be varied. The effect of two types of noise (eight voice babble and impulsive noise) in combination with two levels of reverberation (.3 and .6 sec) was studied on five subjects who were tested binaurally and monaurally, aided and unaided. For the monaural condition, one ear was plugged and masked.

The study revealed that increased reverberation time caused decreased speech discrimination even at these relatively short reverberation times ($p < .01$). Binaural hearing was superior to monaural ($p < .01$); a 4 to 5 dB difference was found in the unaided condition and a 3 dB difference in the aided condition. The monaural/binaural difference obtained in this study is somewhat smaller than the differences reported by Moncur and Dirks (1967) and Gelfand and Hochberg (1976). The reverberation times involved, however, are much shorter in the Nabelek and Pickett (1974a) study. Another factor which may have influenced the finding in the Gelfand and Hochberg (1976) study is the fact that the reverberation was simulated.

The pattern of errors caused by reverberation were similar to those obtained by Miller and Nicely (1955) for noise and filtering conditions. Initial consonants were discriminated better than final consonants in most cases. For all conditions, voicing was discriminated best, and manner was also fairly well discriminated. Perception of the place feature was most affected.

Moncur and Dirks (1967) tested normal-hearing subjects under four conditions of reverberation (0, .9, 1.6, and 2.3 sec). Recordings of the PB-50 word lists were made in a reverberant room through a dummy head with two microphones (interaural cues were thus preserved in the recording process). The signal was at a 45° azimuth to the microphone and the noise was at 0° azimuth. A total of 48 subjects were tested under headphones; 24 subjects with recordings that had been made in quiet, and 24 subjects with recordings that had been made against a two-talker competing speech signal at 0 dB S/N. Testing included three modes of presentation: binaural, monaural-near ear, and monaural-far ear.

Speech discrimination decreased with increasing amounts of reverberation for all of the conditions -- binaural, monaural, in quiet and in noise. Binaural discrimination in quiet dropped from 97.2% in the anechoic condition to 79.7% at .9-sec reverberation, the shortest reverberation condition in this study. The monaural-near ear score dropped from 97.5% to 72.6% in the .9-sec condition. The far-ear score was 45.9% for the same amount of reverberation, although in the anechoic condition far-ear discrimination was 95.6%. Thus, significant changes in discrimination were demonstrated, even when reverberation was under a second. Larger decrements were evident with longer reverberation times.

The binaural scores were superior to monaural scores in all the reverberant conditions. On the average, the monaural/binaural difference (near-ear) was 10%. The monaural-far ear scores were far poorer than the near-ear scores, with the exception of the quiet, anechoic condition. This finding clearly reveals the disadvantage of monaural listening for two different situations, direct and indirect listening.

Millin (1968) examined the effect of small-room reverberation on the speech discrimination of normal-hearing listeners and on hearing-impaired listeners, with and without amplification. A total of 24 subjects were tested (12 subjects per group). Testing was done in two different rooms; a sound-treated room with a very short reverberation time (T=115msec) and a small office with a longer reverberation time (T=450 msec). The use of two different rooms complicates the interpretation of the findings, since the pattern of reflections in two rooms are likely to differ along with the reverberation time.

Another aspect of the experimental design which complicates a comparison between the two groups of listeners is the use of different speech materials for assessing speech discrimination. The CID W-22 list was modified by adding some words, recorded, and used to test the hearing-impaired subjects, while the normal-hearing subjects were tested with the Rush Hughes recording of the PB-50 lists. The normal-hearing listeners were thus tested with a more difficult speech material.

Millin found large differences in discrimination between the reverberant and non-reverberant conditions for both groups of subjects. The mean difference between conditions for the normal-hearing subjects was approximately 22%. Smaller differences were found for the hearing-impaired subjects. It is likely that the use of the Rush Hughes recording is, in part, responsible for the large decrement in discrimination for the 450 msec reverberation condition. Another factor which might account for the large decrement in discrimination for both groups of subjects is the small volume of the test rooms. Nabelek and Robinette's analysis of a number of studies on reverberation demonstrates that reverberation effects are greater in smaller rooms than larger rooms, probably due to differences in the distribution of the pattern of reflections (Nabelek and Robinette, 1978a).

Gelfand and Hochberg (1976) evaluated the effect of simulated reverberation on 30 normal-hearing and 30 hearing-impaired subjects. The Modified Rhyme Test was recorded through a tape-delay system in which distinct reflections were spaced 100, 200, and 300 msec. apart with a 6 dB drop in the amplitude of each reflection. Simulated reverberation times were 1, 2, and 3 sec. Testing was done monaurally and binaurally.

Binaural scores were significantly better than monaural scores for both groups of subjects. Discrimination decreased with increase in reverberation time, but monaural scores decreased more quickly than binaural scores with increased reverberation time. The finding of a binaural advantage for both normal-hearing and hearing-impaired subjects is similar to the finding of Moncur and Dirks (1967) on normal-hearing subjects with recordings made in reverberant environments.

Nabelek and Robinette (1978a) examined the effect of short reverberation (.25 and .5 sec) and noise in a small room (volume = 13.5 m^3). The Modified Rhyme Test was used to test normal and hearing-impaired listeners, binaurally and monaurally. A significant decrease in discrimination occurred for both groups of subjects, but was slightly greater for the normal-hearing than the hearing-impaired listeners.

Binaural discrimination was significantly better than monaural for both normal-hearing and hearing-impaired listeners, but was larger for the normal hearing subjects. For example, at T=.5 sec the binaural advantage for the normal-hearing subjects was 13%, while it was 5.9% for the hearing-impaired listeners.

Gelfand and Silman (1979) studied the effect of .8 sec reverberation on 20 normal-hearing subjects. Recordings of the Modified Rhyme Test were made in a small reverberant room. Monaural discrimination was tested via earphone. Articulation scores and confusion matrices were generated for the reverberant condition and the non-reverberant condition.

Again, discrimination was significantly poorer in reverberation ($p < .001$). A significantly greater number of initial phonemes were identified than final phonemes in quiet and in reverberation ($p < .001$). The pattern of errors for the .8-sec. reverberation time was similar to the pattern of errors reported by Nabelek and Pickett (1974a); place, stop, and frication features were most affected by reverberation. Duration, sibilance, and semivowel features were relatively unaffected. The authors proposed a masking explanation to account for the errors made. Reverberation causes a speech shaped type masking whose effect is similar to that of other maskers.

The issue of the effect of reverberation on speech discrimination as a function of age has received little attention, although recently there has been interest in the prebycusic population. Bergman (1971) noted that reverberation had greater affect on older than younger subjects. Duquesnoy and Plomp (1980) and Plomp and Duquesnoy (1980) found increased speech reception thresholds in reverberation in their older subjects.

Nabelek and Jennings (1981) did include one group of children in their study of speech discrimination ability of normal-hearing subjects with mean ages of 10, 27, 42, 54, 64, and 72 years who were tested under three different reverberation conditions: .4, .8, and 1.2 sec. Recordings were made in a reverberation room with adjustable reverberation time and subjects listened to recordings in both monaural and binaural modes (through headphones). The test material employed was the Modified Rhyme Test. Analysis of variance revealed that reverberation time, mode of listening, and age were all significant factors. Speech discrimination scores deteriorated with age and reverberation, with the exception of the 10-year-old group whose discrimination was poorer than that of the young adults (mean age of 27). This finding of decreased discrimination by children under reverberant conditions is consistent with findings on other forms of degraded speech materials. Because only one group of children was tested, we do not yet have a clear picture of differences in the ability of children of different ages to function in reverberant environments. Nabelek and Jennings recommend that reverberation times no greater than .5 sec be allowed in rooms designed for children and older adults.

Another study designed specifically to measure reverberation effects on children is that of Finitzo-Hieber and Tillman (1978). Subjects in this study were normal-hearing and hearing-impaired children, ages 8 to 13. Monaural discrimination of the Northwestern University-CNC words was tested in soundfield under 12 combinations of reverberation and noise (8 talker babble): reverberation times were 0, .4, and 1.2 sec; signal-to-noise ratios were ∞, +12, +6, and 0 dB.

Increasing the reverberation time from 0.4 to 1.2 sec caused a significant decrease in discrimination for all subjects. The normal-hearing subjects were unaffected by the change from the anechoic condition to .4-sec reverberation. For the hearing-impaired subjects, the increase from 0 to .4-sec-reverberation time also caused a significant decrease in discrimination in quiet and in noise. There was a greater effect of reverberation and noise on the hearing-impaired than on the normal-hearing subjects, although the addition of noise to reverberation caused significant decrements in discrimination, even for the .4-sec-reverberation time (11.7%).

The results of this study follow the same trends as the studies on adults. An interesting observation by the authors, however, was that the normal-hearing children seem to be affected more by reverberation than were adults in a similar experiment done by Crum. In that particular experiment, adults were tested binaurally. Since binaural hearing can increase speech discrimination under reverberant conditions, a developmental study designed to make a direct comparison between children and adults seems necessary to settle this question.

If children may be affected more by reverberation than adults, then the reverberation times appropriate for learning environments should be set according to their needs. Moncur and Dirks (1967) recommend reverberation times of .8 to 1.0 sec as optimal for speech discrimination, although their data show a decrease in discrimination for the .9-sec-reverberation time condition. Knudsen and Harris

(1950) recommend a .75-sec-reverberation time as optimal for normal listeners in a classroom. If, as Ross (1978) suggests, the judgment of the criterion of optimal reverberation time be based on maximum speech discrimination ability, then these recommended reverberation times may be excessive.

Borrild (1978) describes the Danish building regulations as specifying a reverberation time between .6 and .9 sec in the frequency range between 125 and 2000 Hz for classrooms to be used for normal-hearing listeners and reverberation times not to exceed .6 sec in the same frequency range for hearing-impaired listeners. He also describes the Swedish standard which specifies a reverberation time not to exceed .5 sec for hearing-impaired students in a classroom. Nabelek and Jennings (1981) also recommend that reverberation times not exceed .5 sec for young listeners with normal hearing. There is no official standard to be used in the design and construction of schools in the United States.

Surveys of reverberation times in schools reveal that many classrooms for normal-hearing children have reverberation times far in excess of these recommended reverberation times. There does seem to be a decrease in the reverberation times of buildings which have been built more recently. Thomas and John (1957) reported measured reverberation times of 1.3 to 3.4 sec in classrooms, Tolk (1961) reported average reverberation times of 1.2 sec. Kodaras (1960) reported a range of .4 to 1.1 sec in typical elementary school classrooms. In their survey of schools which had been built between 1890 and 1960, McCroskey and Devens (1975) found that the schools which had been constructed most recently had the shorter reverberaton times. It was not uncommon to find reverberation times in excess of 1.0 sec in the older buildings, while the average reverberation time in the new buildings was .6 sec. Newer buildings tend to have lower ceilings and fewer reflective surfaces. For example, acoustic tile is used on the ceilings of newer buildings. These changes in architectural design and in materials used may be responsible for the shorter reverberation times which have been found in the more modern buildings.

The limited amount of information on performance of children on reverberant speech materials prohibits the recommendation of any one level of reverberation time as being acceptable for children of different ages. Further research is needed to determine whether or not there is a developmental effect for reverberation times which might be typical of modern classrooms.

In summary, most of the research which has been done on the effect of reverberation on speech discrimination has been done on adults. These studies reveal that discrimination decreases as reverberation increases. The addition of noise to reverberation causes greater decreases in discrimination than would be expected on the basis of noise or reverberation alone. In reverberation, the binaural listener has an advantage over the monaural listener. The pattern of phoneme errors made in reverberant conditions are similar to those which would be made in noise.

The limited information now available on the performance of children under reverberant conditions suggests that children are more affected by reverberation than are adults. Data is available on the effect of reverberation and noise on monaural discrimination abilities of normal-hearing and hearing-impaired children ages 8 to 13

(Finitzo-Hieber and Tillman, 1978). A developmental study in which binaural discrimination of children under conditions of reverberation, monaural discrimination under reverberation, and the pattern of errors under reverberation are systematically examined is the goal of the present study.

CHAPTER III

METHODOLOGY

A number of factors influence a subject's performance on any measure of auditory ability including his cognitive abilities, his motivation, and his attention span. To appropriately design a study in which the subjects are children, one must consider each of these variables as it singly and in combination contributes to the choice of a test procedure. An inappropriate choice of method will give an erroneous picture of the subject, since inferences about abilities are made from the subject's performance on a given task. Thus it becomes critical that any decision regarding appropriate methodology related to performance tasks on the part of children be based upon an understanding of those variables that may intervene during the stimulus-response process. To the extent that all or most of these variables can be controlled (or at least be accounted for during data analysis), appropriate test procedures can be designed.

When speech materials are used to test adults, the familiarity of the subject with the experimental stimuli can affect the measurement (Broadbent, 1967). The Speech Reception Threshold, for example, can be obtained at lower levels (i.e., better thresholds will be obtained) if the subject is familiarized with the words before testing (Tillman and Jerger, 1959). When Hirsh, et al., (1952) developed the CID (Central Institute for the Deaf) W-22 lists, a list of monosyllabic words to be used for speech discrimination testing, word familiarity was a major factor in the selection of words from the previously developed monosyllabic word lists. The studies of Owens (1961) and

Epstein, Giolas, and Owens (1968) demonstrated that word familiarity influenced intelligibility scores in adults. With children, knowledge of lexical items and word familiarity effects are a special problem. Clearly, if adult materials are used for testing, many of the words have no meaning to the child. Even those lexical items which are known to the child will have been heard less frequently by younger than by older children (Elliott, et al., 1979).

Another factor which is often involved in experimental procedures is memory. Studies have shown that auditory memory span is age dependent (Terman, 1916) and that memory strategies also change with age. Brown (1975) differentiates between memory tasks which are dependent on semantic memory, i.e., memory for units in context, and those tasks which are dependent on episodic memory, i.e., memory for instances in isolation. She suggests that tasks requiring episodic coding will be less sensitive to developmental effects than those which require semantic coding. Also, the younger child is less able to use strategies for recall than the older child. The level of complexity of the task which requires memory should thus be taken into consideration in experimental design.

Motivation and attention of the subject can affect any experimental measure. The test situation should be structured in a way that will maintain the child's level of attention and motivation. Use of reinforcement has been recommended as effective in establishing and maintaining subject-response behavior (Bricker and Bricker, 1969; Lloyd, et al., 1968; Spradlin, et al., 1968).

All of these factors were considered in the experimental design of the present study. A description of the experimental stimuli, production of experimental tapes, subjects, experimental procedures, and method of analysis of data follow.

Experimental Stimuli

Experimental stimuli consisted of VCV (vowel-consonant-vowel) disyllables in which each of the three vowels /i/, /a/, and /u/ was combined with each of 19 consonants (all consonants with the exception of the semi-vowels /w/, /r/, /l/, and /j/). This resulted in 114 nonsense disyllables such as /ipi/, /apa/, and /upu/. These syllables were recorded preceded by a carrier phrase with each syllable of the stimulus receiving equal stress, e.g., /ípí/. The carrier phrase "say the word" was used in order to alert the listener and to increase reverberation effects. Each stimulus appeared twice in the experimental material. Order of presentation was randomized.

Nonsense syllables were chosen as the experimental stimuli because these materials would be less subject to age factors, would minimize possible cognitive effects, and would facilitate an analysis of specific differences in phoneme errors between age groups.

The VCV arrangement of the nonsense syllables was chosen for several reasons. Research has shown that phonemes in final position are more affected by reverberation than phonemes in initial position (Nabelek and Pickett, 1974a,b; Gelfand and Silman, 1979). However, a listing of combinations of vowels with consonants in a final position yielded many stimuli which might have been interpreted as words by subjects; e.g., /it/, /ad/, /ik/, /az/, /uz/, etc. Therefore, the consonant was placed in medial position in order to create nonsense syllables which were not words in American English.

While it would have been of interest to obtain information on perception of consonants in combination with each vowel, time considerations were a major concern in designing the experimental protocol. Smith and Hodgson (1970) found that performance of young subjects deteriorates as the number of test lists increases. Subjects in the present study ranged in age from 5 years to adult, and therefore testing time had to be kept to a minimum to accommodate the shorter attention span of the younger age group. The three vowels /i/, /a/, and /u/ were selected as representative of the three extreme positions in vowel articulation: high, forward; low, back; and high, back, respectively. Acoustically, this gave a range of second formant cues between 900 and 2300 Hz for a male speaker (Peterson and Barney, 1952).

Recording of Experimental Nonsense Syllable Materials

A male talker recorded the list of 114 nonsense disyllables in a double-walled sound-treated room. The equipment used for recording included an Altec 681A low impedance microphone, a Switchcraft 308 TR mixer to amplify the input signal, and a TEAC 35-2 tape recorder. The input signal to the tape recorder was set so that the average peak of the speech did not exceed -5 on the VU meter. Equalization and bias settings on the tape recorder were set according to manufacturer's recommendations for Scotch 206 Magnetic Tape. Recording was done at a speed of 7½ ips.

A procedure developed to analyze peak levels of speech on recorded materials (Levitt, et al., 1978) was used to examine the peak level of the key word in each of the carrier phrases. Levels were found to be within ± 2 dB for each test item. Further equalization of levels was, therefore, not necessary. A 1000 Hz calibration tone and a speech noise segment were recorded at the beginning of the tape at a level which would produce a deflection on a graphic level recording equal to the average peak of the word "word" in the carrier phrase. The 1000 Hz tone was used to set the tape recorder level for playback, while the speech noise was used for calibration in the making of the room recordings.

Production of the Experimental Tapes

The purpose of this study was to obtain information on the phoneme perception abilities of children under reverberant conditions typical of acoustically well-designed classrooms. A review of previous research revealed that real room reverberation was the preferred method for studying the effects of reverberation on speech discrimination (Nabelek and Robinette, 1978b) and that room size could affect the distribution of reflections while not necessarily affecting reverberation time, per se (Nabelek, 1980; Ross, 1978). Recordings were thus made in a room with adjustable reverberation time so that results would not be confounded by inter-room differences. By recording through the Knowles Electronics Manikin for Auditory Research (KEMAR) and an appropriate equalization filter (Killion, 1979), reverberation tapes were produced which could be listened to via headphones. KEMAR was used to represent a student/listener of any age.

The signal source and the microphones in the reverberation room were arranged to simulate a classroom situation. The loudspeaker was placed in the front of the room at a position typical of a teacher standing in the front of a classroom. The KEMAR was positioned to approximate a student seated towards the back of the classroom in a central position. The speech signal was set at 60 dBA at KEMAR's ear, since that level was reported by Pearsons, et al. (1976) as the typical level reaching the student near the back of a classroom.

