DOCUMENT RESUME

ED 043 172	40	EC 030 098

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TITLE Analysis of a Recorded Test for the Measurement of Hearing in Children.

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SPONS AGENCY Bureau of Education for the Handicapped (DHEW/OE), Washington, D.C.

BUREAU NO BR-8-0156

PUB DATE Dec 69

GRANT OEG-0-8-080156-3526(032)

NOTE 36p.

EDRS PRICE EDRS Price MF-$0.25 HC-$1.90

DESCRIPTORS *Audiometric Tests, *Auditory Evaluation, Auditory Perception, *Aurally Handicapped, Aural Stimuli, Clinical Diagnosis, *Exceptional Child Research, Preschool Children, Tape Recordings

ABSTRACT

To study the feasibility of using filtered environmental sounds as test stimuli to determine the auditory sensitivity of young children, a tape recorded test was prepared using environmental sounds which retain their identity when filtered. Twenty normal-hearing preschoolers and 40 hearing impaired children (20 with flat sensori-neural hearing losses, 20 with high-frequency impairments) were evaluated during test and retest sessions. The sound test yielded auditory thresholds for both groups of subjects which were judged as valid and reliable as those obtained from pure-tone testing. Further testing is recommended before the test's potential as a clinical tool is determined. (KW)

OE/BEH
BR 8-0156 PA-40
EC

ED043172

FINAL REPORT
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The research reported herein was performed pursuant to a grant with the Bureau of Education for the Handicapped, U.S. Office of Education, Department of Health, Education, and Welfare. Contractors undertaking such projects under government sponsorship are encouraged to express freely their professional judgment in the conduct of the project. Points of view or opinions stated do not, therefore, necessarily represent official position of the Bureau of Education for the Handicapped.

Department of Health, Education, and Welfare

U.S. Office of Education
Bureau of Education for the Handicapped

ACKNOWLEDGMENTS

Recognition is extended to Earl R. Harford for his development of the research proposal which lead to this study, as well as for his continued support of the research activities throughout the project. A special note of recognition is extended to Barbara R. Murphy, who so ably initiated the clinical evaluation and management of the youngsters who served as research subjects. Tt should be noted that without the active cooperation of both the faculty of The Unity Nursery School, Inc., and the parents of our subjects, this study would not have been possible. Finally, the writer acknowledges the contribution of Keith Gish, who prepared the early filtered sound recordings for trial use in the Northwestern University Hearing Clinics.

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SUMMARY

The purpose of the present study was to investigate the feasibility of using filtered environmental sounds as test stimuli for determining the auditory sensitivity of young children. To this end, a tape recorded test was prepared which contained several randomizations of selected environmental sounds, i.e. those sounds which retain their identity after being filtered. Four filtered signals were chosen for each of three 1/3 octave bands centered at nominal test frequencies of 500, 1000, and 2000 Hz.

Three samples of young children were evaluated during test and retest sessions. Twenty normal-hearing preschoolers and forty hearing-impaired youngsters served as research subjects. The latter group contained twenty children with flat sensori-neural hearing losses with the remainder having marked high frequency impairments. Subject selection criteria required that each child have normal intelligence and that he could be conditioned with relative ease for audiometric testing.

In brief, the filtered environmental sound test yielded auditory thresholds for both normal-hearing and hearing-impaired children which were judged from a clinical viewpoint to be as valid and reliable as those obtained from pure tone testing. While the test appears to have real promise as a clinical tool, further application with a wider variety of pediatric cases is needed before the potentials and limitations of the technique are fully understood.

INTRODUCTION

The audiologist is confronted more frequently today than ever before with very young children whose hearing must be assessed as precisely as is feasible. The initiation of neonatal screening programs which are designed to detect hearing impairment early in life and more effective parental and professional education relative to the causes of hearing impairment in children, account, in part, for the number of early referrals. Moreover, progress is being made in establishing training and guidance programs for the education of pre-school hearing-impaired children. The challenge of evaluating the hearing of these youngsters, which is necessary for appropriate educational management, can only be met by improving current audiological methods for establishing definitive information relative to the hearing capacity they possess.

As just stated, there is a real need for the development of new methodology to evaluate the hearing of young children with suspected auditory impairments so as to yield an accurate assessment of residual hearing. At present, the only acceptable stimuli for generating an audiogram are pure tones. Unfortunately, pure tone stimuli have limited effectiveness with the pediatric population in that preschool youngsters may fail to respond to this type of abstract sound, not because they do not hear the sound, but because the stimulus lacks meaning.

In general, the younger the child is, the less reliable are conventional audiometric test results. Thus, one pressing need when evaluating very young children is for an audiological test with which one can determine hearing levels for various test frequencies when routine audiometry is not effective. Such a test can serve another important function in that it could be used as a cross check on other tests which allegedly provide information regarding auditory sensitivity.

In the past, various authors such as the Ewings (1958), Hardy, Dougherty and Hardy (1959), Myklebust, (1954) and Utley (1949) have advocated the use of noisemakers and environmental sounds to estimate the hearing levels of pediatric cases. The utilization of such sounds is based on the rationale that a young child will respond more consistently to stimuli that are familiar or novel than to pure tones. While this approach is often successful, there are inherent difficulties. First, most noisemakers produce a rather broad frequency signal. This same broad frequency spectrum also is characteristic of most environmental sounds. Consequently, such stimuli provide general rather than specific information relative to the status of a child's hearing capacity for different frequencies. Secondly, most noisemakers do not permit sustained and quantitative control over the intensity of the sounds they produce. Thus, definitive information concerning the precise degree of hearing impairment can not be obtained through the use of noisemakers. This second limitation also applies to the use of environmental sounds. Therefore, the audiometric configuration, in terms of threshold values, legitimately can not be plotted from responses to such broad frequency test signals. Instead, the examining clinician can only arrive at some generalization about the degree of a child's hearing loss and whether the youngster is more responsive to low or to high pitched sounds.

Obviously, the armamentarium of the audiologist will be strengthened when a test which is valid and reliable is developed which can serve either as a substitute for conventional pure tone measurements or as a cross-check on the results obtained from pure tone audiometry. The more precise that the evaluation of a young child's hearing is, the more appropriate can be a program of management, i.e., selection and use of amplification, language and speech training, the monitoring of auditory status over time, etc.

Recognizing the inherent weaknesses and limitations introduced by the relatively broad spectrum signal produced by most noisemakers, Downs and Doster (1959), proposed that the sounds produced by noisemakers, as well as common environmental sounds, be electronically filtered and stored on magnetic tape. With this approach, unwanted frequencies are eliminated. Yet this technique preserves the recognition of many sounds and the physical characteristics of the test-stimuli can be carefully specified. Downs and Doster claim success in testing large numbers of young children from 3 to 5 years of age with familiar sounds filtered into band widths of 250-750 Hz, 1000-2000 Hz, and 3000-5000 Hz. Unfortunately, their report was brief, and to the best of our knowledge, this test has never been fully developed into a standardized tool. The need for exploring the potentials, as well as the limitations, of such an audiometric technique with preschool children is obvious.

In summary, the clinical utilization of recorded filtered environmental sounds does appear to hold promise as an additional tool in the pediatric audiological test battery. However, it is recognized that two pitfalls must be avoided in the selection of filtered environmental sounds as auditory test stimuli. First, the frequency bands must be sufficiently wide so that selected stimuli do retain their familiarity. Otherwise, the abstract nature of the test signals will hold no real advantage over more traditional test materials such as pure tones. For this reason, the use of very high or very low frequency bands is not possible. Second, the frequency components in each set of filtered test stimuli should be mutually exclusive so that a segmental analysis of auditory function across the frequencies most critical for speech perception is possible. Since the attention span of pediatric cases is limited, at best, overtesting is to be avoided. For these reasons, frequency bands centered at 500, 1000 and 2000 Hz appear most desirable. It was with these thoughts in mind that a pilot study, described below, was undertaken.

PILOT STUDY

Being encouraged by the Downs and Doster report, a tape recording was prepared at Northwestern University in 1965 for experimental use. The familiar environmental sounds from the record included in Utley's Auditory Training Album were filtered into relatively narrow bands (approximately 1/3 octave bands). After a brief clinical trial with the initial recording, it became apparent that this approach had merit but that a careful acoustic analysis of the test signals was needed. Further, a validation study was essential.

The following section contains the details of the design and development of this initial tape recording and the preliminary work related to the first stages of analysis.

A.) Recording Procedures

1. A 1000 Hz signal, generated by a Hewlett-Packard 200 AB oscillator, monitored at 1.5 v on a Hewlett-Packard 400 C VTVM, and to zero on the VU meter of an Ampex 601 Tape Recorder was recorded as a calibration signal.

2. Each of two Spencer-Kennedy, Model 302, Variable Filters connected in series was set to pass a band of frequencies nominally between 450 and 550 Hz.

3. The level of each of the sounds on the Utley auditory training record, reproduced through the phonograph circuit of the Grason-Stadler, Model 162, speech audiometer, was adjusted using the calibration potentiometer so that each peaked at zero on the VU meter of the audiometer. Then attenuation was removed, using the Channel I attenuator until the filtered signal peaked at zero on the VU meter of Ampex, Model 601, tape recorder. These two adjustments had to be made for each of the sounds from the disc recording as it was fed through the filter system because the intensity of the recorded sounds varied considerably.

4. Step 3 was repeated for filter band pass settings of 800 to 1200 Hz and for 1800 to 2200 Hz.

During the recording process, it was found that certain of the sounds could not be recorded on the tape because of insufficient signal intensity at the output of the filter system. Other sounds were found to be so severely distorted by the filtering that they could not be recognized and thus were judged to be unacceptable as test stimuli. Still other sounds were judged unacceptable because their duration at peak intensity was very brief. Further, in some instances, short duration intensity peaks as much as 20 dB stronger than the average level of the signal were noted.

Each of the sounds found acceptable at this stage of development was subsequently recorded eight times. The resulting tape was then spliced into four master tapes using two presentations of each of the filtered sounds, and a section of the 1000 Hz calibration signal.

B.) <u>Spectrum Analysis of the Recorded Filtered Sounds</u>

Spectrum analysis of each of the newly recorded filtered signals was accomplished using the Bruel and Kjaer, Model 2112, spectrometer. The output of the Ampex tape recorder was fed to the spectrometer and measurements were made in 1/3 octave bands. Visual readings of the peak meter deflection for each band were made. Of prime interest was the relative intensity in the several 1/3 octave bands around the nominal center frequency of the filtered stimuli.

C.) Selection of the Filtered Sounds for the Working Tape

Four sounds representing each of the three nominal test frequencies were selected which satisfied the following criteria:

1. The 1/3 octave band containing the greatest peak intensity was centered at or in the 1/3 octave above the nominal test frequency.
2. The level of the signal at one octave above and below the nominal test frequency had to be 30 dB less intense than the magnitude of the peak signal within the test band.

The width of the filtered bands is as narrow as practicable while maintaining the audible characteristics of the sound (see attached Figures 1-3, illustrating the spectral composition of the sounds). The sounds that survived these criteria and remained recognizable, were: train whistle, car horn, dog's barking, and party horn for the 500 Hz test items; telephone ring, car horn, doorbell and party horn for the 1000 Hz test items; and telephone ring, duck's quacking, rubber mouse and police whistle for the 2000 Hz test items. The rejection rates of the filters are sufficient to ensure that responses to a filtered sound would be to frequencies closely surrounding the nominal test frequency. Figures 1, 2, and 3 show graphically the relative intensities in 1/3 octave bands for each of the four sounds representing each test frequency.

An additional spectrum analysis of the filtered environmental sounds which were selected as test stimuli was undertaken prior to the initiation of the formal study. In this analysis, a Nelson-Ross spectrum analyzer, model PS011, in conjunction with a Tektronix oscilloscope, model 533A, was utilized. The intensity and frequency dispersion were displayed on the cathode ray tube and photographs were taken of each display. With the aid of a template overlay, it was possible to define rather