In addition to the reverberant recordings, a non-reverberant recording was necessary to obtain information about phoneme discrimination abilities under optimal conditions. This recording was made in an anechoic chamber. Although different equipment was used to make this non-reverberant tape, the frequency responses of the tape recorders and speakers used were comparable to those used for the reverberant recordings. Frequency responses of the tape recorders were flat in the frequency range of interest, and the loudspeakers were also comparable in the frequency region of interest. Differences in equipment therefore did not contribute to any differences between recordings. The difference in volume between the anechoic chamber and the reverberation room also could be ruled out as a variable, since in the anechoic chamber only the direct signal was being recorded.

The reverberant condition recordings were made in the reverberation room at the Auditory Department of the United States Naval Submarine Medical Research Laboratory in Groton, Connecticut. The room has a volume of 156.55 m^3. A schematic of the room and its measurements appear in Figure 1. Three walls of the room are constructed of cement block and the fourth wall has wood paneling over the cement block. The ceiling, which is slanted, is plaster and the floor is covered with linoleum. The critical distance of the room was calculated using the formula of Peutz (1971) as 3.23 meters for the reverberation time of .6 sec and 3.73 meters for the reverberation time of .4 sec.

Reverberation time was varied in this room by adding or removing acoustically absorbent materials. Reverberation time measurements were obtained by introducing gated white noise bursts (2500 msec. duration, 10 msec. rise/decay time) into the reverberation room and calculating decay time after offset with a Bruel and Kjaer SC 2361 reverberation time protractor (Broch and Jensen, 1966). The instrumentation for these measurements is displayed in Figure 2.

The noise signal was introduced into the room through a loudspeaker which was centrally located at a distance 1.8 meters from the front of the room and at an elevation .79 meters from the floor. The sound level meter/filter set was placed on a tripod at a distance 4.57 meters from the speaker.

Figure 3 displays the measured reverberation times as a function of frequency for the two experimental reverberation conditions. The averaged measured reverberation times of the two test conditions were .4 and .6 sec (average of measured reverberation at 500, 1000, and 2000 Hz). These reverberation times are shorter than those found in most classrooms (McCroskey and Devens, 1975) and might be considered to represent desirable classroom acoustics.

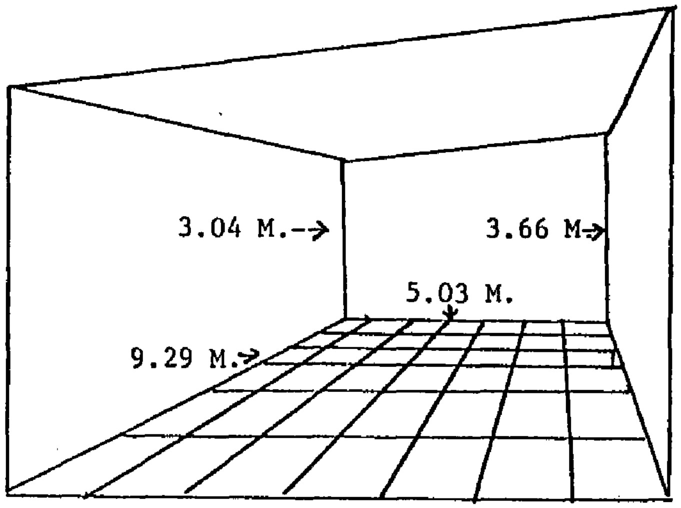

Figure 1. Perspective of the room used to make reverberant recordings.

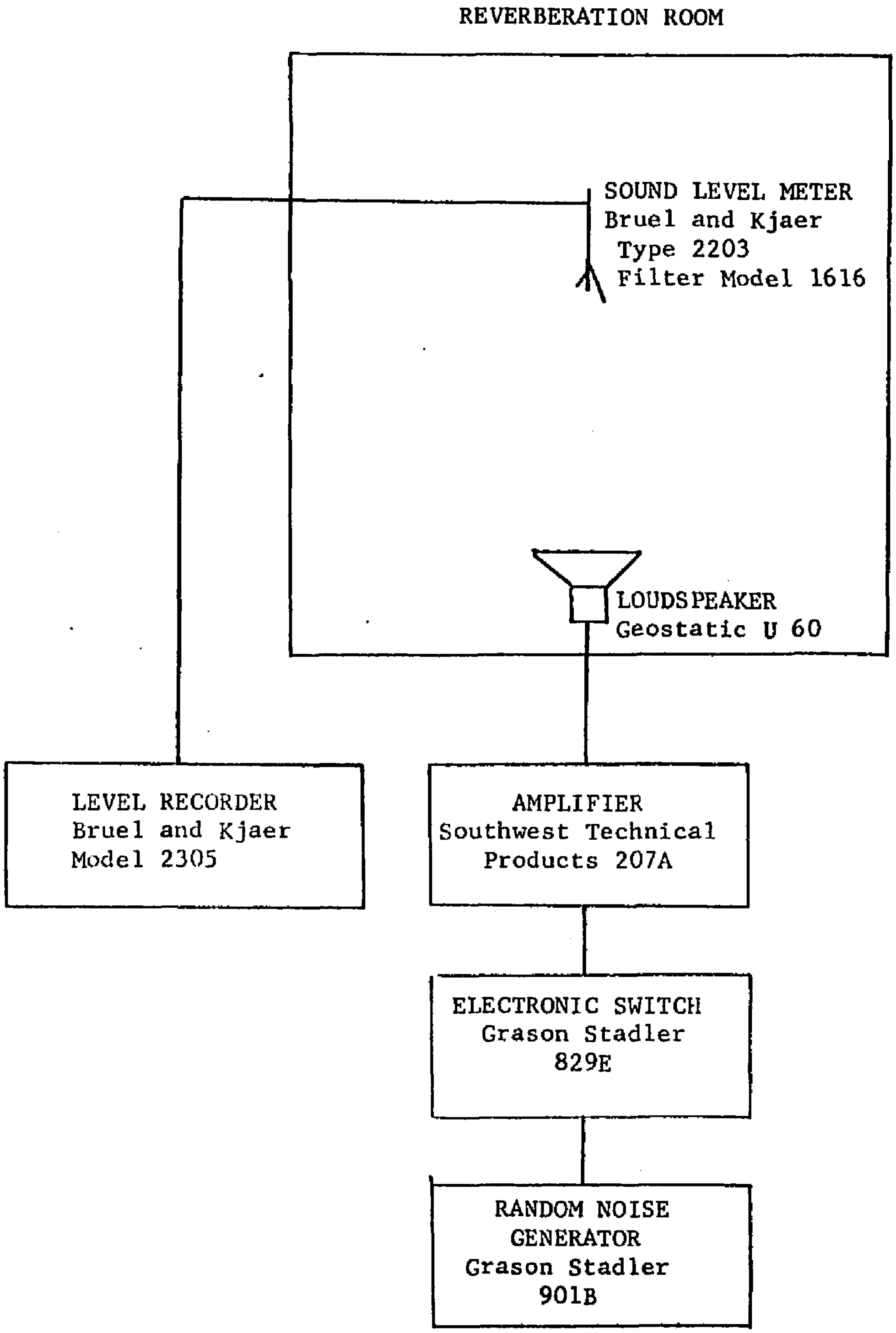

Figure 2. Instrumentation for measurement of reverberation.

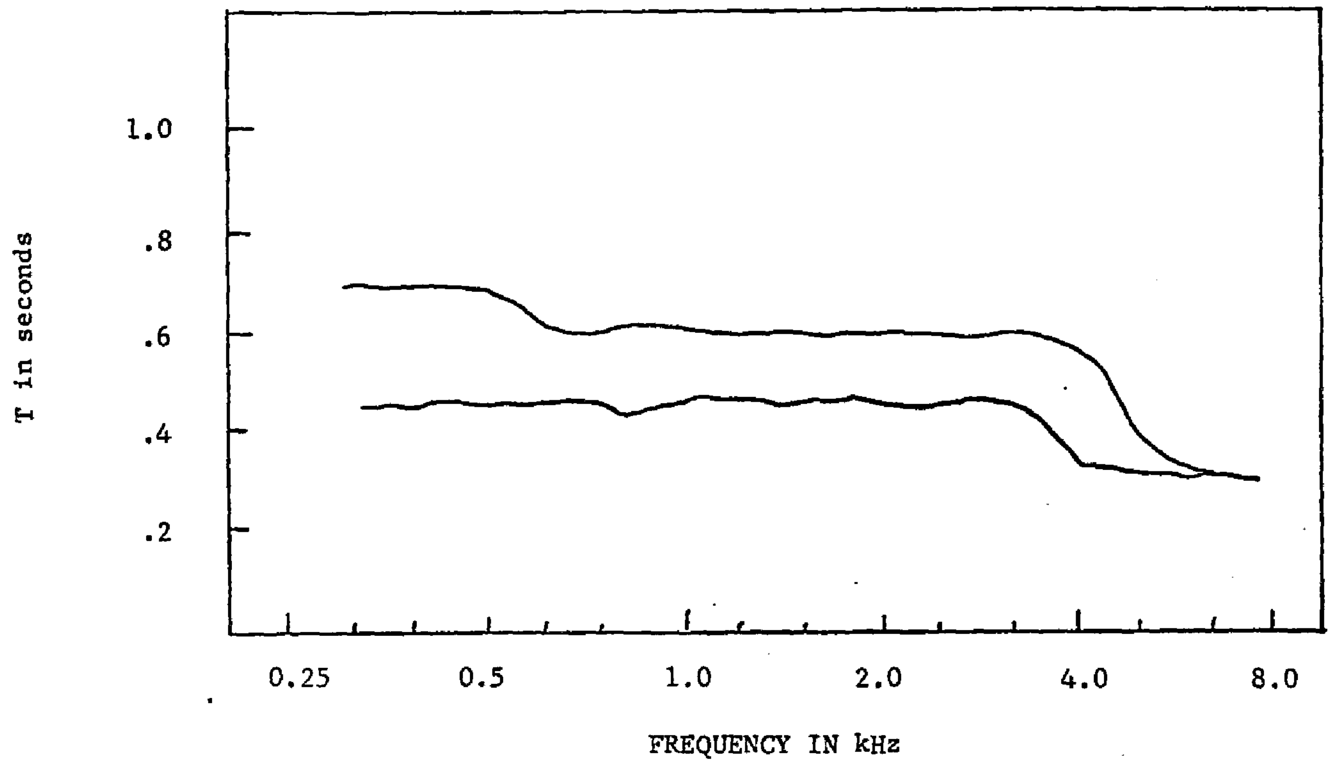

Figure 3. Reverberation time (T) in 1/3-Octave Bands.

A block diagram of the instrumentation required for recording the experimental reverberation tapes is presented in Figure 4. Placement of the loudspeaker was identical to the placement for the reverberation measure. KEMAR was positioned at the location which had been used for the sound level meter during the reverberation measures. The level of the speech signal was set so that the speech noise calibration signal was 60 dBA at the manikin's pinna. The output from each of the microphones in KEMAR was amplified and recorded on a two track tape recorder at a speed of 7½ ips, -10 VU.

A recording was also made through the KEMAR in an anechoic chamber at the Graduate School and University Center, CUNY, in order to obtain a non-reverberant test tape made in a manner similar to the reverberant tapes. The same instrumentation was used for this recording as for the reverberant recordings. The tape recording of the nonsense syllables was introduced into the anechoic chamber through the loudspeaker. The head of KEMAR was placed at a distance .61 meters from the loudspeaker, at 0° azimuth. The calibration noise was set at a level which yielded a signal measuring 60 dBA at the KEMAR's pinna. The output from the KEMAR was amplified and recorded on a two track tape recorder set for 7½ ips. Recording was done at -10 VU.

Speech spectrum noise was added to the non-reverberant test tape to match the noise spectrum on the reverberant tapes. The measured noise levels in octave bandwiths for each test tape are listed in Table 1.

Subjects

Twenty-five normal-hearing children and five normal-hearing adults were subjects for this study. Children were ages 5, 7, 9, 11,

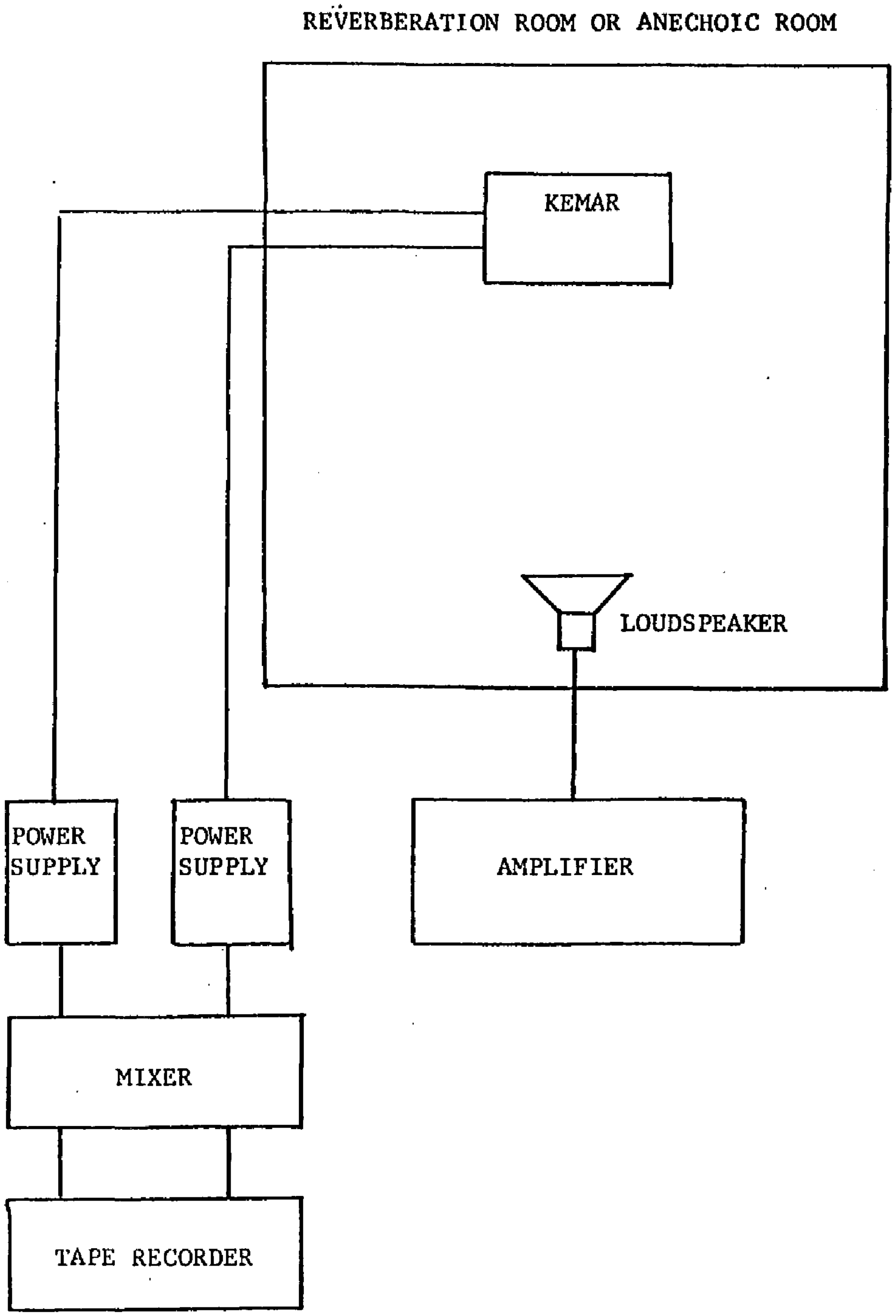

Figure 4. Instrumentation for the recording of reverberant and non-reverberant tapes.

Table 1. Measured Noise Levels at Each Octave Bandwith for Each Reverberation Condition .

Center Frequency Octave band (Hz)	Non-reverberant	.4 seconds	.6 seconds
63	87 dB	85 dB	88 dB
125	87	85	85
250	92	88	88
500	94	90	91
1000	92	91	91
2000	83	86	86
4000	73	75	75
8000	67	68	68

and 13 (five per group). All subjects had normal hearing (thresholds no poorer than 15 dB re. ANSI 1969) with no air-bone gaps. Speech discrimination scores on the CID W-22 were 90% or better. All children were in age-appropriate grades in school. Finally, all children were able to articulate all the consonant sounds that were to be included in the experimental stimuli. This was ascertained by administering the Goldman-Fristoe Test of Articulation which included all of the target consonants in medial position (the position to be tested in the experimental conditions).

Experimental Protocol

All testing was done in a double walled IAC sound-treated room. The instrumentation used for test administration is displayed in Figure 5. Speech recordings were played on a TEAC 35-2 tape recorder. The signal on each channel of the tape was amplified by a Switchcraft mixer and attenuated by a Hewlett Packard attenuator, and presented to the subject via Sennheiser HD 414X headphones which were matched to the output of the attenuator with an 820Ω resistor.

All equipment used for the experimental procedure was calibrated before the experiment began and voltage measurements were used to check the levels of the calibration tones on each track of each of the test tapes prior to each test session. The Sennheiser HD 414X headphones were calibrated in the following manner. A 500 Hz signal was introduced into the soundfield via a Criterion 2001A loudspeaker. The sound pressure level of the signal was measured using a Bruel and Kjaer sound level meter, Type 2203, and associated filter set, Type 1613, at a distance 1 meter from the loudspeaker at 0° azimuth.