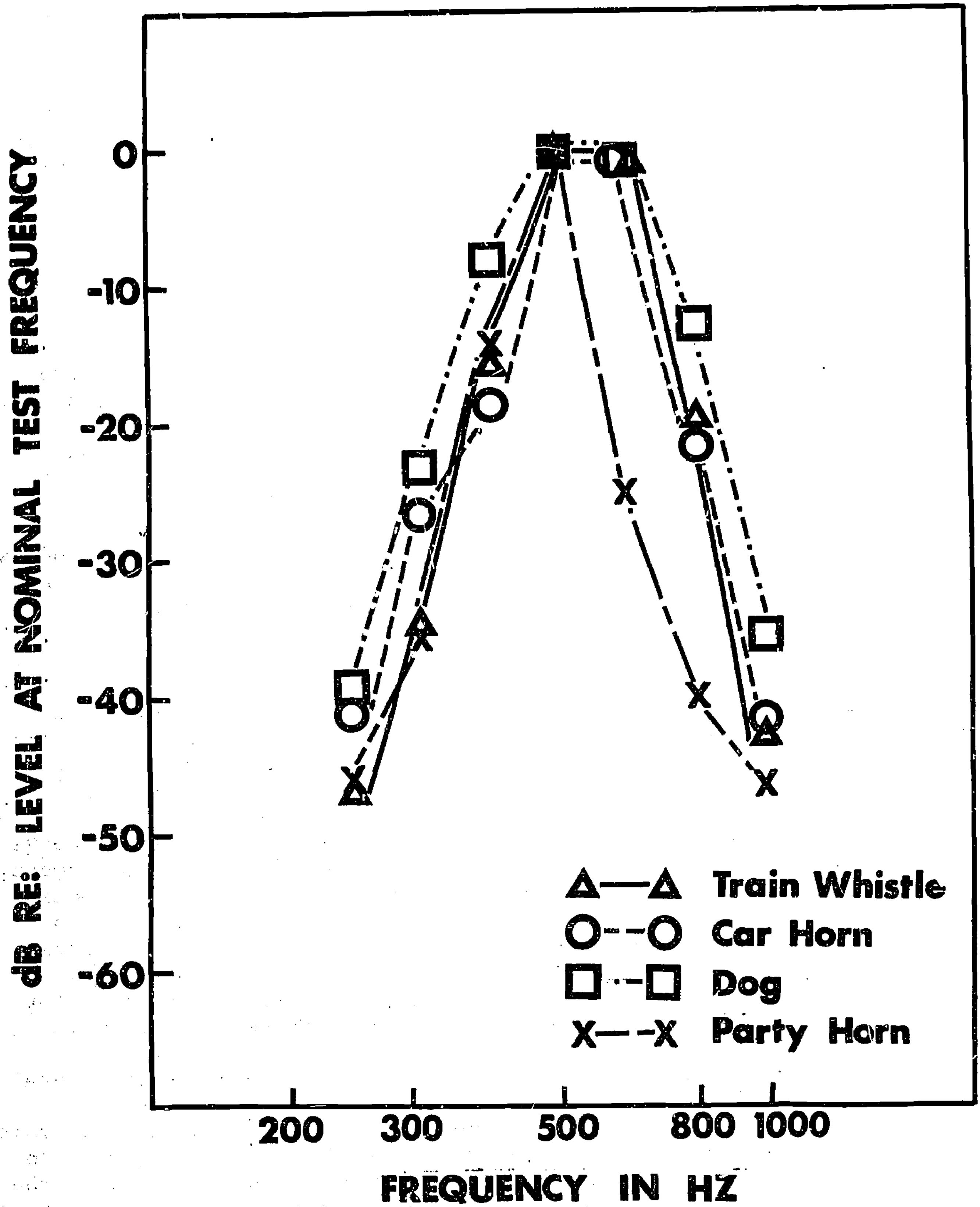

Figure 1. Graphic representation of the energy in the 1/3 octave filter bands for each of the four sounds representing the nominal test frequency of 500 Hz.

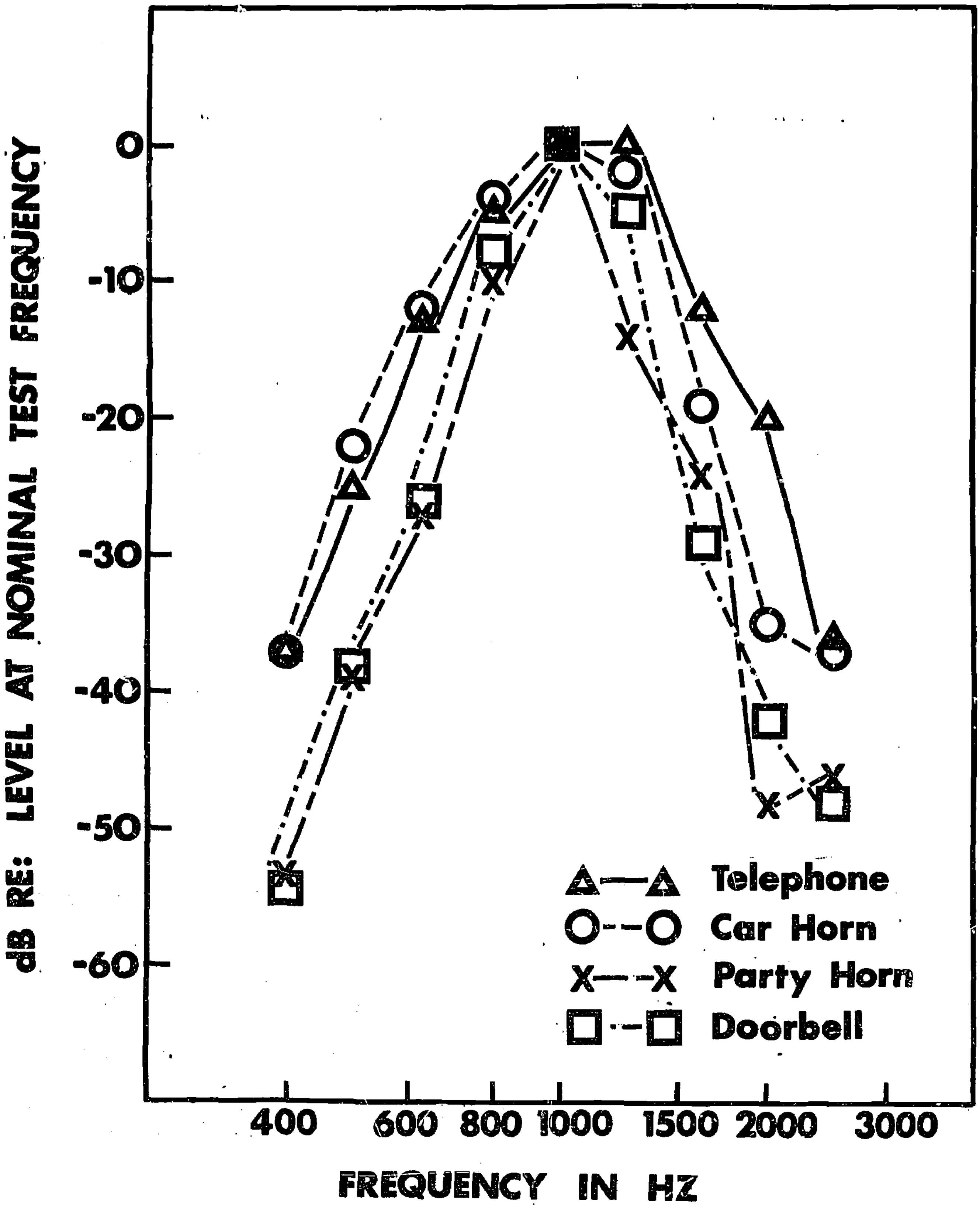

Figure 2. Graphic representation of the energy in the 1/3 octave filter bands for each of the four sounds representing the nominal test frequency of 1000 Hz.