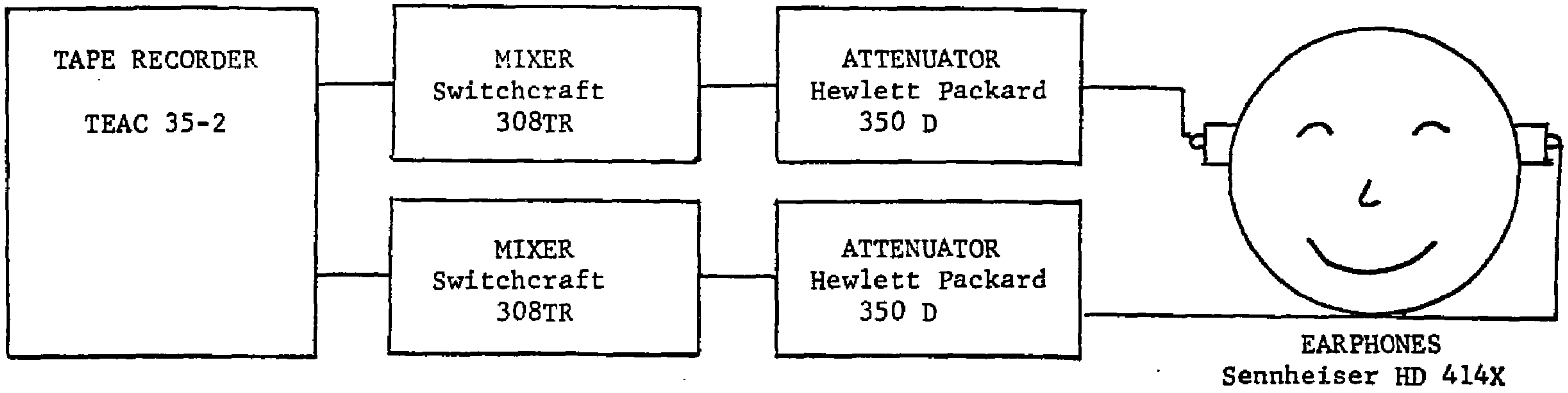

Figure 5. Instrumentation used for test administration.

KEMAR was then placed at the 1 meter position and the output voltage from KEMAR was measured. A 1 volt signal at 500 Hz was then transduced through the Sennheiser phones which were positioned on KEMAR, and a second voltage measurement of the output was made. A voltage ratio was obtained which allowed calculation of the SPL value for a 1 volt signal. This was used as the basis for the setting of the attenuators to obtain a 60 dB SPL signal for testing.

Since voltage measurements taken from the headphones when placed on KEMAR were found to be repeatable (see Table 2), KEMAR was used as the coupler to obtain frequency responses on the headphones on a weekly basis. The frequency transfer characteristic of the Sennheiser HD 414X headphone mounted on KEMAR and the Zwislocki Coupler is displayed in Figure 6.

In addition, an electroacoustic check of calibration of the Grason Stadler 1701 audiometer which was used for the initial pure tone and speech testing was done daily.

Testing was done in one or two testing sessions, depending on the age and the attention span of the subject. Prior to the administration of the experimental procedures, each subject received an audiological evaluation and articulation was assessed with the Goldman-Fristoe Test of Articulation. Only subjects with normal hearing, with speech discrimination scores of 90% or higher on the CID W-22, and with no articulation problems on the Goldman-Fristoe test were included in the study.

The experimental design included three conditions of reverberation, two modes of presentation, and six groups of subjects. The three

Table 2. Voltage Measured with Headphones on KEMAR at 500 Hz (1 Volt Signal). Headphones Were Removed and Repositioned Six Times.

1.	.012 v
2.	.011 v
3.	.012 v
4.	.011 v
5.	.011 v
6.	.012 v

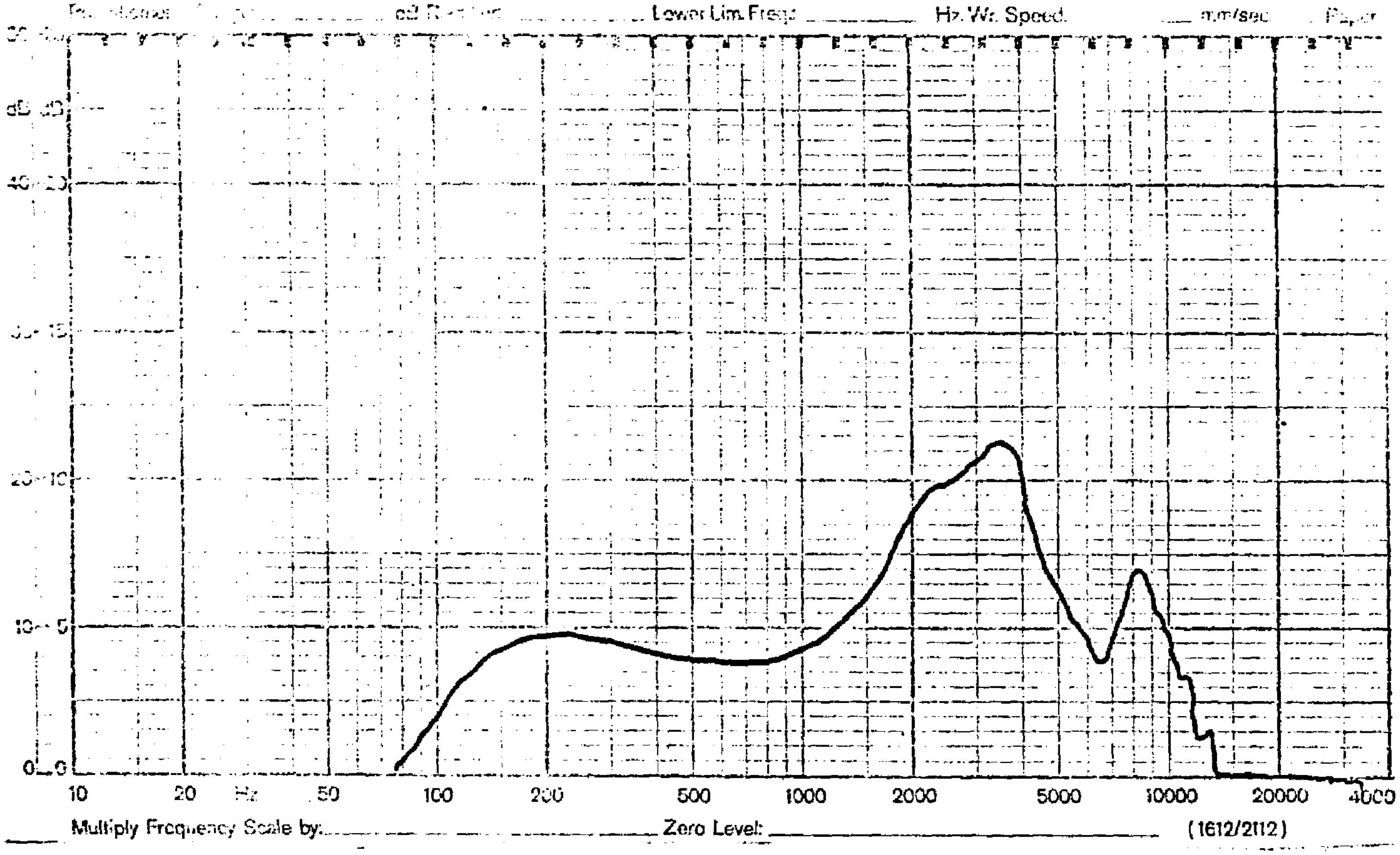

Figure 6. Frequency transfer characteristic of the Sennheiser HD 414X headphone mounted on KEMAR and Zwislocki coupler (input = .7v).

reverberant conditions were: non-reverberant, .4-sec reverberation, and .6-sec reverberation. These three conditions were presented in the binaural mode. In addition, the .6-sec condition was presented in the monaural mode. The order of presentation of conditions was randomized. The ear tested in the monaural mode was alternated, so that right and left ears were tested equally.

Subjects were instructed to repeat the stimulus word and the examiner transcribed responses on an answer sheet. The instructions which were given the subjects and a sample of the answer sheet used by the examiner are included in Appendix B. Repetition was chosen as the method of response because it placed little, if any, demands on memory, therefore minimizing cognitive demands. It also allowed ongoing assessment of the subject's attentiveness.

The experimental tapes were presented binaurally at a level of 60 dB SPL (in each headphone). When speech was presented monaurally, attenuation was decreased to match intensity so that differences in loudness would not account for any monaural/binaural differences.

During the experimental session(s), each subject was given a rest period after each experimental list. In order to sustain subject attention and motivation, children were given tangible reinforcement after each 15 test items and were given a "prize" for participation at the end of the test session.

Only the .6-sec condition was tested in both the binaural and monaural mode, since this was the longer reverberation time and would probably allow the demonstration of a binaural advantage. Another reason for testing both modes for only one condition was the concern for the length of the test session(s). Since some of the subjects were young children, minimization of total test time was desirable.

Analysis of Data

Analysis of variance techniques were used to determine the significance of the factors of reverberation, subject and their interactions within each age group.

The effect of reverberation, age, and their interactions and mode of presentation, age, and their interactions were also determined using analysis of variance techniques. The Duncan Multiple Range Test was used to determine the significance of differences between mean scores of age groups and reverberation conditions (Winer, 1971).

Confusion matrices were generated for each reverberation condition for each age group. The G^2 analysis (Bishop, et al., 1975) was used to determine significant differences between confusion matrices.

CHAPTER IV

RESULTS

In this study the effect of reverberation on the phoneme discrimination of 5, 7, 9, 11, and 13-year-old children was investigated. A group of adults was also included as a control group. Binaural phoneme discrimination of each subject was tested using 114 nonsense disyllables (VCV) at nominal reverberation times of 0, .4, and .6-sec. Monaural discrimination was also tested for the .6-sec condition.

First, discrimination scores were analyzed using repeated measures analysis of variance techniques (Winer, 1971) to determine the effects of the factors of reverberation, age, subject, and their interactions. The second part of the analysis was done to determine the effect of mode of presentation, age, and their interactions on phoneme discrimination ability. In the third part of the analysis, confusion matrices were analyzed using the G^2 statistic (Bishop, et al., 1975) to determine whether or not patterns of error differed as a function of age and reverberation.

Discrimination scores of all subjects in each experimental condition are listed in Appendix C.

Reverberation and Age

Phoneme discrimination scores were analyzed to determine whether reverberation times which were representative of good classroom acoustics affected phoneme discrimination ability and to determine whether discrimination ability changed as a function of age. A separate analysis of the findings of each of the six age groups was done prior to any group comparisons.

Six two-way analyses of variance with repeated measures on subjects were done in order to avoid averaging over the age factor and thus to minimize uncontrolled sources of error variance (Winer, 1971). Phoneme discrimination scores in proportions were first converted to arc sine units in order to stabilize the error variance (Brownlee, 1965). The results of these analyses displayed in Table 3, indicated that reverberation significantly influenced phoneme discrimination in each age group ($p \angle .001$). Between-subject differences did not reach statistical significance in any of the analyses.

The mean discrimination scores and standard deviations for each age group and each condition appear in Table 4. All statistical calculations were carried out in arc sine units and then results were reconverted to proportions. The use of arc sine units reduced the positive skew on the distribution due to the scores of older subjects falling close to the ceiling (most scores were 90% or better), and thus allowed appropriate comparison of the variability in scores across age groups.

Figure 7 illustrates mean phoneme discrimination scores in arc sine units for each of the reverberation conditions as a function of age. It is evident that increasing reverberation caused a decrease in phoneme discrimination in each age group. This finding has been well documented on adults in the past. The figure also illustrates a general tendency for performance to improve with age.

An analysis of variance was also done to determine the effects of age and reverberation. Again, the scores were converted to arc sine units to stabilize the error variance. Results of this analysis, displayed in Table 5, revealed that the factors of reverberation ($p < .001$) and age ($p < .004$) were both highly significant.

Table 3. Summary Of Analysis Of Variance For Each Age Group For Factors Of Reverberation And Subject.

AGE	SOURCE OF VARIATION	SUMS OF SQUARES	DF	MEAN SQUARES	F RATIO	PROBABILITY LESS THAN:
5	Reverberation	1.03621	2	0.51811	30.630	0.001
	Subject	0.21662	4	0.05415	3.202	0.076
	Interaction	0.13532	8	0.01692		
	Total	1.38815	14			
7	Reverberation	0.81576	2	0.40788	71.454	0.001
	Subject	0.09539	4	0.02385	4.178	0.041
	Interaction	0.04567	8	0.00571		
	Total	0.95681	14			
9	Reverberation	0.96858	2	0.48429	18.541	0.001
	Subject	0.20803	4	0.05201	1.991	0.189
	Interaction	0.20896	8	0.02612		
	Total	1.38557	14			
11	Reverberation	0.51068	2	0.25534	20.091	0.001
	Subject	0.13858	4	0.03464	2.726	0.106
	Interaction	0.10167	8	0.01271		
	Total	0.75092	14			
13	Reverberation	0.31200	2	0.15600	36.703	0.001
	Subject	0.02591	4	0.00648	1.524	0.283
	Interaction	0.03400	8	0.00425		
	Total	0.37191	14			
Adult	Reverberation	0.25403	2	0.12702	25.214	0.001
	Subject	0.02505	4	0.00626	1.243	0.366
	Interaction	0.04030	8	0.00504		
	Total	0.31938	14			

Table 4 Mean Discrimination Scores And Standard Deviations In Proportions For Each Reverberation Condition By Age Group.

AGE		RT=0 sec Binaural	RT=.4 sec Binaural	RT=.6 sec Binaural	RT=.6 sec Monaural
5	$\bar{x}$	.963	.816	.772	.640
	s.d.	.001	.005	.010	.004
7	$\bar{x}$	.976	.863	.833	.812
	s.d.	.001	.002	.003	.001
9	$\bar{x}$	.974	.860	.804	.774
	s.d.	.003	.002	.014	.008
11	$\bar{x}$	.970	.898	.847	.821
	s.d.	.001	.002	.010	.004
13	$\bar{x}$	.979	.928	.905	.879
	s.d.	.002	.001	.001	.010
Adult	$\bar{x}$	.981	.934	.918	.903
	s.d.	.002	.002	.001	.009

Table 5 Summary Of Analysis Of Variance For Factors Of Reverberation And Age.

SOURCE OF VARIATION	SUMS OF SQUARES	DF	MEAN SQUARES	F RATIO	PROBABILITY LESS THAN:
Reverberation	0.73306	2	0.36653	71.644	0.001
Age	0.18995	5	0.03799	7.426	0.004
Interaction	0.05116	10	0.00512		
Total	0.97418	17			

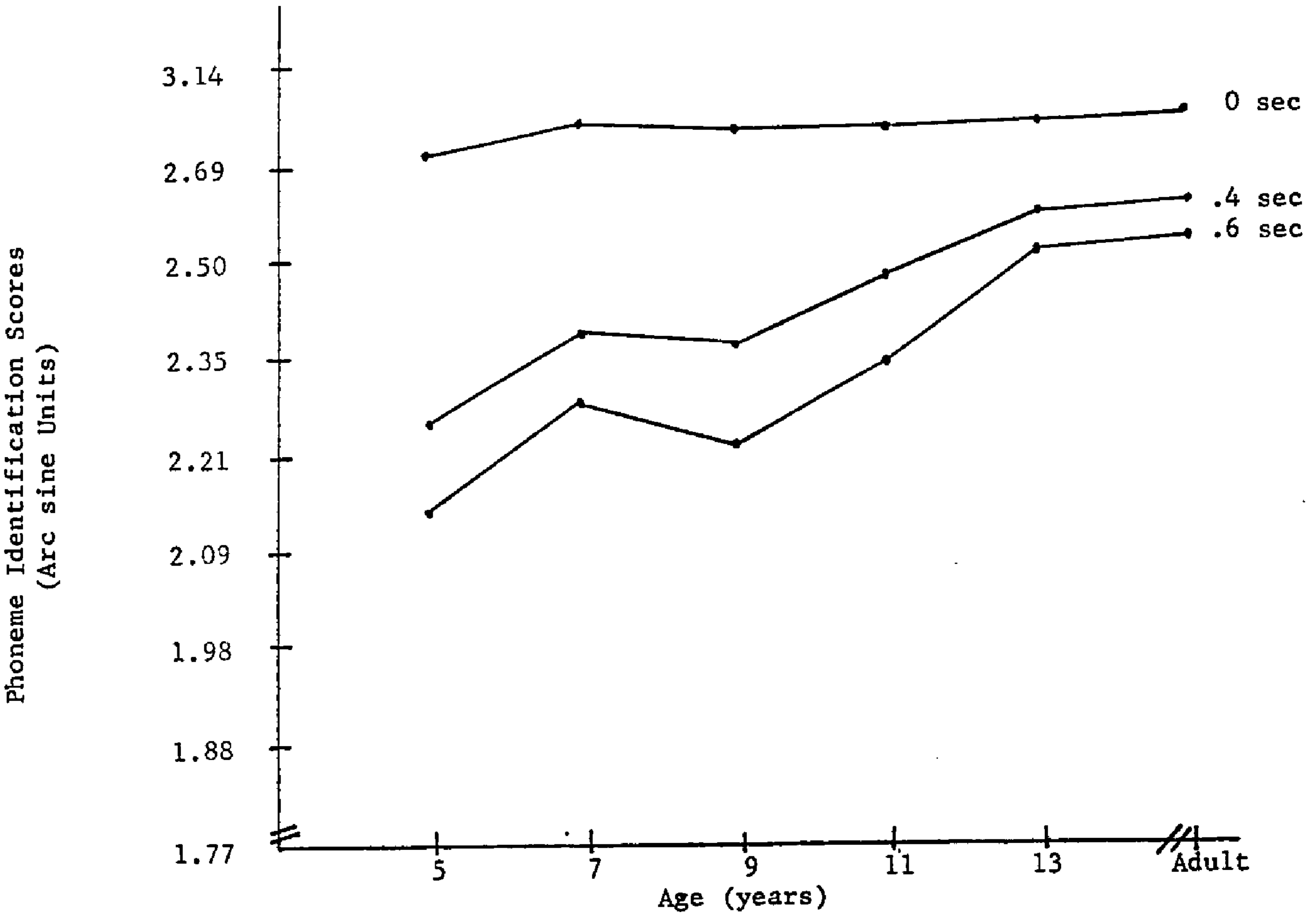

Figure 7. Mean phoneme identification scores as a function of age and reverberation time (sec).

The Duncan Multiple Range Test was used to compare group means (collapsed across conditions) to determine when performance of children of a specific age group differed from that of other age groups. Those age groups whose means did not differ significantly from one another, ($p \angle .05$) were placed into homogeneous subsets: The means of the 5, 7, and 9-year-olds formed one subset; the 7, 9, and 11-year-olds formed a second subset; the 11 and 13-year-olds a third subset; and the 13-year-olds and adults a fourth subset.

This analysis demonstrated overlap among the subjects of different ages. Nevertheless, there were significant differences ($p < .05$) between the younger age groups (5, 7, and 9-year-olds) and the older age groups (13 and adults).

A second *post hoc* analysis was done to determine which reverberent conditions differed significantly. The mean scores of the three reverberant conditions (collapsed across age) were compared using the Duncan Multiple Range Test. The mean for each condition differed significantly from the means for the other conditions ($p < .05$). In other words, the mean score of the .4-sec condition differed significantly from the non-reverberant condition. Similarly the .6-sec condition differed significantly from the .4-sec condition.

Mode of Presentation and Age Effects

Mode of presentation (binaural vs. monaural) was an additional experimental factor in the .6-sec condition. The results of an analysis of variance with age and mode as factors are listed in Table 6. The effect of age ($p < .005$) and mode of presentation ($p < .039$) were both

Table 6 Summary Of Analysis Of Variance For Factors Of Mode Of Presentation And Age.

SOURCE OF VARIATION	SUMS OF SQUARES	DF	MEAN SQUARES	F RATIO	PROBABILITY LESS THAN:
Mode of presentation	0.03270	1	0.03270	7.665	0.039
Age	0.37600	5	0.07520	17.630	0.005
Interaction	0.02133	5	0.00427		
Total	0.43003	11			

significant.

Figure 8 illustrates mean monaural and binaural phoneme scores (in arc sine units) as a function of age. Discrimination increased with increasing age for both monaural and binaural modes of presentation, and the binaural scores were better than monaural scores for all age groups. A _post-hoc_ comparison of the monaural/binaural difference for the 5-year-olds and the 7-year-olds revealed a significant difference between the performance of the two age groups; the two difference scores were 4 standard deviations apart.

A test for differences between the monaural/binaural performance in the older groups (7, 9, 11, 13-year-olds and adults) was significant at the .01 level. Thus, although the observed differences were small, they were statistically significant. Clearly, the difference between the two conditions was much larger for the youngest subjects, probably due to their poor performance in the monaural condition.

Analysis of the data has revealed that age, reverberation, and mode of presentation all affect performance on a phoneme discrimination task. Discrimination significantly improves with increase in age, significantly decreases with increase in reverberation, and binaural discrimination scores are better than monaural scores for all age groups, with 5-year-olds showing the largest differences.

Pattern of Errors as a Function of Reverberation and Age

The pattern of errors was analyzed to determine whether or not there were differences in the errors under different amounts of reverberation, for different ages, and for mode of presentation. Confusion matrices were generated for each age group for each reverberation con-

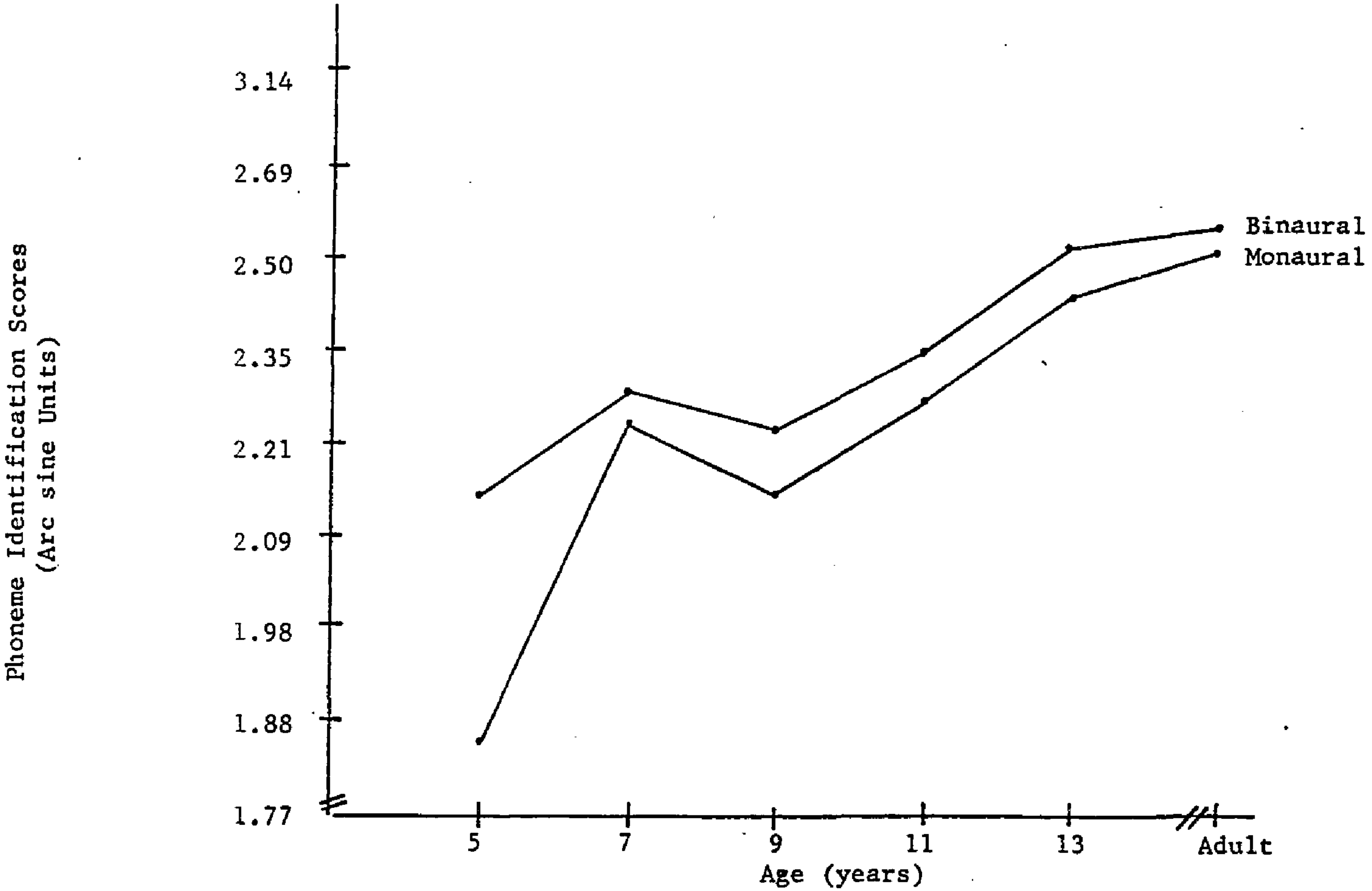

Figure 8. Mean monaural and binaural scores as a function of age (.6-sec-reverberation time).

dition. These matrices are included in Appendix D. The G^2 statistic (Bishop, et al., 1975) was used to compare the pattern of errors of the different matrices and to determine whether any two rows of the matrices being compared differed significantly. Paired comparisons were made between the non-reverberant and the reverberant conditions for each group and each of the five groups of children within each reverberation condition.

The results of the comparisons between the reverberant and non-reverberant conditions for each age group are summarized in Table 7. The confusion matrices of the younger subjects for the reverberant conditions differed more from the non-reverberant condition than those of the older subjects. In all cases, more errors were made in the reverberant conditions than in the non-reverberant condition.

In the non-reverberant condition, very few errors were made by any subjects. There were some place errors on fricatives and nasals. The most common substitutions were f/θ, v/ð. and m/ŋ.

Inspection of Table 7 reveals that the phonemes most affected by reverberation were /p, b, k, g, g, v, θ, m, ŋ /. The errors were primarily place and manner errors. The place errors involved the fricatives /f, v, θ, and ð /, the stops /p, b, k, g/ and the nasals /ŋ and m/. Many of the manner errors involved confusions between stops and fricatives , i.e., stops were substituted for fricatives or fricatives were substituted for stops. There were fewer manner errors involving nasals.

Voicing errors also occurred infrequently. The errors which did occur mainly involved the fricatives or affricates. Substitutions were f/v, ð/θ, and ʒ/ʃ. The only voicing error in the stop category was d/t.

Table 7. Summary Of The G^2 Analysis Of Phoneme Confusion Matrices Showing Those Target Phonemes Whose Error Rate Differed Significantly ($p < .05$) Between Reverberant and Non-Reverberant Conditions For Each Age Group.

Age 5 - /p, g, ŋ, m, v, θ/

Age 7 - /p, b, g, m, v/

Age 9 - /b, k, v, θ, m/

Age 11 - /k, f, θ/

Age 13 - /p/

Adult - /θ/

A comparison of matrices using the G^2 statistic was also done to assess how the performance of each group of children differed from that of the adult group for each condition. A summary of these findings is presented in Table 8. The matrices of the 5, 7, and 9-year-olds differed most from that of the adults. The number of phonemes which differed significantly between the matrix of each age group and the adult matrix increased with increasing difficulty of condition, i.e., increase in reverberation or monaural listening.

Thus the analysis of the pattern of errors reveals the importance of age in the type of error that is made. Not only do younger children make more errors than older children and adults on nasals and fricatives, they also make different errors, specifically errors on the affricates.

Table 8. Summary Of The G^2 Analyses Of Phoneme Confusion Matrices Showing Those Target Phonemes Whose Error Rate Differed Significantly ($p < .05$) Between A Specific Age Group And Adult Performance For Each Reverberation Condition.

AGE	T=.4 sec BINAURAL	T=.6 sec BINAURAL	T=.6 sec MONAURAL
5	/g, ŋ/	/m, ŋ, g/	/v, θ, tʃ, m, ŋ/
7	/v/	/p/	/tʃ, dʒ/
9	/v/	/b, m/	/θ, ŋ/
11	-	-	-
13	-	/p/	/k/

CHAPTER V

DISCUSSION

Four major questions were proposed at the outset of this study:

(1) Do short reverberation times (.4 and .6 sec) typical of modern classrooms affect phoneme discrimination ability in school-age children?

(2) Does phoneme discrimination ability change as a function of age under these short reverberant conditions?

(3) Is there an increase in the phoneme discrimination performance under binaural listening conditions as compared with monaural listening?

(4) What is the pattern of phoneme errors caused by the above reverberation times and does the pattern change as a function of age?

Each of these issues will be addressed in light of the results of this study.

Reverberation and Phoneme Discrimination

Analysis of the data revealed that phoneme discrimination ability was affected by the relatively short reverberation times employed in this study. Results of the six repeated measures analyses of variance used to determine the effect of reverberation time on phoneme discrimination in each age group revealed that discrimination significantly decreased as reverberation increased for each group of subjects ($p < .001$).

The effect of reverberation on speech discrimination of adults has been studied by previous investigators. A group of adults was included in the present study in order to obtain normative data on the nonsense syllable stimuli used in this experiment. The focus of the present study was on the phoneme discrimination ability of children of different ages under reverberant conditions, a subject which has received little attention. The findings of the present study will be discussed with reference to the findings of previous studies on adults and with those available on children.

The results of several studies on the effect of short reverberation times on speech discrimination of adults are presented graphically in Figure 9, which also includes the results of the present study. Only studies in which normal-hearing adults were tested in quiet are included for comparison.

In comparing these studies, one must take into account the differences in experimental design which can affect test results. For example, results of the two studies in which open-set word tests were employed (Millin, 1968; Moncur and Dirks, 1967) revealed much larger decrements in discrimination than the studies in which a closed-response word test was used (Gelfand and Silman, 1979; Nabelek and Jennings, 1981). Use of a closed-response format could be expected to limit word familiarity effects. The use of nonsense syllables in the present study serves the same purpose.

The discrimination of nonsense syllables by adults under reverberant conditions in the present study is similar to the results reported by Nabelek and Jennings (1981) for discrimination of 27-year-old subjects of the MRT under reverberation. While Nabelek and Jennings did not find a decrease in discrimination for the .4-sec condition, a mean decrease of 1.2% was noted in the present study. It is possible that the open-set format and the use of nonsense syllables in the present study made the discrimination task slightly more difficult. The 2.4%

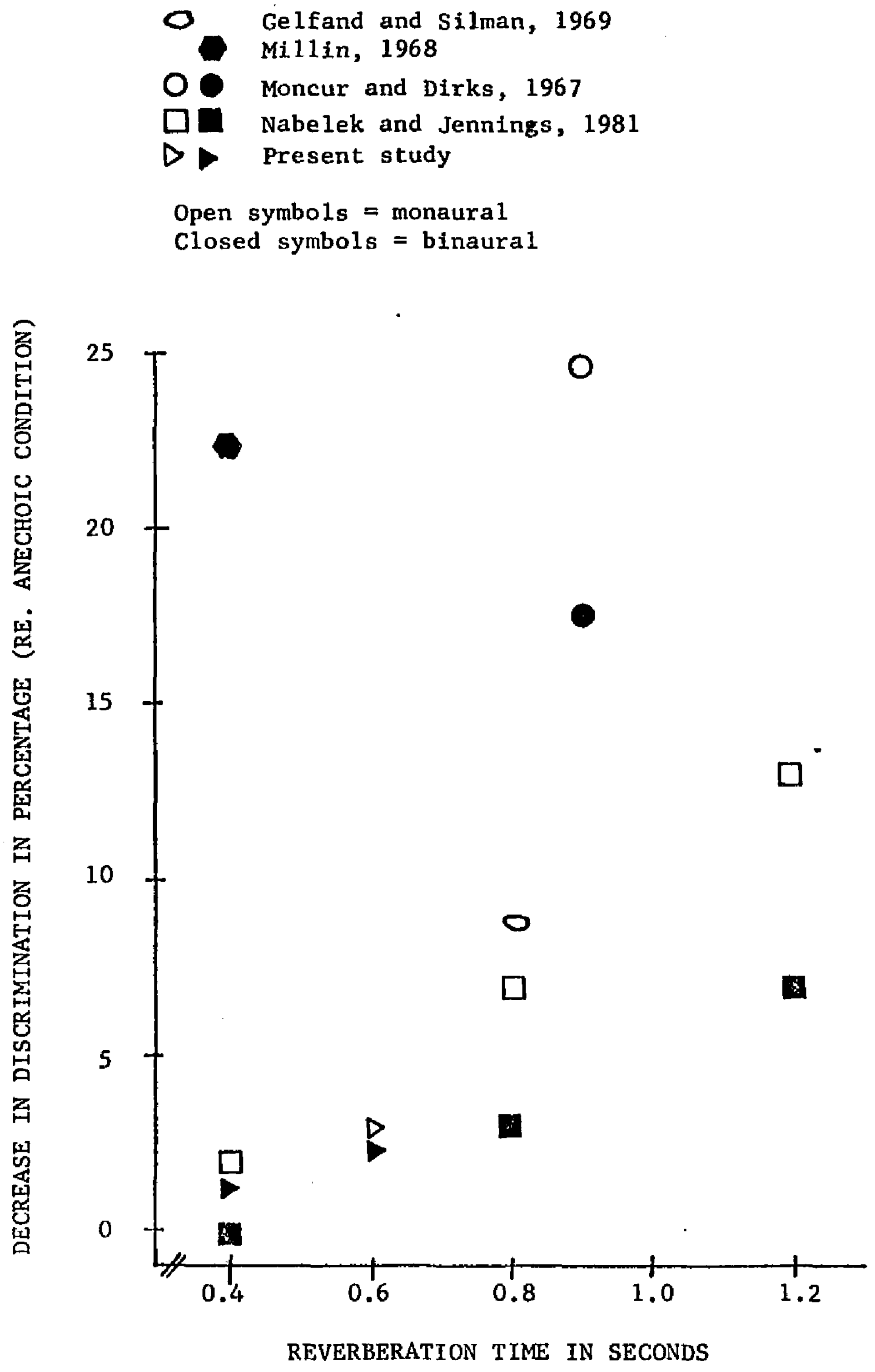

Figure 9. Comparison of studies on the effect of reverberation on speech discrimination of adults.

decrease in discrimination in the .6-sec (binaural) condition is similar to the 3% decrease reported by Nabelek and Jennings for their .8-sec condition.

The data available from previous studies on the effect of short reverberation times on the speech discrimination of normal-hearing children and data from the present study are presented graphically in Figure 10. Again, only the quiet experimental condition is used as a basis for comparison. The findings of the present study are in good agreement with those of Nabelek and Jennings (1981), despite the fact that Nabelek and Jennings used a closed-set format and real words (MRT). The 10-year-old children in the Nabelek and Jennings study showed a 6% and 12% decrease in binaural discrimination of the words on the MRT for the .4-sec and the .8-sec conditions, respectively. The monaural discrimination decreased by 8% and 17% for the .4 and .8-sec conditions, respectively. The 9-year-olds in the present study showed a 5% decrease in discrimination of nonsense syllables in the .4-sec (binaural) condition, 8% in the .6-sec (binaural) condition, and 11.5% in the .6-sec (monaural) condition.