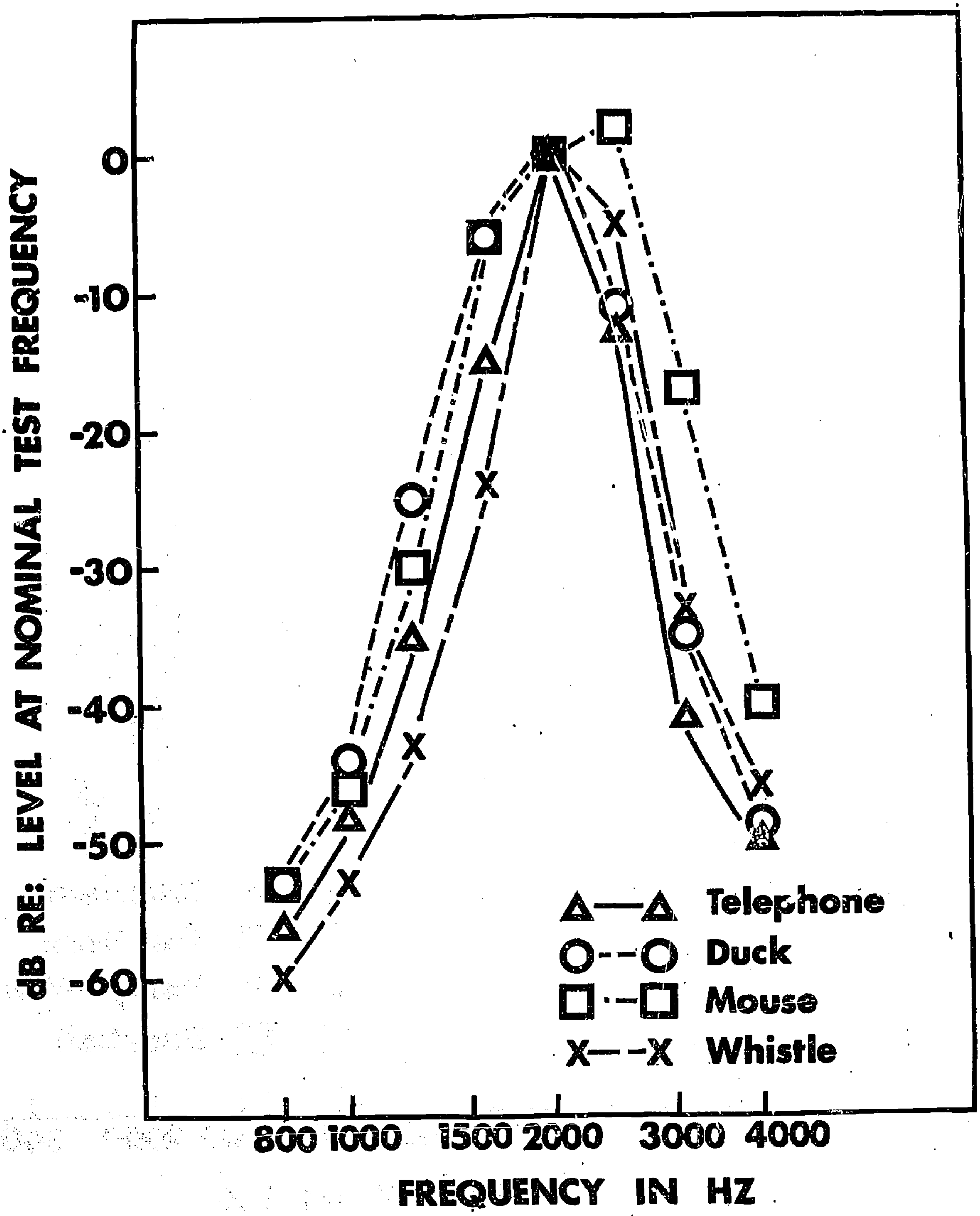

Figure 3. Graphic representation of the energy in the 1/3 octave filter bands for each of the four sounds representing the nominal test frequency of 2000 Hz.

precisely the spectral composition of each sound. The test stimuli, with the exception of one 1000 Hz filtered sound, were found to be acceptable for the use intended. This particular stimulus was subsequently re-recorded after being filtered to eliminate the objectionable energy at 700 Hz noted during the preceding analysis.

During the very early activities which preceded the initiation of the formal research study, the filtered environmental sound tape had been utilized to establish thresholds of auditory sensitivity relative to audiometric zero with a small group of young adult listeners having normal hearing. At that time, it was found that such thresholds correlated fairly well with the pure-tone thresholds of 500, 1000 and 2000 Hz.

A major shortcoming of much published auditory research based on the use of test stimuli other than pure tones with children, is that normative data regarding threshold intensities for the alternate stimuli were never carefully and systematically collected. Thus, one cannot validly compare threshold data obtained with different auditory signals. For this reason, both pure-tone thresholds (500, 1000 and 2000 Hz) and filtered-sound thresholds for the three test bands (500, 1000 and 2000 Hz) were collected in a sound treated environment for a sample of ten young adults who were highly motivated and who were known to have normal hearing. All test stimuli were delivered via TDH 39 earphones monitored in MX/41AR cushions.

Table 1 includes the averaged threshold data for pure tones and for filtered environmental sounds collected for the sample of adults with normal hearing.

TABLE 1

Normative data expressed in dB SPL for ten normal adult listeners.

	Frequency in Hz		
	500	1000	2000
Pure-Tone Thresholds	12.1	10.2	12.0
Filtered Sound Thresholds	14.0	12.4	9.6
Difference in dB	-1.9	-2.2	+2.4

From the data in Table 1, it can be seen that thresholds of auditory sensitivity are essentially equivalent for the two different sets of stimuli when all threshold data are expressed in sound pressure levels. The threshold differences of -1.9 to +2.4 dB are not considered to be significant since the measurements were completed in 4 dB increments with filtered environmental sounds and in 5 dB steps with pure tones.

It should be noted that the sample of normal adult listeners yielded average pure tone thresholds which deviated from ISO 1964 norms by 2 dB, 3 dB and 2.5 dB for the test frequencies of 500, 1000 and 2000 Hz, respectively. Therefore, it is reasonable to assume that the environmental sound thresholds are in error by the same magnitude. Thus, the threshold sound pressure levels for filtered environmental sounds were corrected by the preceding amounts so that comparisons between pure tone and environmental sound measurements would be feasible. The values presented in Table II were utilized when converting threshold data from sound pressure to hearing levels for the experimental groups.

TABLE II

Norms for filtered environmental sounds
expressed in dB SPL*

Frequency in Hz		
500	1000	2000
12.0	9.4	7.1

* Corrected to conform to ISO 1964 pure tone standards.

It was after the collection and analysis of the preceding data for adult listeners that the formal study was initiated with young children having either normal or impaired hearing.

FINDINGS AND ANALYSIS

The present research investigation was designed to provide definitive information regarding the following research questions:

1. Can filtered environmental sounds be used to generate an audiometric configuration which corresponds to the pure tone audiogram at 500, 1000 and 2000 Hz for young children having normal hearing?

2. Can these same filtered environmental sounds be used to generate an audiometric configuration which corresponds to the pure tone audiogram for 500, 1000 and 2000 Hz in young children with various degrees and different configurations of hearing impairment?

3. If the filtered environment sound test is found to yield valid estimates of auditory sensitivity, can these filtered environmental sound thresholds be repeated on retest? That is, what is the test-retest reliability of responses to filtered environmental sounds?