The decrease in discrimination reported by Finitzo-Hieber and Tillman (1978) is smaller than the change reported by Nabelek and Jennings (1981) or that found in the present study. Use of different experimental stimuli may have contributed to these differences between findings. Finitzo-Hieber and Tillman used real words in an open-set format, Nabelek and Jennings used real words in a closed-set format, and nonsense syllables in an open-set format were used in the present study. Theoretically, one might predict that the Finitzo-Hieber and Tillman

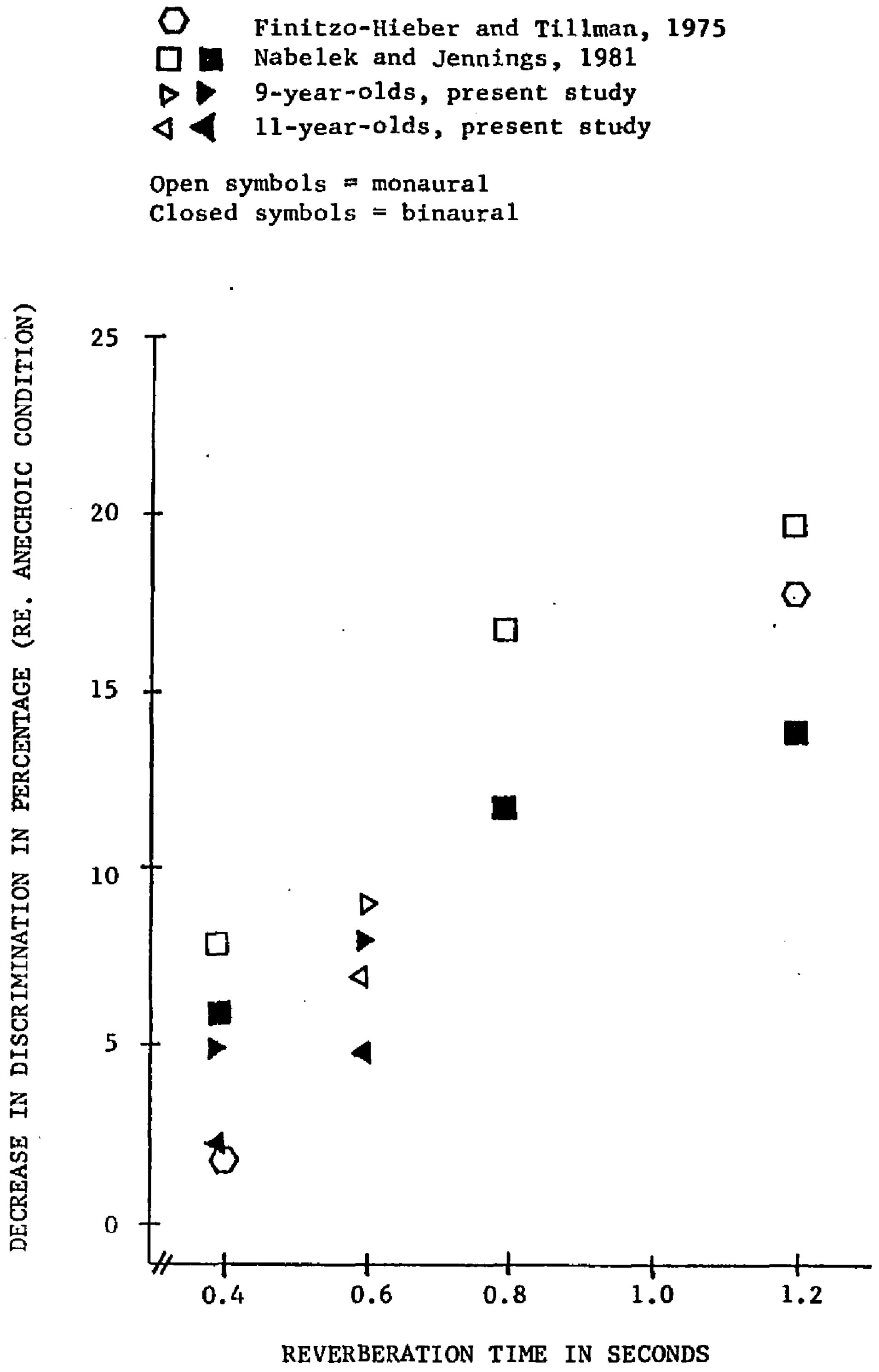

Figure 10. Comparison of studies on the effect of reverberation on speech discrimination of children.

task would be more difficult than the task in the Nabelek and Jennings study. The magnitude of the difference between the Finitzo-Hieber and Tillman study and the present study can best be examined by comparing and contrasting the findings of the former study with a specific group of subjects in the present study. An examination of the ages of the subjects included in the Finitzo-Hieber dissertation (1976) reveals that only three of twelve subjects were younger than age 10 (two were 9 years old and one was 8 years old). Most of the subjects were 10 and 11 years old. Only one subject was 12 years old. Clearly the trend in the present study is a decrease in the effect of reverberation in the .4-sec condition as the children get older. By age 11, there is only a 2.3% difference between the non-reverberant and the .4-sec condition (binaural), a finding similar to the 2% reported by Finitzo-Hieber and Tillman. However, Finitzo-Hieber and Tillman tested subjects in the monaural mode. If a monaural discrimination score had been obtained for the .4-sec condition in the present study, a decrease in discrimination larger than 2.3% would probably be found. Note that Nabelek and Jennings (1981) obtained a 6% decrease for the .4-sec binaural condition and an 8% decrease for the .4-sec monaural condition.

The findings of the present study are consistent with the results of previous studies. Reverberation does cause a decrease in phoneme discrimination ability, even at the relatively short reverberation times of .4 and .6 sec. The magnitude of the decrease in discrimination found in the present study is in good agreement with the findings of Nabelek and Jennings (1981) for adults and for children. Much larger decreases in discrimination of adults were reported by Millin (1968) for similar amounts of reverberation.

Millin's use of the Rush Hughes recording of the PB-50's and the fact that the rooms were very small in volume made the experimental task much more difficult for his subjects than for subjects of other studies. Moncur and Dirks (1967) also used an open-set word test and employed longer reverberation times than those used in the present study.

The present study is also in good agreement with the findings of Nabelek and Jennings on children. While Finitzo-Hieber and Tillman (1978) found only a 2% decrease in discrimination for monaural listening in .4-sec reverberation, Nabelek and Jennings (1981) found a larger decrease for the same reverberation time. A comparison with the Finitzo-Hieber and Tillman study is somewhat difficult, since only binaural testing was done for the .4-sec condition in the present study. Nevertheless, it is likely that had monaural testing been done, a slightly larger decrease would have been found than that reported by Finitzo-Hieber and Tillman. A 5% decrease was obtained for the binaural condition, .6-sec reverberation time, for 11 year old subjects in the present study.

Reverberation and Age

Nabelek and Jennings (1981) reported significant differences between the performance of 10-year-old children and adults. The present study reveals that younger children are affected more by reverberation than are older children. The results of an analysis of variance in which reverberation and age were factors indicated that both factors were statistically significant. A post-hoc analysis using the Duncan Multiple Range Test revealed that performance of 5, 7, 9, and 11-year-olds differed from that of 13-year-olds and adults. In other words, adult-like performance was not attained until age 13.

The decrease in discrimination found in the 5, 7, and 9-year-old children for the .4 and .6-sec reverberation time (binaural condition) in the present study is similar in magnitude to the decrease in discrimination reported by Nabelek and Jennings for their normal-hearing adults in the 1.2-sec reverberation condition. A comparison of the results of these two studies is presented in Table 9. Binaural discrimination of adults decreased by 3% and 7% for the .8 and 1.2-sec conditions in the Nabelek and Jennings study, while the decrease in the children's binaural discrimination in the present study ranged from 6% to 1.6% (ages 5 to 13) for the .4-sec condition and from 8% to 2.6% for the .6-sec condition. Thus, amounts of reverberation which have little practical significance for the adult's understanding of running speech may affect the ability of the child.

Because nonsense syllables were used as the stimuli in the present study, it is difficult to predict the ability to discriminate running speech under similar amounts of reverberation. A classic study by Miller, Heise, and Lichten (1951) revealed the contribution of contextual cues to speech discrimination. The type of speech material used, as well as the size of the message set, affected the threshold of intelligibility for speech-in-noise. Digits, sentence materials, and nonsense syllables were the three materials employed in the study. The sentences provided a context for the key words being tested and were intelligible 50% of the time at a -4 dB speech-to-noise ratio. The nonsense syllables required a +3 dB speech-to-noise ratio for the

Table 9 Comparison Of The Decrease In Discrimination of 27-Year-Old Subjects Under Reverberant Conditions (Nabelek And Jennings, 1981) And Children Under Reverberant Conditions (Present Study).

Age of Subjects (years)	Reverberation Time (seconds)	Decrease in Discrimination (re. anechoic) in Percentage	Stimulus
27	.4	0	Modified Rhyme Test
	.8	3	
	1.2	7	
5	.4	6	Nonsense Syllables
7	.4	4.9	
9	.4	5	
11	.4	2.3	
13	.4	1.6	
5	.6	8	Nonsense Syllables
7	.6	6	
9	.6	8	
11	,6	5	
13	.6	2.6	

listeners to acheive threshold. Therefore, as contextual cues decreased, listening conditions had to be improved in order for the signal to be understood.

Hirsh, Reynolds and Joseph (1954) used nonsense syllables, monosyllables, spondees, polysyllables, and sentences at varying speech-to-noise ratios, under various filtered conditions, and at different intensities in quiet. Their findings were similar to those of Miller, et al. (1951); the intelligibility of speech was found to be a function of the physical conditions as well as contextual cues. Intelligibility of difficult materials (nonsense syllables and monosyllables) increased less rapidly as a function of the speech-to-noise ratio than the intelligibility of easier materials.

Another area of research which supports the supposition that understanding of running speech under reverberant conditions would be superior to that of nonsense syllable materials under the same conditions are the studies of recognition of mispronunciations in running speech, shadowing of speech, and phoneme monitoring tasks. These studies which have been reviewed in detail by Cole and Jakimik (1978) support the contention that knowledge of the language and of context prevents the listener from identifying errors which have been purposefully introduced by the experimenter, and that the person listening to running speech does not attend to all of the acoustic information in the speech wave. In other words, a certain amount of "noise" does not interfere with perception of a speech signal, if semantic knowledge and knowledge of context can be used.

However, Marslen-Wilson and Welsh (1978) point out that while there is an interaction between the cognitive ("top-down") and acoustic ("bottom-up") aspect of perception of running speech, word recognition is very much dependent on the perception of the initial phonemes in words. The knowledge of language cannot be used until the initial phoneme is identified correctly. This limits the number of words which can be used appropriately in a specific context.

Despite the fact that nonsense syllables are not representative of everyday speech and that they are more difficult than sentence materials, they were used in the present study for several reasons: to provide a speech material which would be relatively insensitive to word familiarity effects and knowledge of language, to provide a material that would be relatively insensitive to memory effects, and to provide a material that would facilitate analysis of the errors made under conditions of reverberation. While use of words in a closed-set format can minimize word-familiarity effects, such a paradigm would have limited the age range of subjects who could participate in the study.

In the present study, the phoneme discrimination of adults was still excellent for the .6-sec condition, despite the fact that the effect of reverberation was statistically significant. When one considers that nonsense syllables were the stimuli employed in this study and that in the "real world" semantic and syntactic knowledge would be used by the adult to clarify possible phoneme confusions, it is doubtful that these adults would experience difficult listening to speech in a room with .6-sec reverberation time in quiet. However, it has been demonstrated that younger children are less able to utilize semantic and contextual cues in difficult listening situations than are older children and adults.

For example, Elliott (1979) found an age-related change in performance of children aged 9 to 17 on the high-probability sentences of the SPIN test at the 0 dB S/N ratio. Adult-like performance was not attained until age 15. Performance of the 11 and 13-year-olds was significantly poorer than that of 15 and 17-year-olds ($p < .05$). Performance of the 9-year-olds was significantly poorer that that of the 11-year-olds. The performance of the subjects did not differ in quiet, or on the low-predictability sentences in noise. Significant differences in performance were evident only on the high-predictability sentences at the 0 dB signal-to-noise ratio. This demonstrates that subjects younger than age 15 were unable to make use of all the contextual cues contained in the high-probability sentences when competing speech was present.

Marshall, et al. (1979) also reported that discrimination scores of children ages 5 to 11 were poorer than scores of adults on sentence materials which had been distorted by switching between ears, interruption, or by low-pass filtering, despite the fact that vocabulary was appropriate for the youngest children included in the study. Finally, Maccoby (1967) demonstrated that selective listening skills increase in children from age 5 to age 12. As a child grows older, he is better able to identify speech materials presented against competition. Older children were better able to report target words or phrases of either high or low sequential probability than younger children when these materials were presented against competing speech, with or without a preparatory set.

The developmental effect found in the present study is in good agreement with other auditory developmental studies and with the statement by Fior (1972) that adult-like performance on many auditory tasks is achieved by age 13. The more complex the task (discrimination versus threshold), or the more difficult the task (low redundant versus redundant), the more likely that the child will be older before adult-like performance is demonstrated.

For example, in the Siegenthaler (1969) study, adult-like performance was reached by age 8 on some of the simpler tasks (pure tone threshold, speech reception threshold, and speech discrimination in quiet), while on more difficult tasks such as speech-in-noise, performance continued to increase until age 11.

The performance of children cannot be described in incremental stages as a function of age. Performance changes gradually and at different rates for different children. While the younger children are more affected by reverberation than the older children, there is an overlap in performance between age groups. In fact, the performance of the 7-year-olds in this study was slightly better on the average than the 9-year-olds. However, the trend of improvement in performance reaching asymptote at age 13 is clear.

The effect of reverberation in the present study is similar to that of competing speech, time compression of speech, or noise in other developmental studies. Berlin, et al. (1973), Mirabile, et al. (1978), Beasley, et al. (1976), Elliott, et al. (1979), Elliott, (1979), and Marshall, et al. (1979) have all demonstrated developmental changes in the ability of children to function in difficult listening conditions. It is difficult to determine the factors which underly the differences in performance between the younger and older subjects in the present study. Although minimal demands were placed on memory, other cognitive differences might have contributed to the superior performance of older subjects. Greater frequency of usage of phonemes might also play a role in explaining inter-age differences.

Practical Implications of the Reverberation Effect

That children's performance was poorer than adults, despite the fact that the reverberation times employed were relatively short and in quiet (+19 dB S/N), has important implications for the acoustical design of classrooms for normal-hearing children. Children need shorter reverberation times than do adults in order to achieve maximum speech discrimination, but the specification for design of classrooms has been based on adult performance.

According to Knudsen and Harris (1950), the optimum reverberation time for a classroom is .75 sec (between 512 and 2048 Hz). This optimum time was derived from studies of adult's discrimination of speech in reverberant environments. Surveys of classrooms reveal that actual reverberation times in classrooms sometimes meet this criterion for optimal listening. McCroskey and Devens (1975) reported that measured reverberation times in classrooms ranged between .6 and 1.2 sec. Kodaras' study of elementary schools revealed times ranging from .4 sec to 1.1 sec. But, is a reverberation time of .75 sec optimal for children?

Previous studies have demonstrated that the combined effect of noise and reverberation is more than additive (Finitzo-Hieber and

Tillman, 1978; Nabelek and Mason, 1981). For example, if 1.2 sec reverberation in quiet causes an 18% decrease in speech discrimination and noise alone causes a 34% decrease, one might expect that the combination of these two factors would be additive and cause a 52% decrease in discrimination. In fact, a 65% decrease in discrimination was obtained for the combination of reverberation and noise by Finitzo-Hieber and Tillman (1978). This is similar to the effect reported by Lacroix, Harris, and Randolph (1979) for combinations of filtering, noise, interruption, or time compression.

The child in the classroom is often forced to listen at less than optimal signal-to-noise ratios. Sanders (1965) reported that measured noise levels in kindergartens were 69 dB (B scale), a +1 S/N ratio. In elementary school rooms, noise levels were recorded at 62 dB (B). These poor signal-to-noise ratios could be expected to interfere with the speech reception of speech by children. The addition of reverberation would further affect speech perception.

In fact, the amount of reverberation which would allow optimal listening for young children in reverberation and noise would be shorter than the .75-sec reverberation time recommended by Knudsen and Harris. In order for children to obtain maximum discrimination of a speech signal, close to anechoic conditions are required. The present study revealed significant decreases in phoneme discrimination in children at T=.6 sec, at a favorable signal-to-noise ratio. Shorter reverberation times would be necessary for maximum discrimination in quiet, and still shorter times for reverberation in noise.

Nabelek and Jennings (1981) recommended that reverberation times not exceed .5 sec for rooms designed for listening by children. This recommendation was based on the performance of 10-year-old children. The present study revealed that the younger the child, the poorer his ability to function in reverberation. Therefore, even .5-sec reverberation in a classroom may not allow maximum discrimination of speech by normal-hearing primary school children. Finitzo-Hieber and Tillman's recommendation that reverberation times not exceed .4-sec for hearing-impaired children should also be applied to classrooms for normal-hearing children, ages 5 to 11.

Reverberation and the Binaural Advantage

Binaural scores were superior to monaural in each age group. A binaural advantage (binaural score - monaural score, averaged over age groups) was significant ($p < .05$). There was also a significant difference between the 5-year-olds and the 7-year-olds. The 5-year-olds were clearly more affected by the reverberation than the other age groups. This finding may reflect the younger child's need for a high fidelity signal. The performance of the younger children was poorer than that of the older children for binaural discrimination of reverberant speech. Removal of the interaural cues which can cause the squelching of reverberation (cf., Koenig (1950),discussed below) caused a greater decrement in speech discrimination of the 5-year-olds than of the other children.

The binaural advantage found in the present study is similar to that obtained by Nabelek and Jennings (1981) for their 10-year-old subjects at .4-sec reverberation time. They obtained a 2% binaural advantage for their 10-year-olds for $T = .4$ sec, and a 5-6% binaural advantage for the 1.2-sec condition. A 2.3% advantage was obtained for the 5-year-olds in the present study. The differences for older subjects were somewhat smaller. Much larger binaural effects have been found in other studies.

Two aspects of the experimental design of the present study may account for the size of the binaural effect: the fact that the reverberation times used were shorter than some of the times used in other studies, or the fact that noise was not used in the present study. Some of the other studies which have demonstrated a larger binaural advantage for reverberant listening have employed longer reverberation times. For example, the shortest reverberation time used by Moncur and Dirks (1967) was .9-sec, Nabelek and Pickett (1974 a,b) demonstrated large binaural effects for short reverberation times (.3 and .6 sec), but added noise.

The finding of a larger binaural advantage in the youngest subjects (age 5) is important because it illustrates the young child's need for a clear signal, not a louder signal. In the present study, the binaural condition might be more accurately described as a dichotic signal. The output from each of KEMAR's microphones was recorded on a separate channel and the right ear recording was presented to the subject's right ear and the left ear recording to the subject's left ear. The interaural differences which are part of listening with two ears were thus preserved. Furthermore, intensity of the monaural condition was adjusted to equal that of the binaural signal so that intensity differences would not confound results (while there would be an intensity difference in "real world" monaural listening, the purpose here was to determine the contribution of binaural processing to discrimination of reverberant speech).

Koenig (1950) reported a phenomenon which he described as a binaural squelch of reverberation. Better speech discrimination was obtained when two separate telephone systems (microphone/receivers) were used to conduct the sound than if one microphone and two receivers were used. Use of a dichotic signal thus served to lessen the effect of reverberation.

A more recent study by Koenig, et al. (1977) investigated masking level differences for non-speech and speech signals in reverberant environments. When subjects listened to recordings in which a signal recorded through a manikin in a reverberant room was used to mask an identical, non-reverberant signal, masking level differences were obtained which ranged from 2.5 to 4.5 dB. An analysis of the late reflections (those which would cause the perception of reverberation) in the ears of the manikin used to make the reverberent recordings revealed a lack of correlation between the signal in the two ears. Binaural processing of these uncorrelated signals would thus account for the ability to squelch reverberation. The 5-year-old seemingly is able to take advantage of these interaural differences, since his binaural discrimination of the reverberant signal is far superior to monaural discrimination of a reverberant signal at equal intensity.

In summary, a small, but significant binaural advantage was obtained in the .6-sec reverberation condition. The 5-year-old subjects exhibited a larger binaural difference than older subjects. Monaural discrimination of these 5-year-olds was far poorer than that of older subjects. The finding of deterioration in speech discrimination of degraded speech being greater for younger than for older subjects is consistent with results of other studies using different types of distortion.