Any child designated as a research subject for this investigation was known to have an intelligence quotient within normal limits (90 or above). For hearing impaired subjects, performance tests rather than verbal measures were considered. Further, each youngster had been found during preliminary measurements to be testable when the examiners utilized some form of conditioned pure-tone audiometry, e.g., play audiometry, VRA (Visual Reinforcement Audiometry) and/or TROCA (Tangible Reinforcement Operant Conditioning Audiometry). Finally, only those children were included in this study whose response pattern was judged to be of good reliability by the examiners.

Two groups of preschool children were selected for our validity and reliability study of the filtered environment sound test. Group I consisted of 20 normal hearing children (12 females and 8 males) between the ages of 3 years, one month and 5 years, eleven months, with the median age being four years and four months.[1] In contrast, Group II consisted of 40 hearing-impaired children having sensorineural impairments.

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1. It is of interest that 4 children initially reported by parents to have normal hearing were excluded from this study since they were found during the first test session to have a mild conductive impairment. A fifth child was also excluded when it was noted that not only was there a conductive hearing loss but also that a marked high frequency sensorineural impairment above 3000 Hz was present.

This sample of subjects was divided into two subgroups. Group IIa consisted of children with marked high frequency losses while Group IIb consisted of children with relatively flat hearing losses. The twenty children (9 females, 11 males) in Group IIb having hearing losses with a relatively flat configuration ranged in age from 3 years, 0 month to 5 years, 10 months. The median age of this hearing-impaired sample was 4 years, 4 months; the same as that for the normal-hearing sample.

The initial research design specified that all hearing impaired subjects in the present study would fall into the preschool age category. However, due to the late age at which many children with marked high-frequency hearing impairments are identified, we were unable to locate twenty children below the age of six who met the subject selection criteria for Group IIa. After a careful consideration of the alternatives, it was decided to include children from the primary grades in Group IIa rather than limit the research subjects to a very small number. The reasoning underlying this decision was that there would be sufficient evidence to judge both the clinical utility and reliability of measurements with familiar filtered environmental sounds from the data obtained with Groups I and IIb. However, a determination of the validity of such measurements with subjects having marked high-frequency losses is of paramount importance before the utilization of a filtered environment sound tape could be recommended for the routine audiological assessment of children from a varied clinical population. One study has disclosed that marked high frequency hearing losses may comprise 16% of the pediatric population with hearing impairment. (Matkin, 1968).

The 20 subjects which comprised the sample, labeled in this study as IIa, consisted of eleven males and nine females. After an exhaustive search, seven youngsters of preschool age (three years, 8 months to five years, eleven months) were located. The remaining subjects were older, ranging in age from 6 years, 2 months to eleven years, nine months. After grouping the identifying information for the preschool and school age children, it was found that the median age of the twenty subjects was six years and six months. Thus, the median age of the children in Group IIa was two years and two months greater than that of the children in either Group I or IIb, where the median age was four years and four months.

All of the audiological measurements associated with this project were completed at the Northwestern University Hearing

Clinic, Evanston Campus, in a sound-treated suite having minimal levels of ambient noise. Pure-tone stimuli were generated by a portable Maico audiometer, model MA 2, having TDH 39 earphones housed in MX/41AR cushions. The taped environmental sound stimuli were fed from an Ampex, model 351, tape recorder into a speech audiometer, Grason Stadler, model 162, whose output circuit was terminated with the same type of earphones and cushions as described above. The calibration of these units was carefully monitored throughout the present study.

The measurements of auditory sensitivity for the test ear of all research subjects was undertaken with 500, 1000 and 2000 Hz pure tones and with filtered environmental sounds in the 500, 1000 and 2000 Hz test bands. The ear designated as the test ear of both normal hearing and hearing impaired subjects was alternated between left and right. Further, the order of stimulus presentation was carefully counterbalanced, with respect to both stimulus type and test frequency, in order to reduce either systematic learning effects or the influence of the fatigue factor. Finally, tester bias was kept to a minimum by utilizing two qualified examiners. Data was collected for each research subject from a test and from a retest session.

A comparison of the threshold data obtained with normal-hearing children (Group I) while utilizing pure tones (PT) and filtered environmental sounds (ES) revealed that these two different types of stimuli yielded essentially the same information regarding the auditory sensitivity.

A straightforward method for comparing the research findings for the sample of young normal-hearing children is to plot mean data on a standard audiogram form after converting all thresholds from sound pressure levels to hearing levels. Average response levels are seen in Figure 4. Differences between pure tone and environment sound thresholds of 1 and 2 dB were seen at 500 and 1000 Hz, with the largest difference being 6 dB at 2000 Hz. The marked similarity in these audiometric thresholds suggest that the filtered environmental sound measurements were valid with Group I. It is of interest that the audiometric configuration for the normal hearing group is slightly rising. While there is no apparent explanation for this observation, it may be a subtle indication that a very mild conductive hearing loss was present in some

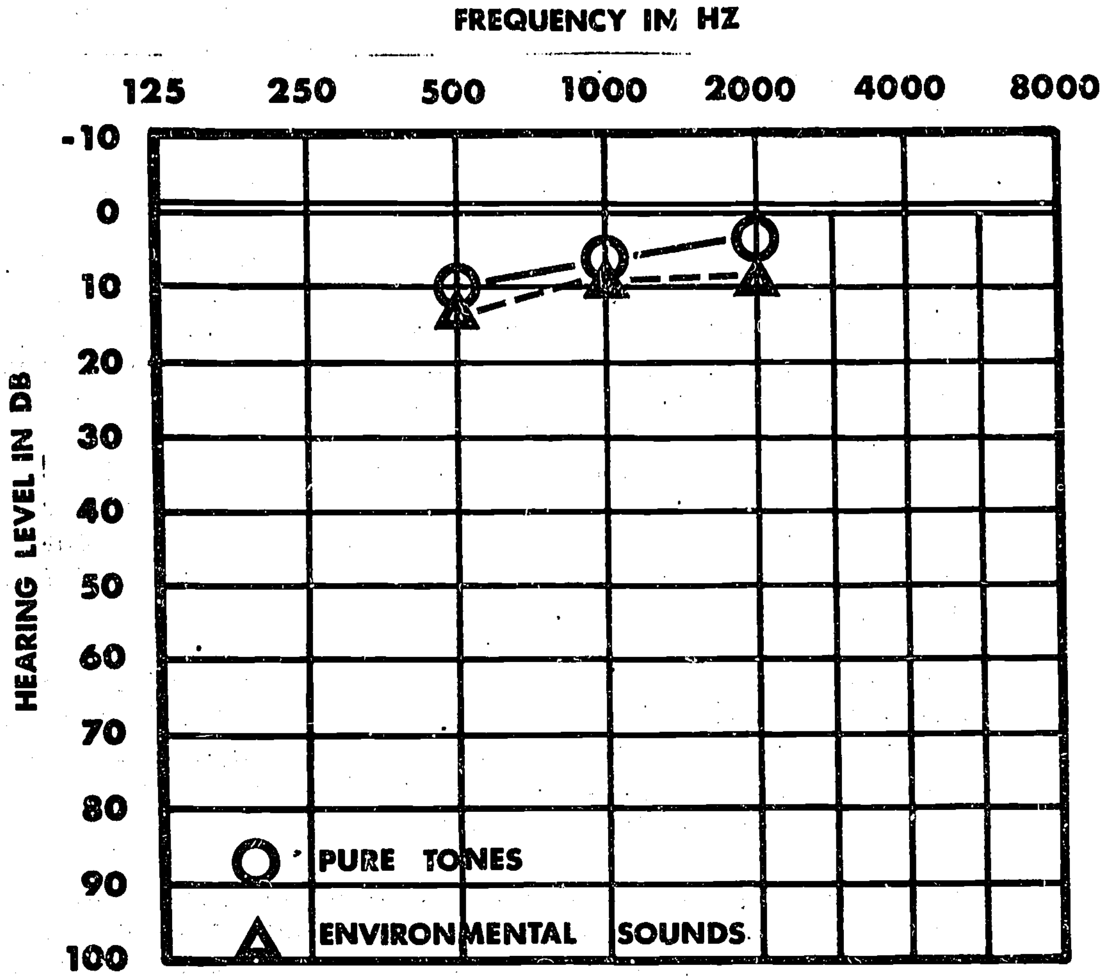

Figure 4. Mean threshold response levels re: 1964 ISO pure tone norms for normal hearing sample of preschool children (N=20).

cases even though a screening test revealed that all subject's hearing was within normal limits. As an alternate method of analysis, a difference score (PT-ES) was computed for each of the three test frequencies of 500, 1000 and 2000 Hz for each subject on the basis of threshold estimates expressed in sound pressure levels. These difference scores were utilized to compute both measures of central tendency and dispersion. These statistics are presented in Table III where it can be seen that both mean and median difference scores for the various test frequencies range from approximately 3 to 5 dB. Considering the young age of the subjects, as well as the fact that the test stimuli were varied in either 4 dB steps with filtered sounds or 5 dB steps with pure tones, a difference score of 5 dB or less is not considered to be of clinical significance. Equally impressive was the small magnitude of both the standard deviations and semi-interquartile ranges for these difference scores.

In view of these findings, the first research question can be answered in the affirmative. That is, filtered environmental sounds can be used to generate an audiometric configuration which corresponds to the pure tone audiograms at 500, 1000 and 2000 Hz for young children having normal hearing.

TABLE III

Mean and median difference scores from the comparison of sound pressure response levels for pure tones and filtered environmental sounds obtained with normal hearing preschoolers (PT minus ES). Standard deviations (SD) and semi-interquartile ranges (SIR) are also included, (N=20).

Test Frequency

	500 Hz	1000 Hz	2000 Hz
Mean	-3.09	-4.75	-3.75
Median	-2.90	-4.85	-2.9
SD	3.45	5.24	5.39
SIR	2.80	3.25	3.17

It is of interest that all of the difference scores in Table III for the normal hearing group are negative. This finding indicates that both mean and median thresholds for pure tones occurred at slightly lower sound pressure levels than those obtained with familiar environmental sounds. This finding was not anticipated since the prevailing notion among many professional workers in communicology is that the perception of familiar test sounds represents a more concrete experience for young children than listening to pure tones. Consequently, responses to environmental sound test stimuli are expected to occur at somewhat lower intensity levels. The results obtained in this study with normal-hearing children, who had been conditioned for audiometric testing, fail to substantiate this notion.

The analysis of the findings for both groups of hearing-impaired children is also encouraging with regard to the validity of the environmental sound test measurements. Mean thresholds for the two hearing-impaired groups are presented in Figures 5 and 6. As was the case with the normal-hearing youngsters, the marked similarity in average thresholds is striking. Further, the magnitude of average difference scores is relatively small when pure tone and environmental threshold estimates expressed in sound pressure levels are compared. Table IV includes the findings for Group IIb, pre-schoolers with flat sensorineural hearing losses, while Table V includes the data collected from youngsters with marked high frequency losses. Note that the average difference scores across frequency for both groups are 3 dB or less, with the exception of the findings for Group IIa at 2000 Hz. In addition, the measures of dispersion suggest that many individual difference scores for the hearing impaired groups are 5 dB or less. Therefore, it was demonstrated that filtered environmental sounds can be utilized with children having flat hearing losses as well as with normal hearing youngsters to obtain accurate estimates of auditory sensitivity.