Pattern of Errors

With the exception of early studies by Knudsen (1929), Steinberg (1929) and Fant's report of work by Ormestead (1973), little information is available on phoneme confusions obtained with an open-set test. The work of Nabelek and Pickett (1974 a,b,), Nabelek and Mason (1981), and Gelfand and Silman (1979) all involved the Modified Rhyme Test, a closed-response word test. Results of the present study are in basic agreement with those of previous studies, although the pattern of errors does not conform in detail with the results obtained when the Modified Rhyme Test is used.

Analysis of the confusion matrices generated in the present study revealed that the most common errors were place and manner errors. The feature of voicing was resistant to reverberation effects. This finding corresponds to the findings of Nabelek and Pickett (1974a,b) and Gelfand and Silman (1979) on the Modified Rhyme Test and is consistent with the findings of Miller and Nicely (1955) for perception of CV syllables under some conditions of masking and filtering.

The pattern of stop-fricative, fricative-stop confusions is similar to the pattern of errors made in the study reported by Knudsen (1929) where b/v, g/v, b/f, k/θ, and t/θ were among the confusions recorded. Ormestead (reported by Fant, 1973) has also reported that the b/v confusion is the most common error caused by reverberation (Norwegian language).

The feature of nasality was well preserved among the older subjects, although there were many confusions within the category. Among the younger subjects, however, more manner errors involving nasals did occur.

In this study the phonemes most affected by reverberation were /p, b, k, g, f, v, θ, m and ŋ/. A comparison of the confusions found in the present study to those reported by Gelfand and Silman (1979) for consonants in the final position revealed differences. For example, a number of the errors made by adult subjects in the present study involved confusions among fricatives or between fricatives and stops, e.g., /f/ and /θ/, /v/ and /ð/, /v/ and /b/ were confused by adults. These errors were not made on the MRT because these contrasts were not provided as choices among the foil words. The use of a closed-response set test by Gelfand and Silman and an open-set test in the present study may, in part, account for these differences. Another factor which may have influenced the substitutions made by subjects in the present study is the use of VCV nonsense words. The placement of the consonant in medial position subjects it to both forward and backward masking effects.

There were more similarities between the errors of the children and adults than there were differences. That is, children made more errors than the adults primarily in the same categories. Although the analysis also revealed some difference in the pattern of errors, one should be cautious in interpreting this finding because of the small number of errors involved. The differences between the adults and the younger children were particularly interesting in the monaural condition where children's errors on the fricatives and affricates were clearly different from adults'. For instance, the 5-year-olds substituted /p, b, d, f, θ, ð, z, and h/ for /v/, while adults substituted/ð, θ, g, and b/. The substitutions of the children involved more errors on the feature of voicing, including the use of the voiceless fricative /h/. Semivowels were also used by children in place of consonants. Although the phonemes /j/, /h/, and /l/ were not presented as stimuli, they were given as responses by children and not by adults.

Adult listeners did not make errors on the affricates, while the younger children did make errors. Substitutions included errors in the features of voicing (dʒ/tʃ), continuance (ʃ/tʃ), or change of multiple features (j/tʃ). While the errors on the nasals primarily involved confusions between /m/ and /ŋ/ in adults, in children fricatives and stops were substituted for nasals in addition to the "within-category" confusions.

Thus it appears that some of the errors made by children occur on features that are more resistant to the masking effects of reverberation in adults--the features of voicing and nasality, as well as the consonantal feature. Although perception of vowels never was in error for the disyllables used, semi-vowels were substituted for consonants by children, but not by adults.

In summary, the pattern of errors obtained in the present study for .4 and .6-second reverberation conditions was similar to the pattern reported by previous investigators; place of articulation information was most affected, followed by manner, and nasality. Voicing was relatively unaffected. The exact pattern of errors of specific phonemes differed from studies in which a closed-response set was used because the allowable substitutions were circumscribed by the foils provided in the test in that particular case.

The pattern of errors differed from that of adults in some details. Although most of the error types were similar, percentage error on particular phonemes was higher. Again, performance changed as a function of age. Younger children made more errors that differed from adult errors. Some of the confusions exhibited by children, but not by adults included the features of voicing, substitution of fricatives for nasals, and substitution of semi-vowels for consonants. Children also made errors on affricates, an error that adults did not make.

CHAPTER VI

SUMMARY, CONCLUSIONS AND FUTURE RESEARCH

Summary

While the effect of reverberation on speech discrimination of adults has been examined in depth, very little research has been done to determine its effect on children. Yet, previous research has demonstrated that children are less able to discriminate distorted speech signals than adults. Furthermore, younger children are affected more than older children. While the recent studies of Finitzo-Hieber and Tillman (1979) and Nabelek and Jennings (1981) provided important information about the ability of children to function in reverberant environments, neither study approached the issue from a developmental standpoint.

The purpose of the present study was to determine whether or not the ability of children to discriminate phonemes under reverberant conditions typical of classrooms would change as a function of age. Related issues which were investigated included the nature of the binaural advantage in children under reverberant conditions and a comparison of the pattern of phoneme errors made by children of different ages to that of adults in the reverberant conditions.

Twenty-five children ages 5, 7, 9, 11, and 13 (five subjects per age group) were the subjects in this experiment. All children had normal hearing for pure tones, speech discrimination scores better than 90% on the CID W-22 lists, normal intelligence (as determined by age-appropriate school placement), and normal articulation skills. A group of five normal-hearing adults was also included in order to obtain asymptotic measures on the experimental stimuli.

Experimental stimuli consisted of 114 nonsense disyllables (VCV) in a carrier phrase (say the word). These materials were recorded through a KEMAR manikin in an anechoic chamber and a reverberation room in which reverberation time was varied to produce two reverberant conditions nominally .4 and .6 sec. Placement of the KEMAR in the reverberation room was at a position in excess of the critical distance. After processing through the Killion equalization filter (Killion, 1979), test materials were presented through Sennheiser HD 414X headphones.

Testing was done in a sound-treated room. The four experimental conditions included three conditions which were tested in the binaural mode; non-reverberant, .4 and .6-sec reverberation time, and one in the monaural mode: .6-sec reverberation time. For the binaural conditions, a signal at a 60 dB sound pressure level was introduced to each earphone. In the monaural condition, a signal level of 63 dB SPL was introduced to the test ear.

Data were subjected to analysis of variance techniques. The Duncan Multiple Range Test was used to determine significant differences between age groups and between reverberation conditions (Winer, 1971). In addition, confusion matrices were compared using the G^2 statistic (Bishop, et al, 1975).

Major Findings

The major findings of this study were:

1. The relatively short reverberation times employed in this study caused significant decreases in phoneme discrimination of all subjects.

2. Phoneme discrimination scores for the reverberant conditions improved with increasing age. Analysis of variance techniques revealed that age was a significant factor in determining discrimination ability.

3. Binaural listening was superior to monaural listening for all age groups in the .6-sec-reverberation condition. The monaural/binaural difference was statistically significant. In addition, the monaural/binaural difference was larger for the 5-year-olds than for other ages.

4. The pattern of phoneme errors obtained in the reverberant conditions was similar to that reported by other investigators. Place and manner errors were most common. Voicing and nasality errors were rare. The place errors involved the fricatives /f, v, θ, ð /, stops /p, b, k, g/, and nasals /m, ŋ/. The majority of the manner errors involved confusions between stops and fricatives.

5. In general, the children made the same type of errors as the adults, but made more errors. However, the younger children (5, 7, and 9-year-olds) did make some substitutions which differed from those of older children and adults. These errors included the features of voicing, affrication, and the consonantal feature.

The results of this study have implications for the design of rooms to be used by children for listening to speech signals. Because younger children are more affected by reverberation than older children, reverberation in classrooms should be as short as possible to allow optimal speech discrimination. Reverberation times in classrooms for normal-hearing children should not exceed .4 seconds.

The fact that monaural presentation caused much poorer discrimination in the 5-year-olds than in other age groups is consistent with findings of other studies in which degraded speech signals have been used with children. This finding emphasizes the child's need for a redundant signal in order to obtain optimal discrimination. Similarly, error patterns of the 5, 7, and 9-year-old children revealed errors on features which are resistant to the effects of reverberation in adults, again, emphasizing the need for a redundant speech signal.

Recommendations for Future Research

Use of an open-set nonsense syllable test proved to be a valuable method of obtaining information about phoneme confusions without the constraint of semantic or syntactic considerations. This type of task should be considered for use in further investigations of the effect of reverberation on adults and children.

Further information should be obtained on the developmental aspect of phoneme perception in noise. Patterns of phoneme errors for noise and reverberation conditions should be compared in order to obtain insight into the similarities and differences between these two types of maskers.

Investigations of phoneme perception in reverberation and in noise should also be done on hearing-impaired children and on children with learning disabilities in order to determine if perception is similar to that of normal-hearing children in overall effect and pattern.

The binaural advantage for understanding of speech in reverberation should be further investigated using more children (both normal-hearing and hearing-impaired), longer reverberation times, and combinations of reverberation and noise.

APPENDIX A

Listing of age, sex, and grade for the experimental subjects (children ages 5, 7, 9, 11, and 13).

Subject	Age	Sex	Grade
1	66 mo.	F	kindergarten
2	61 mo.	F	kindergarten
3	67 mo.	F	kindergarten
4	68 mo.	M	kindergarten
5	68 mo.	M	kindergarten
6	95 mo.	F	second
7	90 mo.	M	first
8	85 mo.	M	first
9	85 mo.	F	first
10	93 mo.	M	first
11	119 mo.	F	fifth
12	119 mo.	M	fifth
13	114 mo.	F	fourth
14	109 mo.	F	fourth
15	113 mo.	F	fourth
16	143 mo.	F	sixth
17	136 mo.	M	fifth
18	137 mo.	F	sixth
19	140 mo.	F	sixth
20	137 mo.	M	fifth
21	167 mo.	M	eighth
22	167 mo.	F	eighth
23	157 mo.	F	seventh
24	156 mo.	M	seventh
25	159 mo.	M	seventh

APPENDIX B

Instructions and answer sheets for the experiment.

Instructions:

You will be hearing a man say some funny words-- words like "ipi" and "upu". Do you think you can say those words? "Say the word ipi."

Good.

Sometimes the words will be very funny. The words are not real words. You repeat the word that you hear and I will write down what you say.

NAME____________________ AGE________ COND. _____ Date _________

NONSENSE SYLLABLE TEST

a. uθu ___
b. aʒa ___
c. ivi ___
d. igi ___
e. uʃu ___
1. aŋa ___
2. iʒi ___
3. uʒu ___
4. afa ___
5. ubu ___
6. uʒu ___
7. idʒi ___
8. imi ___
9. ata ___
10. uŋu ___
11. idʒi ___
12. ivi ___
13. uðu ___
14. uʃu ___
15. uʃu ___
16. iti ___
17. aga ___
18. uku ___
19. isi ___
20. adʒa ___
21. uvu ___
22. apa ___
23. iʒi ___
24. ama ___
25. udʒu ___
26. izi ___
27. ama ___
28. iði ___
29. ubu ___
30. ava ___
31. ibi ___
32. udʒu ___
33. utu ___
34. atʃa ___
35. unu ___
36. ufu ___
37. iθi ___
38. ibi ___
39. ada ___
40. aʃa ___
41. iŋi ___
42. aka ___
43. aʒa ___
44. aba ___
45. izi ___
46. upu ___
47. aʒa ___
48. uðu ___
49. apa ___
50. umu ___
51. ipi ___
52. itʃi ___
53. uvu ___
54. uθu ___
55. aθa ___
56. umu ___
57. igi ___
58. uθu ___
59. iŋi ___
60. aga ___
61. ini ___
62. utu ___
63. idi ___
64. asa ___
65. unu ___
66. iʃi ___
67. afa ___
68. isi ___
69. ana ___
70. udu ___
71. usu ___
72. ifi ___
73. ugu ___
74. ada ___
75. uŋu ___
76. aba ___
77. usu ___
78. igi ___
79. udu ___
80. aθa ___
81. iti ___
82. aza ___
83. itʃi ___
84. adʒa ___
85. aŋa ___
86. ufu ___
87. iʃi ___
88. imi ___
89. aza ___
90. uku ___
91. utʃu ___
92. iði ___
93. ivi ___
94. aða ___
95. uzu ___

NONSENSE SYLLABLE TEST (cont'd)

96. ava ___

97. ugu ___

98. ata ___

99. ipi ___

100. ana ___

101. aða ___

102. ifi ___

103. aka ___

104. upu ___

105. iθi ___

106. aʃa ___

107. iki ___

108. ini ___

109. asa ___

110. idi ___

111. iki ___

112. atʃa___

113. uzu ___

114. utʃu___

APPENDIX C

Discrimination scores for each subject in four experimental conditions: Non-reverberant, .4-second reverberation time (binaural), .6-second reverberation time (binaural), and .6-second reverberation time (monaural).

Non-reverberant		.4 sec. Binaural		.6 sec. Binaural		.6 sec. Monaural	
Prop.	Arc sine	Prop.	Arc sine	Prop.	Arc sine	Prop.	Arc Sine
Age 5-Subjects 1-5							
.974	2.8177	.833	2.2916	.860	2.3746	.728	2.0488
.956	2.7189	.728	2.0488	.605	1.7926	.544	1.6509
.982	2.8725	.798	2.2143	.798	2.2143	.632	1.8338
.956	2.7189	.904	2.4981	.833	2.2916	.675	1.9177
.947	2.6906	.816	2.2653	.763	2.1177	.623	1.8132
Age 7- Subjects 6-10							
.974	2.8177	.895	2.4655	.877	2.4341	.842	2.3186
.991	2.9516	.860	2.3746	.825	2.2916	.789	2.1895
.956	2.7189	.798	2.2143	.781	2.1652	.754	2.0944
.974	2.8177	.886	2.4655	.798	2.2143	.833	2.2916
.983	2.8801	.877	2.4341	.886	2.4655	.842	2.3186
Age 9- Subjects 11-15							
1.00	3.0783	.860	2.3746	.851	2.3462	.816	2.2395
.974	2.8177	.868	2.4039	.912	2.5322	.798	2.2143
.965	2.7652	.851	2.3462	.632	1.8338	.675	1.9391
.965	2.7652	.807	2.2395	.763	2.1177	.711	2.0042
.965	2.7652	.912	2.5322	.860	2.3746	.868	2.4039
Age 11- Subjects 16-20							
.974	2.8177	.921	2.5681	.860	2.3746	.833	2.2916
.965	2.7652	.886	2.4655	.754	2.0944	.781	2.1652
.956	2.7652	.877	2.4341	.781	2.1652	.772	2.1412
.974	2.8177	.877	2.4341	.930	2.6062	.825	2.2653
.983	2.8801	.930	2.6062	.912	2.5322	.895	2.4981
Age 13-Subjects 21-25							
.991	2.9516	.921	2.5681	.886	2.4655	.842	2.3186
.982	2.8725	.921	2.5681	.895	2.4981	.868	2.4039
.982	2.8725	.930	2.6062	.939	2.6467	.956	2.7189
.956	2.7189	.921	2.5681	.895	2.4981	.789	2.1895
.982	2.8725	.947	2.6906	.912	2.5322	.939	2.6467
Adult							
.974	2.8177	.930	2.6062	.912	2.5322	.868	2.4039
.974	2.8177	.974	2.8177	.930	2.6062	.912	2.5322
.991	2.9516	.947	2.6467	.921	2.5681	.904	2.4981
.974	2.8177	.930	2.6062	.904	2.4981	.851	2.3462
.991	2.9516	.921	2.5681	.921	2.5681	.982	2.8725

APPENDIX D

Confusion Matrices for each age group in each reverberation condition.

Age 5: Non-reverberant condition.

Stimuli:

	Responses:																				
	p	b	t	d	k	g	f	v	θ	ð	s	z	ʃ	ʒ	tʃ	dʒ	m	n	ŋ	h	j	l
p	29	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
b	0	29	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
t	0	0	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
d	0	0	0	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
k	1	0	0	0	29	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
g	0	0	0	1	0	29	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
f	0	0	0	0	0	0	23	0	7	0	0	0	0	0	0	0	0	0	0	0	0	0
v	0	0	0	0	0	0	0	28	0	2	0	0	0	0	0	0	0	0	0	0	0	0
θ	0	0	0	0	0	0	1	0	28	1	0	0	0	0	0	0	0	0	0	0	0	0
ð	0	0	0	0	0	0	0	1	1	28	0	0	0	0	0	0	0	0	0	0	0	0
s	0	0	0	0	0	0	0	0	0	0	30	0	0	0	0	0	0	0	0	0	0	0
z	0	0	0	0	0	0	0	0	0	0	0	30	0	0	0	0	0	0	0	0	0	0
ʃ	0	0	0	0	0	0	0	0	0	0	0	0	30	0	0	0	0	0	0	0	0	0
ʒ	0	0	0	0	0	0	0	0	0	0	0	0	0	30	0	0	0	0	0	0	0	0
tʃ	0	0	0	0	0	0	0	0	0	0	0	0	0	0	30	0	0	0	0	0	0	0
dʒ	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	30	0	0	0	0	0	0
m	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	30	0	0	0	0	0
n	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	30	0	0	0	0
ŋ	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	26	0	0	0

Age 5: .4 second condition.

	Responses:																					
Stimuli:	p	b	t	d	k	g	f	v	θ	ð	s	z	ʃ	ʒ	tʃ	dʒ	m	n	ŋ	h	j	l
p	25	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0
b	0	24	0	2	0	0	0	3	1	0	0	0	0	0	0	0	0	0	0	0	0	0
t	0	0	29	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
d	0	1	0	26	0	1	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0
k	6	0	3	1	20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
g	0	0	0	7	0	19	0	1	1	0	0	1	0	0	0	0	0	0	0	0	1	0
f	4	0	1	0	0	0	20	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0
v	1	4	0	1	0	1	3	12	1	5	0	0	0	0	0	0	0	0	0	2	0	0
θ	1	0	0	0	0	0	5	0	24	0	0	0	0	0	0	0	0	0	0	0	0	0
ð	0	0	1	0	0	0	0	5	1	23	0	0	0	0	0	0	0	0	0	0	0	0
s	0	0	0	0	0	0	0	0	0	0	30	0	0	0	0	0	0	0	0	0	0	0
z	0	0	0	1	0	0	0	0	0	0	0	29	0	0	0	0	0	0	0	0	0	0
ʃ	0	0	0	1	0	0	0	0	0	0	0	0	29	0	0	0	0	0	0	0	0	0
ʒ	0	0	0	0	0	0	0	0	0	0	0	0	1	29	0	0	0	0	0	0	0	0
tʃ	0	0	0	0	0	0	0	0	0	0	0	0	1	1	28	0	0	0	0	0	0	0
dʒ	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	28	0	0	0	0	0	0
m	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	25	4	0	0	0	0
n	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	1	27	0	0	0	0
ŋ	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	5	5	16	0	0	3

Age 5: .6 second condition (binaural)

	Responses:																				
Stimuli:	p	b	t	d	k	g	f	v	θ	ð	s	z	ʃ	ʒ	tʃ	dʒ	m	n	ŋ	h	j	l
p	17	0	2	0	5	0	1	2	0	0	0	0	0	0	0	1	0	0	0	2	0	0
b	2	25	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
t	1	0	28	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
d	0	0	0	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
k	5	0	2	1	21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
g	0	0	0	2	2	18	0	0	0	1	0	0	0	0	0	0	0	0	0	1	5	1
f	4	1	0	0	0	0	17	0	6	0	0	0	0	0	0	1	0	0	0	1	0	0
v	1	5	0	1	0	1	0	19	0	1	0	0	0	0	0	0	0	0	0	2	0	0
θ	6	0	0	0	0	0	6	0	16	0	0	0	0	0	0	0	0	0	0	2	0	0
ð	0	0	0	2	0	1	0	5	1	19	0	2	0	0	0	0	0	0	0	0	0	0
s	0	0	0	0	1	0	0	0	0	0	29	0	0	0	0	0	0	0	0	0	0	0
z	0	0	0	0	0	0	0	0	0	0	0	30	0	0	0	0	0	0	0	0	0	0
ʃ	0	0	0	0	0	0	0	0	0	0	0	0	27	3	0	0	0	0	0	0	0	0
ʒ	0	1	0	0	0	0	0	0	0	0	0	0	0	29	0	0	0	0	0	0	0	0
tʃ	0	0	0	0	0	0	0	0	0	0	0	0	1	0	27	2	0	0	0	0	0	0
dʒ	0	0	0	1	0	1	0	0	0	0	0	0	0	1	0	27	0	0	0	0	0	0
m	0	0	0	0	0	0	0	5	0	0	0	0	0	0	0	0	19	4	0	2	0	0
n	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	28	0	0	0	0
ŋ	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	10	2	14	0	1	2

Age 5: .6 second condition(monaural)

Responses:

Stimuli:	p	b	t	d	k	g	f	v	θ	ð	s	z	ʃ	ʒ	tʃ	dʒ	m	n	ŋ	h	j	l
p	10	1	4	0	8	0	2	1	1	0	0	0	0	0	0	0	0	0	0	3	0	0
b	1	19	0	1	0	0	1	5	0	1	0	0	0	0	0	0	0	0	0	2	0	0
t	0	0	27	0	1	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0
d	0	1	3	22	0	3	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
k	3	0	3	0	21	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
g	0	0	0	3	3	14	0	3	0	0	0	0	0	0	0	1	0	1	0	1	4	0
f	2	0	2	0	0	0	15	0	6	0	1	2	0	0	0	0	0	0	0	2	0	0
v	3	8	0	2	0	0	1	9	2	2	0	1	0	0	0	0	0	0	0	2	0	0
θ	3	1	6	0	1	0	3	1	15	0	0	0	0	0	0	0	0	0	0	0	0	0
ð	1	0	0	3	0	0	0	4	3	14	0	3	0	1	0	1	0	0	0	0	0	0
s	0	0	0	0	0	0	0	0	1	0	29	0	0	0	0	0	0	0	0	0	0	0
z	0	0	0	0	0	0	0	1	0	0	0	29	0	0	0	0	0	0	0	0	0	0
ʃ	0	0	0	0	0	0	0	0	1	0	0	0	25	4	0	0	0	0	0	0	0	0
ʒ	0	0	0	0	0	0	0	0	0	0	0	2	1	27	0	0	0	0	0	0	0	0
tʃ	0	0	0	0	0	0	0	0	0	0	0	0	7	0	21	2	0	0	0	0	0	0
dʒ	0	0	0	0	0	0	0	0	0	0	0	0	1	5	0	24	0	0	0	0	0	0
m	0	3	0	1	0	2	0	5	0	1	0	0	0	0	0	0	9	4	0	5	0	0
n	0	0	0	3	0	0	0	1	0	0	0	0	0	1	0	0	1	23	0	0	0	1
ŋ	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	7	6	13	0	0	2

Age 7: Non-reverberant condition

Stimuli:	Responses: p	b	t	d	k	g	f	v	θ	ð	s	z	ʃ	ʒ	tʃ	dʒ	m	n	ŋ	h	j	l
p	29	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
b	0	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
t	0	0	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
d	0	0	0	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
k	0	0	0	0	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
g	0	0	0	0	0	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
f	0	0	0	0	0	0	26	0	3	1	0	0	0	0	0	0	0	0	0	0	0	0
v	0	0	0	0	0	0	0	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0
θ	0	0	0	0	0	0	3	0	27	0	0	0	0	0	0	0	0	0	0	0	0	0
ð	0	0	0	0	0	0	0	2	0	28	0	0	0	0	0	0	0	0	0	0	0	0
s	0	0	0	0	0	0	0	0	0	0	30	0	0	0	0	0	0	0	0	0	0	0
z	0	0	0	0	0	0	0	0	0	0	0	30	0	0	0	0	0	0	0	0	0	0
ʃ	0	0	0	0	0	0	0	0	1	0	0	0	29	0	0	0	0	0	0	0	0	0
ʒ	0	0	0	0	0	0	0	0	0	0	0	0	0	30	0	0	0	0	0	0	0	0
tʃ	0	0	0	0	0	0	0	0	0	0	0	0	0	0	30	0	0	0	0	0	0	0
dʒ	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	30	0	0	0	0	0	0
m	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	30	0	0	0	0	0
n	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	30	0	0	0	0
ŋ	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	27	0	0	0

Age 7: .4 second condition

Responses:

Stimuli:	p	b	t	d	k	g	f	v	θ	ð	s	z	ʃ	ʒ	tʃ	dʒ	m	n	ŋ	h	j	l
p	25	0	1	0	3	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
b	0	23	0	0	0	2	0	4	0	1	0	0	0	0	0	0	0	0	0	0	0	0
t	0	0	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
d	0	0	0	29	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
k	4	0	0	0	26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
g	0	0	0	5	0	24	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
f	2	0	0	0	0	0	24	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0
v	1	5	0	0	0	1	1	18	0	2	0	2	0	0	0	0	0	0	0	0	0	0
θ	2	0	0	0	2	0	8	0	16	0	2	0	0	0	0	0	0	0	0	0	0	0
ð	0	0	0	0	0	0	0	6	0	21	0	3	0	0	0	0	0	0	0	0	0	0
s	0	0	0	0	0	0	0	0	0	0	30	0	0	0	0	0	0	0	0	0	0	0
z	0	0	0	0	0	0	0	0	0	0	0	30	0	0	0	0	0	0	0	0	0	0
ʃ	0	0	0	0	0	0	0	0	0	0	0	0	30	0	0	0	0	0	0	0	0	0
ʒ	0	0	0	0	0	0	0	0	0	0	0	0	0	30	0	0	0	0	0	0	0	0
tʃ	0	0	1	0	0	0	0	0	0	0	0	0	0	0	29	0	0	0	0	0	0	0
dʒ	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	29	0	0	0	0	0	0
m	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	23	7	0	0	0	0
n	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	30	0	0	0	0
ŋ	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	1	25	0	0	1

Age 7: .6 second condition (binaural)

Responses:

Stimuli:	p	b	t	d	k	g	f	v	θ	ð	s	z	ʃ	ʒ	tʃ	dʒ	m	n	ŋ	h	j	l
p	21	0	2	0	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
b	0	20	0	0	0	1	1	7	0	0	0	0	0	0	0	0	0	1	0	0	0	0
t	0	0	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
d	0	1	0	29	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
k	1	0	2	1	26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
g	0	1	0	3	0	24	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0
f	2	0	1	0	0	0	26	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
v	2	1	1	1	0	4	0	18	0	2	0	0	0	0	0	0	0	0	1	0	0	0
θ	4	0	1	0	1	0	6	2	15	0	1	0	0	0	0	0	0	0	0	0	0	0
ð	0	0	0	1	0	0	0	7	0	19	0	3	0	0	0	0	0	0	0	0	0	0
s	0	0	0	0	0	0	0	0	0	0	30	0	0	0	0	0	0	0	0	0	0	0
z	0	0	0	0	0	0	0	0	0	1	0	29	0	0	0	0	0	0	0	0	0	0
ʃ	0	0	0	0	0	0	0	0	0	0	0	0	27	3	0	0	0	0	0	0	0	0
ʒ	0	0	0	0	0	0	0	0	0	0	0	0	0	30	0	0	0	0	0	0	0	0
tʃ	0	0	2	0	0	0	0	0	0	0	0	0	0	0	28	0	0	0	0	0	0	0
dʒ	0	0	0	2	0	0	0	0	0	0	0	0	0	1	0	27	0	0	0	0	0	0
m	0	2	0	1	0	0	0	0	0	0	0	0	0	0	0	0	24	3	0	0	0	0
n	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	30	0	0	0	0
ŋ	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	2	22	0	0	1

Age 7: .6 condition (monaural)

Stimuli:

	Responses:																					
	p	b	t	d	k	g	f	v	θ	ð	s	z	ʃ	ʒ	tʃ	dʒ	m	n	ŋ	h	j	l
p	20	0	1	0	6	0	2	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
b	0	17	0	1	1	3	1	6	0	0	0	0	0	0	0	0	1	0	0	0	0	0
t	1	0	29	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
d	0	0	0	29	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
k	2	0	1	0	27	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
g	0	0	0	2	0	25	0	0	0	0	0	0	0	0	0	0	1	0	1	0	1	0
f	2	0	0	0	0	0	23	1	3	0	1	0	0	0	0	0	0	0	0	0	0	0
v	1	1	0	2	0	0	0	24	0	0	0	0	0	0	0	0	1	0	0	1	0	0
θ	4	0	0	0	2	0	7	1	16	0	0	0	0	0	0	0	0	0	0	0	0	0
ð	0	0	0	2	0	0	0	7	0	19	0	2	0	0	0	0	0	0	0	0	0	0
s	0	0	0	0	0	0	0	0	0	0	30	0	0	0	0	0	0	0	0	0	0	0
z	0	0	0	0	0	0	0	0	0	0	0	30	0	0	0	0	0	0	0	0	0	0
ʃ	0	0	0	0	0	0	0	0	0	0	0	0	27	3	0	0	0	0	0	0	0	0
ʒ	0	0	0	0	0	0	0	0	0	0	0	0	0	28	0	2	0	0	0	0	0	0
tʃ	0	0	0	0	0	0	0	0	0	0	0	0	5	0	23	1	0	0	0	0	1	0
dʒ	0	0	0	1	1	0	0	0	0	0	0	0	0	7	0	21	0	0	0	0	0	0
m	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	25	3	2	0	0	0
n	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	28	0	0	0	2
ŋ	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	4	22	0	0	0

Age 9: Non-reverberant condition.

Stimuli:	Responses: p	b	t	d	k	g	f	v	θ	ð	s	z	ʃ	ʒ	tʃ	dʒ	m	n	ŋ	h	j	l
p	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
b	0	28	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
t	0	0	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
d	0	0	0	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
k	0	0	0	0	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
g	0	0	0	0	0	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
f	0	0	0	0	0	0	27	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0
v	0	0	0	0	0	0	0	26	0	4	0	0	0	0	0	0	0	0	0	0	0	0
θ	0	0	0	0	0	0	1	0	28	1	0	0	0	0	0	0	0	0	0	0	0	0
ð	0	0	0	0	0	0	0	2	0	28	0	0	0	0	0	0	0	0	0	0	0	0
s	0	0	0	0	0	0	0	0	0	0	30	0	0	0	0	0	0	0	0	0	0	0
z	0	0	0	0	0	0	0	0	0	0	0	30	0	0	0	0	0	0	0	0	0	0
ʃ	0	0	0	0	0	0	0	0	0	0	0	0	30	0	0	0	0	0	0	0	0	0
ʒ	0	0	0	0	0	0	0	0	0	0	0	0	0	30	0	0	0	0	0	0	0	0
tʃ	0	0	0	0	0	0	0	0	0	0	0	0	0	0	30	0	0	0	0	0	0	0
dʒ	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	30	0	0	0	0	0	0
m	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	30	0	0	0	0	0
n	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	30	0	0	0	0
ŋ	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	28	0	0	0

Age 9: .4 second condition

Responses:

Stimuli:	p	b	t	d	k	g	f	v	θ	ð	s	z	ʃ	ʒ	tʃ	dʒ	m	n	ŋ	h	j	l
p	27	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
b	0	21	0	1	0	1	0	5	0	2	0	0	0	0	0	0	0	0	0	0	0	0
t	0	0	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
d	0	0	0	29	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
k	7	0	0	0	23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
g	0	0	0	4	0	23	0	2	0	0	0	0	0	0	0	0	0	0	0	1	0	0
f	2	0	0	0	0	0	24	1	3	0	0	0	0	0	0	0	0	0	0	0	0	0
v	0	7	0	0	0	0	1	19	0	2	0	0	0	0	0	0	0	0	0	1	0	0
θ	1	0	0	0	0	0	8	0	21	0	0	0	0	0	0	0	0	0	0	0	0	0
ð	0	0	0	1	0	0	0	4	1	24	0	0	0	0	0	0	0	0	0	0	0	0
s	0	0	0	0	0	0	0	0	0	0	30	0	0	0	0	0	0	0	0	0	0	0
z	0	0	0	0	0	0	0	0	0	0	0	30	0	0	0	0	0	0	0	0	0	0
ʃ	0	0	0	0	0	0	0	0	0	0	0	0	30	0	0	0	0	0	0	0	0	0
ʒ	0	0	0	1	0	0	0	0	0	0	0	0	0	28	0	1	0	0	0	0	0	0
tʃ	0	0	0	0	0	0	0	0	0	0	0	0	1	0	29	0	0	0	0	0	0	0
dʒ	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	30	0	0	0	0	0	0
m	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	20	7	0	0	0	1
n	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	29	0	0	0	0
ŋ	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	2	25	0	0	1

Age 9: .6 second condition (binaural)

Responses:

Stimuli:	p	b	t	d	k	g	f	v	θ	ð	s	z	ʃ	ʒ	tʃ	dʒ	m	n	ŋ	h	j	l
p	27	0	0	0	2	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
b	0	16	0	0	0	0	0	12	0	2	0	0	0	0	0	0	0	0	0	0	0	0
t	0	0	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
d	0	0	1	28	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
k	4	0	1	0	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
g	0	0	0	3	0	21	0	3	0	1	0	0	0	0	0	1	0	0	0	1	0	0
f	4	0	0	0	0	0	21	1	3	0	0	0	0	0	0	0	0	0	0	1	0	0
v	0	2	1	2	0	0	1	21	0	2	0	0	0	0	0	0	0	0	0	1	0	0
θ	5	0	0	1	0	0	7	0	13	4	0	0	0	0	0	0	0	0	0	0	0	0
ð	0	0	0	0	0	0	0	6	0	24	0	0	0	0	0	0	0	0	0	0	0	0
s	0	0	0	0	0	0	0	0	0	0	30	0	0	0	0	0	0	0	0	0	0	0
z	0	0	0	0	0	0	0	0	0	0	0	30	0	0	0	0	0	0	0	0	0	0
ʃ	0	0	0	0	0	0	0	0	0	0	0	0	30	0	0	0	0	0	0	0	0	0
ʒ	0	0	0	0	0	0	0	0	0	0	0	0	0	29	0	1	0	0	0	0	0	0
tʃ	0	0	0	0	0	0	0	0	0	0	0	0	1	0	28	1	0	0	0	0	0	0
dʒ	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	30	0	0	0	0	0	0
m	0	0	0	0	0	1	0	5	0	0	0	0	0	0	0	0	19	3	0	0	0	2
n	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	1	27	0	0	0	0
ŋ	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	5	3	19	0	0	2

Age 9: .6 second condition (monaural)

Stimuli:	Responses:																					
	p	b	t	d	k	g	f	v	θ	ð	s	z	ʃ	ʒ	tʃ	dʒ	m	n	ŋ	h	j	l
p	23	0	2	0	2	0	2	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
b	0	17	0	4	0	0	1	5	0	2	0	1	0	0	0	0	0	0	0	0	0	0
t	0	0	29	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
d	0	0	0	27	0	1	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0
k	4	0	4	0	22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
g	0	0	0	3	0	20	0	3	0	0	0	0	0	0	0	1	0	0	0	1	2	0
f	5	0	0	0	0	0	23	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0
v	0	4	0	2	0	0	0	18	0	4	0	0	0	0	0	0	1	0	0	1	0	0
θ	2	0	1	2	0	0	8	0	12	5	0	0	0	0	0	0	0	0	0	0	0	0
ð	0	1	0	0	0	1	0	4	0	23	0	1	0	0	0	0	0	0	0	0	0	0
s	0	0	0	0	0	0	0	0	0	0	30	0	0	0	0	0	0	0	0	0	0	0
z	0	0	0	0	0	0	0	0	0	0	1	29	0	0	0	0	0	0	0	0	0	0
ʃ	0	0	0	0	0	0	0	0	0	0	0	0	29	1	0	0	0	0	0	0	0	0
ʒ	0	0	0	0	0	0	0	0	0	0	0	0	0	28	0	2	0	0	0	0	0	0
tʃ	0	0	0	0	0	0	0	0	0	0	0	0	2	0	26	2	0	0	0	0	0	0
dʒ	0	0	0	0	0	0	0	0	0	1	0	1	0	3	0	25	0	0	0	0	0	0
m	0	0	0	1	0	0	0	8	0	0	0	0	0	0	0	1	17	2	0	0	0	1
n	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	2	25	0	0	0	1
ŋ	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	6	18	0	0	0