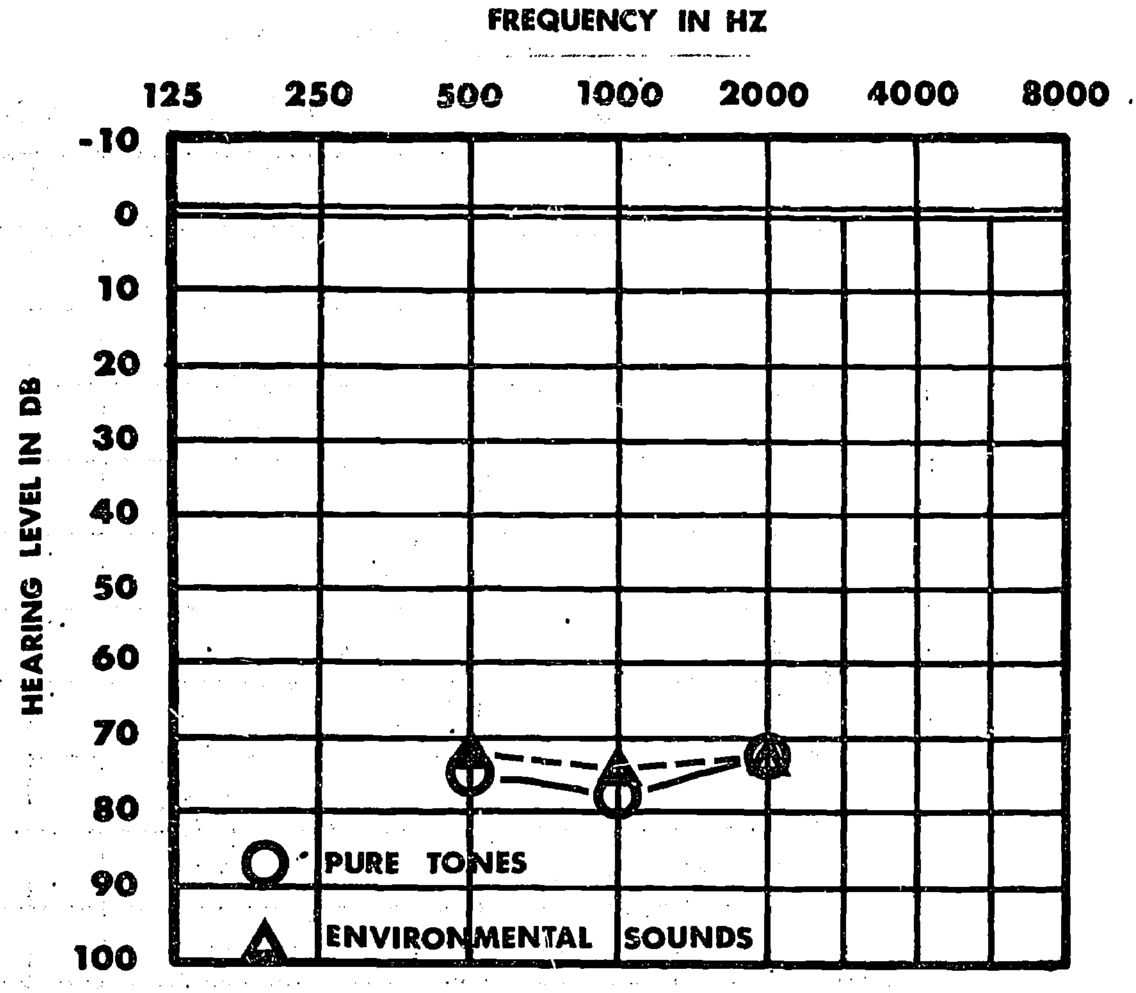

Figure 5. Mean threshold response levels re: 1964 ISO pure tone norms for children having flat sensorineural hearing losses (N=20).

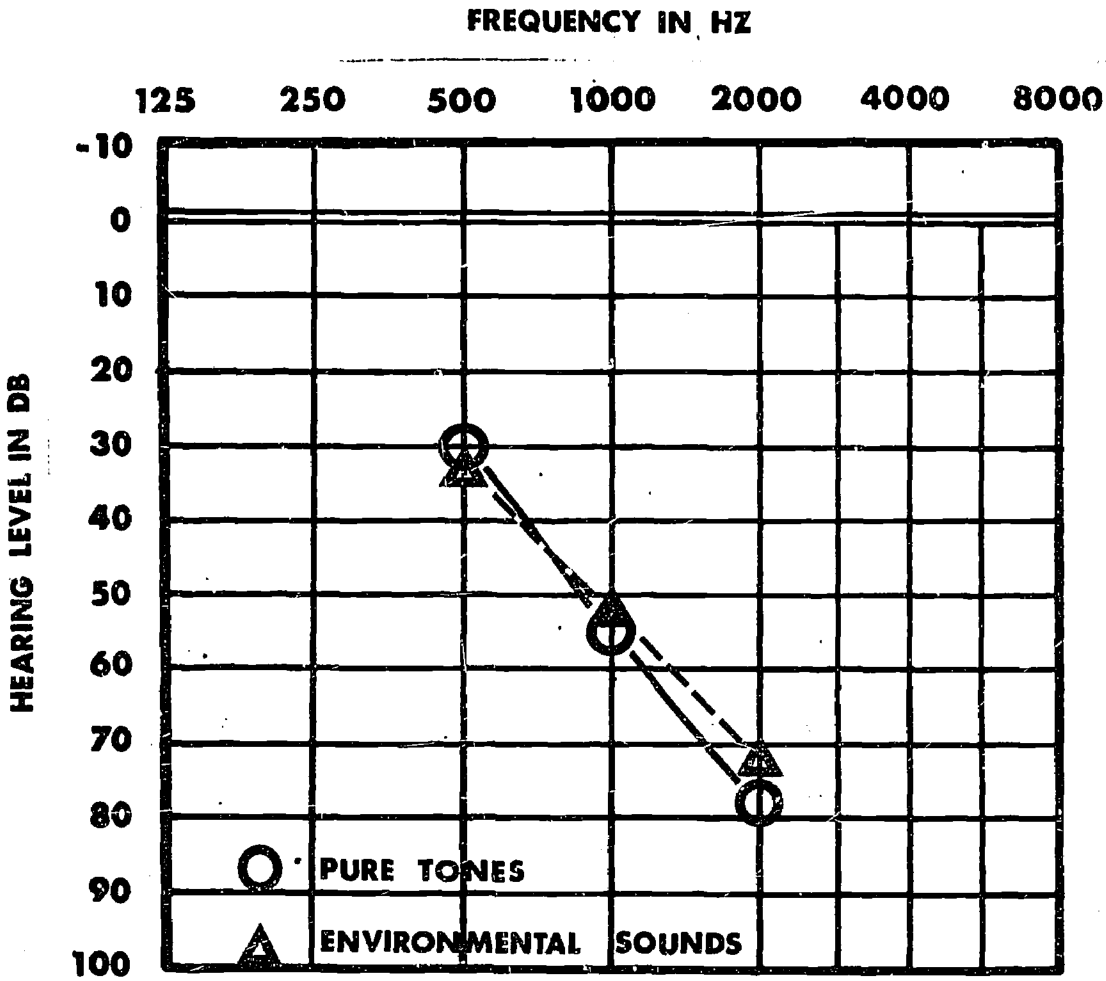

Figure 6. Mean threshold response levels re: 1964 ISO pure tone norms for children having high frequency sensorineural impairment (N=20).

TABLE IV

Mean and median difference scores from the comparison of sound pressure response levels for pure tones and filtered environmental sounds obtained with preschool children having sensorineural hearing loss with a relatively flat configuration (PT minus ES), (N=20).

	Test Frequency		
	500 Hz	1000 Hz	2000 Hz
Mean	+2.15	+.31	+1.94
Median	+2.40	+0.30	+1.75
SD	5.42	4.93	7.94
SIR	2.50	2.50	4.25

TABLE V

Mean and median difference scores from the comparison of sound pressure response levels for pure tones and filtered environmental sounds obtained with children having marked high frequency sensorineural impairments (PT minus ES), (N=20).

	Test Frequency		
	500 Hz	1000 Hz	2000 Hz
Mean	-2.96	+1.19	+6.82
Median	-2.80	+1.40	+5.40
SD	4.20	5.39	9.62
SIR	3.15	3.80	6.90

It was noted above that the largest average difference scores and standard deviations were seen at 2000 Hz with children having marked high frequency losses. The data analysis disclosed that environmental sound thresholds at 2000 Hz were somewhat better than those obtained with pure tones with this particular group. This finding is not surprising. To explain, the filtered high frequency environmental sound stimuli, while centered at 2000 Hz, contained substantial energy in the lower adjacent frequencies. With a marked high frequency impairment, the configuration of the hearing loss is often quite precipitous between the frequencies of 1000 Hz and 2000 Hz. Thus, one might hypothesize that responses to the 2000 Hz environmental sound test bands are somewhat better than the response to 2000 Hz pure tones because the former thresholds actually reflect auditory sensitivity for a slightly lower frequency where the hearing loss is not as great. Nevertheless, differences in thresholds for young children obtained with two different types of auditory stimuli which are on the average of 10 dB or less are clinically acceptable. Thus, the second research question can also be answered in the affirmative. In other words, it is possible to use filtered environmental sounds and obtain valid measures of auditory sensitivity at 500, 1000 and 2000 Hz. Further, such thresholds correspond to the pure tone audiogram with young children having various degrees of hearing loss and different audiometric configurations.