Age 11: Non-reverberant condition

Stimuli: / Responses:

	p	b	t	d	k	g	f	v	θ	ð	s	z	ʃ	ʒ	tʃ	dʒ	m	n	ŋ	h	j	l
p	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
b	0	28	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
t	0	0	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
d	0	0	0	29	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
k	0	0	0	0	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
g	0	0	0	1	0	29	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
f	0	0	0	0	0	0	28	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0
v	0	0	0	0	0	0	0	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0
θ	0	0	0	0	0	0	4	0	26	0	0	0	0	0	0	0	0	0	0	0	0	0
ð	0	0	0	0	0	0	0	2	0	28	0	0	0	0	0	0	0	0	0	0	0	0
s	0	0	0	0	0	0	0	0	0	0	30	0	0	0	0	0	0	0	0	0	0	0
z	0	0	0	0	0	0	0	0	0	0	0	30	0	0	0	0	0	0	0	0	0	0
ʃ	0	0	0	0	0	0	0	0	0	0	0	0	30	0	0	0	0	0	0	0	0	0
ʒ	0	0	0	0	0	0	0	0	0	0	0	0	0	30	0	0	0	0	0	0	0	0
tʃ	0	0	0	0	0	0	0	0	0	0	0	0	0	0	30	0	0	0	0	0	0	0
dʒ	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	30	0	0	0	0	0	0
m	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	29	1	0	0	0	0
n	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	30	0	0	0	0
ŋ	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	3	0	26	0	0	0

Age 11: .4 second condition

Stimuli:	Responses: p	b	t	d	k	g	f	v	θ	ð	s	z	ʃ	ʒ	tʃ	dʒ	m	n	ŋ	h	j	l
p	28	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
b	0	21	0	0	0	0	0	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0
t	0	0	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
d	0	0	0	26	0	1	0	1	0	1	0	0	0	0	0	0	0	1	0	0	0	0
k	5	0	1	1	23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
g	0	0	0	2	0	26	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0
f	1	0	0	0	0	0	25	1	3	0	0	0	0	0	0	0	0	0	0	0	0	0
v	0	2	0	0	0	0	2	24	0	1	0	0	0	0	0	0	0	0	0	1	0	0
θ	0	0	0	0	0	0	4	0	25	1	0	0	0	0	0	0	0	0	0	0	0	0
ð	0	0	0	0	0	0	0	4	0	25	0	1	0	0	0	0	0	0	0	0	0	0
s	0	0	0	0	0	0	0	0	1	0	29	0	0	0	0	0	0	0	0	0	0	0
z	0	0	0	0	0	0	0	0	0	0	0	30	0	0	0	0	0	0	0	0	0	0
ʃ	0	0	0	0	0	0	0	0	0	0	0	0	29	1	0	0	0	0	0	0	0	0
ʒ	0	0	0	0	0	0	0	1	0	0	0	0	0	28	0	1	0	0	0	0	0	0
tʃ	0	0	0	0	0	0	0	0	0	0	0	0	0	0	30	0	0	0	0	0	0	0
dʒ	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	28	0	0	0	0	0	0
m	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	28	2	0	0	0	0
n	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	29	0	0	0	0
ŋ	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	1	27	0	0	0

Age 11: .6 second condition (binaural)

Responses:

Stimuli:	p	b	t	d	k	g	f	v	θ	ð	s	z	ʃ	ʒ	tʃ	dʒ	m	n	ŋ	h	j	l
p	26	0	1	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
b	0	26	0	1	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
t	0	0	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
d	0	0	0	29	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
k	4	0	2	0	24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
g	0	0	0	4	0	21	0	3	0	0	0	0	0	0	0	0	0	0	2	0	0	0
f	6	0	1	0	1	0	19	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0
v	0	3	0	1	0	1	2	20	0	1	0	0	0	0	0	0	0	0	1	1	0	0
θ	5	1	1	0	0	0	4	0	19	0	0	0	0	0	0	0	0	0	0	0	0	0
ð	0	0	0	1	0	0	0	5	0	22	0	2	0	0	0	0	0	0	0	0	0	0
s	0	0	0	0	0	0	0	0	0	0	30	0	0	0	0	0	0	0	0	0	0	0
z	0	0	0	0	0	0	0	0	0	0	1	29	0	0	0	0	0	0	0	0	0	0
ʃ	0	0	0	0	0	0	0	0	0	0	0	0	30	0	0	0	0	0	0	0	0	0
ʒ	0	0	0	0	0	0	0	0	0	0	0	0	0	30	0	0	0	0	0	0	0	0
tʃ	0	0	0	0	0	0	0	0	0	0	0	0	0	0	30	0	0	0	0	0	0	0
dʒ	0	0	0	0	0	0	0	1	0	0	0	0	0	4	0	25	0	0	0	0	0	0
m	0	1	0	1	0	0	0	2	0	0	0	0	0	0	0	0	24	2	0	0	0	0
n	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	3	26	0	0	0	0
ŋ	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	2	22	0	0	0

Age 11: .6 second condition (monaural)

Stimuli:	p	b	t	d	k	g	f	v	θ	ð	s	z	ʃ	ʒ	tʃ	dʒ	m	n	ŋ	h	j	l
p	23	0	3	0	3	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
b	0	22	0	0	0	2	0	5	0	0	0	0	0	0	0	0	0	0	0	1	0	0
t	0	0	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
d	0	0	0	27	0	1	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0
k	1	0	1	0	28	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
g	0	0	0	5	0	17	0	2	0	0	0	0	0	0	0	2	0	0	2	0	2	0
f	4	1	2	0	0	0	21	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0
v	0	4	0	1	0	1	0	23	0	0	0	0	0	0	0	1	0	0	0	0	0	0
θ	4	1	1	0	0	0	5	1	18	0	0	0	0	0	0	0	0	0	0	0	0	0
ð	0	0	0	2	0	0	0	6	0	22	0	0	0	0	0	0	0	0	0	0	0	0
s	0	0	0	0	0	0	0	0	0	0	30	0	0	0	0	0	0	0	0	0	0	0
z	0	0	0	0	0	0	0	0	0	0	0	30	0	0	0	0	0	0	0	0	0	0
ʃ	0	0	0	0	0	0	0	0	0	0	0	0	26	4	0	0	0	0	0	0	0	0
ʒ	0	0	0	0	0	0	0	0	0	0	0	0	0	29	0	1	0	0	0	0	0	0
tʃ	0	0	2	0	0	0	0	0	0	0	0	0	0	0	28	0	0	0	0	0	0	0
dʒ	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	27	0	0	0	0	0	0
m	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	21	4	1	0	0	0
n	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	28	0	0	0	0
ŋ	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	4	21	0	0	0

Responses:

Age 13: Non-reverberant condition

Stimuli:	Responses: p	b	t	d	k	g	f	v	θ	ð	s	z	ʃ	ʒ	tʃ	dʒ	m	n	ŋ	h	j	l
p	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
b	0	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
t	0	0	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
d	0	0	0	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
k	0	0	0	0	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
g	0	0	0	0	0	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
f	0	0	0	0	0	0	28	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0
v	0	0	0	0	0	0	0	25	0	5	0	0	0	0	0	0	0	0	0	0	0	0
θ	0	0	0	0	0	0	2	0	28	0	0	0	0	0	0	0	0	0	0	0	0	0
ð	0	0	0	0	0	0	0	0	0	30	0	0	0	0	0	0	0	0	0	0	0	0
s	0	0	0	0	0	0	0	0	0	0	30	0	0	0	0	0	0	0	0	0	0	0
z	0	0	0	0	0	0	0	0	0	0	0	30	0	0	0	0	0	0	0	0	0	0
ʃ	0	0	0	0	0	0	0	0	0	0	0	0	30	0	0	0	0	0	0	0	0	0
ʒ	0	0	0	0	0	0	0	0	0	0	0	0	0	30	0	0	0	0	0	0	0	0
tʃ	0	0	0	0	0	0	0	0	0	0	0	0	0	0	30	0	0	0	0	0	0	0
dʒ	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	30	0	0	0	0	0	0
m	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	29	1	0	0	0	0
n	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	30	0	0	0	0
ŋ	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	29	0	0	0

Age 13: .4 second condition

Stimuli:

	Responses:																					
	p	b	t	d	k	g	f	v	θ	ð	s	z	ʃ	ʒ	tʃ	dʒ	m	n	ŋ	h	j	l
p	29	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
b	1	27	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
t	0	0	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
d	0	0	0	29	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
k	2	0	0	0	28	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
g	0	0	0	1	0	29	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
f	1	0	0	0	0	0	25	0	3	0	1	0	0	0	0	0	0	0	0	0	0	0
v	0	1	0	0	0	0	1	24	0	4	0	0	0	0	0	0	0	0	0	0	0	0
θ	0	0	0	0	0	0	6	0	24	0	0	0	0	0	0	0	0	0	0	0	0	0
ð	0	0	0	0	0	0	0	3	0	26	0	1	0	0	0	0	0	0	0	0	0	0
s	0	0	0	0	0	0	0	0	0	0	30	0	0	0	0	0	0	0	0	0	0	0
z	0	0	0	0	0	0	0	0	0	0	0	30	0	0	0	0	0	0	0	0	0	0
ʃ	0	0	0	0	0	0	0	0	0	0	0	0	30	0	0	0	0	0	0	0	0	0
ʒ	0	0	0	0	0	0	0	0	0	0	0	0	0	30	0	0	0	0	0	0	0	0
tʃ	0	0	0	0	0	0	0	0	0	0	0	0	0	0	30	0	0	0	0	0	0	0
dʒ	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	30	0	0	0	0	0	0
m	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	23	5	0	0	0	2
n	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	29	0	0	0	0
ŋ	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	27	0	0	1

Age 13: .6 second condition (binaural)

Stimuli:	Responses: p	b	t	d	k	g	f	v	θ	ð	s	z	ʃ	ʒ	tʃ	dʒ	m	n	ŋ	h	j	l
p	22	0	0	0	7	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
b	0	27	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
t	0	0	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
d	0	0	0	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
k	2	0	0	0	28	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
g	1	0	0	1	0	26	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0
f	1	0	0	0	0	0	28	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
v	0	1	0	0	0	2	1	22	1	3	0	0	0	0	0	0	0	0	0	0	0	0
θ	1	1	0	0	0	0	7	0	21	0	0	0	0	0	0	0	0	0	0	0	0	0
ð	0	0	0	0	0	1	0	4	0	25	0	0	0	0	0	0	0	0	0	0	0	0
s	0	0	0	0	0	0	0	0	0	0	30	0	0	0	0	0	0	0	0	0	0	0
z	0	0	0	0	0	0	0	0	0	0	0	30	0	0	0	0	0	0	0	0	0	0
ʃ	0	0	0	0	0	0	0	0	0	0	0	0	30	0	0	0	0	0	0	0	0	0
ʒ	0	0	0	0	0	0	0	0	0	0	0	0	1	29	0	0	0	0	0	0	0	0
tʃ	0	0	0	0	0	0	0	0	0	0	0	0	0	0	30	0	0	0	0	0	0	0
dʒ	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	28	0	0	0	0	0	0
m	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	26	4	0	0	0	0
n	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	28	0	0	0	0
ŋ	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	27	0	0	0

Age 13: .6 second condition (monaural)

Responses:

Stimuli:	p	b	t	d	k	g	f	v	θ	ð	s	z	ʃ	ʒ	tʃ	dʒ	m	n	ŋ	h	j	l
p	23	0	0	0	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
b	0	21	0	0	0	3	0	5	0	1	0	0	0	0	0	0	0	0	0	0	0	0
t	0	0	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
d	0	0	0	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
k	3	0	0	0	27	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
g	0	0	0	0	0	23	0	3	0	0	0	0	0	0	0	0	1	0	1	0	2	0
f	1	0	0	0	0	0	24	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0
v	0	2	0	0	0	3	1	23	0	0	0	1	0	0	0	0	0	0	0	0	0	0
θ	1	0	0	0	1	0	4	1	23	0	0	0	0	0	0	0	0	0	0	0	0	0
ð	0	0	0	0	0	1	0	3	1	24	0	0	0	0	0	0	0	0	0	0	0	1
s	0	0	0	0	0	0	0	0	0	0	30	0	0	0	0	0	0	0	0	0	0	0
z	0	0	0	0	0	0	0	0	0	0	0	30	0	0	0	0	0	0	0	0	0	0
ʃ	0	0	0	0	0	0	0	0	0	0	0	0	29	1	0	0	0	0	0	0	0	0
ʒ	0	0	0	0	0	0	0	0	0	0	0	0	0	30	0	0	0	0	0	0	0	0
tʃ	0	0	1	0	0	0	0	0	0	0	0	0	0	0	29	0	0	0	0	0	0	0
dʒ	0	0	0	1	1	0	0	0	0	0	0	0	0	3	0	25	0	0	0	0	0	0
m	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	23	3	0	0	0	2
n	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	30	0	0	0	0
ŋ	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	2	0	27	0	0	0

Adult: Non-reverberant condition

Stimuli:	Responses:																					
	p	b	t	d	k	g	f	v	θ	ð	s	z	ʃ	ʒ	tʃ	dʒ	m	n	ŋ	h	j	l
p	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
b	0	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
t	0	0	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
d	0	0	0	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
k	0	0	0	0	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
g	0	0	0	0	0	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
f	0	0	0	0	0	0	27	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0
v	0	0	0	0	0	0	0	27	0	3	0	0	0	0	0	0	0	0	0	0	0	0
θ	0	0	0	0	0	0	2	0	28	0	0	0	0	0	0	0	0	0	0	0	0	0
ð	0	0	0	0	0	0	0	0	0	30	0	0	0	0	0	0	0	0	0	0	0	0
s	0	0	0	0	0	0	0	0	0	0	30	0	0	0	0	0	0	0	0	0	0	0
z	0	0	0	0	0	0	0	0	0	0	0	30	0	0	0	0	0	0	0	0	0	0
ʃ	0	0	0	0	0	0	0	0	0	0	0	0	30	0	0	0	0	0	0	0	0	0
ʒ	0	0	0	0	0	0	0	0	0	0	0	0	0	30	0	0	0	0	0	0	0	0
tʃ	0	0	0	0	0	0	0	0	0	0	0	0	0	0	30	0	0	0	0	0	0	0
dʒ	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	30	0	0	0	0	0	0
m	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	30	0	0	0	0	0
n	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	30	0	0	0	0
ŋ	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	27	0	0	0

Adult: .4 second condition

Stimuli:	Responses: p	b	t	d	k	g	f	v	θ	ð	s	z	ʃ	ʒ	tʃ	dʒ	m	n	ŋ	h	j	l
p	28	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
b	0	23	0	1	0	2	0	2	0	2	0	0	0	0	0	0	0	0	0	0	0	0
t	0	0	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
d	0	0	0	29	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
k	2	0	0	0	28	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
g	0	0	0	1	0	28	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
f	0	0	0	0	0	0	28	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0
v	0	0	0	0	0	1	0	26	0	3	0	0	0	0	0	0	0	0	0	0	0	0
θ	0	0	0	0	0	0	7	0	23	0	0	0	0	0	0	0	0	0	0	0	0	0
ð	0	0	0	0	0	0	0	1	0	29	0	0	0	0	0	0	0	0	0	0	0	0
s	0	0	0	0	0	0	0	0	0	0	30	0	0	0	0	0	0	0	0	0	0	0
z	0	0	0	0	0	0	0	0	0	0	0	30	0	0	0	0	0	0	0	0	0	0
ʃ	0	0	0	0	0	0	0	0	0	0	0	0	30	0	0	0	0	0	0	0	0	0
ʒ	0	0	0	0	0	0	0	0	0	0	0	0	0	30	0	0	0	0	0	0	0	0
tʃ	0	0	0	0	0	0	0	0	0	0	0	0	0	0	30	0	0	0	0	0	0	0
dʒ	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	30	0	0	0	0	0	0
m	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	28	2	0	0	0	0
n	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	28	0	0	0	0
ŋ	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	28	0	0	0

Adult: .6 second condition (binaural)

Responses:

Stimuli:	p	b	t	d	k	g	f	v	θ	ð	s	z	ʃ	ʒ	tʃ	dʒ	m	n	ŋ	h	j	l
p	29	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
b	1	25	0	0	0	1	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
t	0	0	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
d	0	0	0	29	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
k	1	0	1	0	28	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
g	0	0	0	0	0	28	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0
f	1	0	0	0	0	0	26	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0
v	0	2	0	0	0	1	0	21	0	6	0	0	0	0	0	0	0	0	0	0	0	0
θ	1	0	0	0	0	0	10	0	19	0	0	0	0	0	0	0	0	0	0	0	0	0
ð	0	0	0	0	0	0	0	4	0	26	0	0	0	0	0	0	0	0	0	0	0	0
s	0	0	0	0	0	0	0	0	0	0	30	0	0	0	0	0	0	0	0	0	0	0
z	0	0	0	0	0	0	0	0	0	0	0	30	0	0	0	0	0	0	0	0	0	0
ʃ	0	0	0	0	0	0	0	0	0	0	0	0	29	1	0	0	0	0	0	0	0	0
ʒ	0	0	0	0	1	0	0	0	0	0	0	0	0	29	0	0	0	0	0	0	0	0
tʃ	0	0	0	0	0	0	0	0	0	0	0	0	0	0	30	0	0	0	0	0	0	0
dʒ	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	29	0	0	0	0	0	0
m	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	27	2	0	0	0	0
n	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	30	0	0	0	0
ŋ	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	29	0	0	0

Adult: .6 second condition (monaural)

Responses:

Stimuli:	p	b	t	d	k	g	f	v	θ	ð	s	z	ʃ	ʒ	tʃ	dʒ	m	n	ŋ	h	j	l
p	24	0	0	0	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
b	2	17	0	2	0	4	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0
t	0	0	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
d	0	0	0	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
k	0	0	5	0	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
g	0	0	0	2	0	26	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0
f	0	0	0	0	0	0	25	1	4	0	0	0	0	0	0	0	0	0	0	0	0	0
v	0	1	0	0	0	1	0	23	1	4	0	0	0	0	0	0	0	0	0	0	0	0
θ	2	0	0	0	0	0	8	0	20	0	0	0	0	0	0	0	0	0	0	0	0	0
ð	0	0	0	0	0	0	0	2	0	28	0	0	0	0	0	0	0	0	0	0	0	0
s	0	0	1	0	0	0	0	0	0	0	29	0	0	0	0	0	0	0	0	0	0	0
z	0	0	0	0	0	0	0	0	0	0	0	30	0	0	0	0	0	0	0	0	0	0
ʃ	0	0	0	0	0	0	0	0	0	0	0	0	27	2	1	0	0	0	0	0	0	0
ʒ	0	0	0	0	0	0	0	0	0	0	0	0	0	30	0	0	0	0	0	0	0	0
tʃ	0	0	0	0	0	0	0	0	0	0	0	0	0	0	30	0	0	0	0	0	0	0
dʒ	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	29	0	0	0	0	0	0
m	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	24	3	1	0	0	0
n	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	30	0	0	0	0
ŋ	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	I	0	29	0	0	0

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