Another manner of analyzing the information obtained with all three research groups during the initial test sessions, is seen in Table VI. In this table, the total number of individual difference scores, pure tone vs environmental sounds, for each test frequency is presented as a function of the magnitude of the PT-ES difference. In this instance, the sign of the difference scores is disregarded. An analysis of these results discloses that less than 10% of all difference scores exceed 10 dB. In fact, 61% of the differences were 5 dB or less. Restated, differences between pure tone and environmental thresholds greater than 10 dB were rare with the exception of a few scores at 2000 Hz with subjects having high-frequency hearing losses, (Group IIa).

To summarize, the first two research questions concerning the validity of environmental sound measurements with children as stated on page 11 can be answered in the affirmative. That is, the data obtained in this study with both normal-hearing and hearing-impaired children indicate that the environmental sound measurements did yield valid threshold estimates as compared to pure tone thresholds.

It should be clearly stated that with the present three research groups, filtered environmental sounds did not prove

TABLE VI

An analysis of the differences in pure tone and environmental sound thresholds which were obtained during the test session with three samples of children.

PT-ES Differences	Group I (Normals)			Group IIa (High Frequency Impairments)			Group IIb (Flat Hearing Loss)		
	500Hz	1000Hz	2000Hz	500Hz	1000Hz	2000Hz	500Hz	1000Hz	2000Hz
± 5 dB or <	14	10	13	11	15	9	16	13	9
± 6 to 10 dB	6	8		9	4	5	3	7	7
± 11 to 15 dB		1	1		1	1			3
± 16 to 20 dB		1	1			4	1		1
± > 20 dB						1			

to be significantly more effective than pure tones as test stimuli. In other words, thresholds obtained with filtered environmental sounds were no better than pure tone findings despite the theoretical advantage of using concrete and familiar stimuli with very young subjects. However, it must be kept in mind that all audiometric data in this study were collected from children who could be successfully conditioned for auditory testing. Therefore, caution should be exercised in extending the above conclusion to test situations where distraction audiometry is undertaken with young children. Distraction audiometry refers to those circumstances where observations are made of unconditioned auditory response behavior.

The third and final research question formulated at the initiation of the present research concerned the reliability of filtered environmental sound measurements for young children.

The data in Table VII indicates that the reliability of such measurements for all three samples of research subjects was excellent. It will be noted that all average difference scores between test sessions I and II are 3.4 dB or less.

With the exception of the findings at 500 Hz for Group I, all difference scores in Table VII are positive. These positive scores indicate that responses occurred at slightly lower intensity levels during the retest session. Thus it appears that a small learning or practice effect is present. However, the small differences in the test and retest scores are not considered to be of clinical significance, especially since measurements with environmental sounds were made in 4 dB step increments.

Table VIII presents the number of instances in which individual threshold differed by 5 dB or less, 6 to 10 dB, etc., for each group between the test and retest sessions. Again, the sign of the difference scores is disregarded. An analysis of this table, revealed that 78% of the individual difference scores (ES_1 vs ES_2) were 4 dB or less. In fact, there were only three instances (less than 2%) in which the test and retest thresholds for filtered environmental sounds differed by a magnitude greater than 10 dB. Considering the above findings, the third research question can also be answered in the affirmative. That is, on the

TABLE VII

Average thresholds expressed in sound pressure levels obtained during test sessions I and II with filtered environmental sounds for three groups of young children.

	Group I (Normals)			Group IIa (High Frequency Impairment)			Group IIb (Flat Hearing Loss)		
	500Hz	1000Hz	2000Hz	500Hz	1000Hz	2000Hz	500Hz	1000Hz	2000Hz
Test 1	23.3	19.0	16.6	43.6	61.8	79.5	83.6	85.0	80.7
Test 2	23.5	16.6	16.2	40.2	58.7	76.2	83.3	84.1	78.3
Difference in dB	-0.2	+2.4	+0.4	+3.4	+3.1	+3.3	+0.3	+0.9	+2.4

TABLE VIII

An analysis of the differences in filtered environmental sound thresholds which were obtained during two test sessions for three samples of children (N=60).

ES_1-ES_2 Differences	Group I (Normals)			Group IIa (High Frequency Impairment)			Group IIb (Flat Hearing Loss)		
	500Hz	1000Hz	2000Hz	500Hz	1000Hz	2000Hz	500Hz	1000Hz	2000Hz
± 4 dB or <	17	12	16	13	17	16	17	17	16
± 6 to 10 dB	3	8	3	7	3	4	2	2	4
± 12 to 16 dB							1	1	
± 18 to 22 dB			1						
± > 22 dB									

basis of the present research study, filtered environmental sound tests can be considered as yielding estimates of auditory sensitivity which are repeatable. In other words, the test-retest reliability when using filtered environmental sounds as test stimuli is excellent with all three experimental groups.

Finally, it was of interest to compare the reliability of thresholds established with environmental sounds and with pure tones. An analysis of the differences in pure tone findings from the two test sessions is presented in Table IX. In brief, it can be seen both that the reliability of the pure tone thresholds is quite good and that such reliability is similar to that noted earlier for the environmental sound threshold data. (See Table VIII). To be specific, 96% of the pure tone thresholds from the two test sessions was within 5 dB of one another. Further, there was only one instance at 500 Hz where the test and retest pure tone thresholds for a hearing-impaired subject differed by a value greater than 10 dB. The fact that the reliability of the pure tone and environmental sound thresholds is quite similar makes the recorded filtered environmental sound test even more appealing as an alternate clinical tool for audiological assessment of preschool children.

TABLE IX

An analysis of the differences in pure tone thresholds which were obtained during two test sessions for three samples of children (N=60).

PT_1-PT_2 Differences	Group I (Normals)			Group IIa (High Frequency Impairment)			Group IIb (Flat Hearing Loss)		
	500Hz	1000Hz	2000Hz	500Hz	1000Hz	2000Hz	500Hz	1000Hz	2000Hz
0 dB	11	12	12	15	11	14	7	11	9
5 dB	8	8	7	5	9	15	11	8	10
10 dB	1		1			1	1	1	1
15 dB							1		
20 dB									

CONCLUSIONS

The results from the present research study suggest that a recorded filtered environmental sound test, such as the one described herein, does have promise as a clinical technique for determining auditory sensitivity within the frequency range critical for the perception of speech. Such a test might be used either as a substitute for traditional pure tone audiometry or as a means for assessing the reliability of pure tone findings. Either application is feasible since both the validity and reliability of thresholds for filtered environmental sounds appear to be quite acceptable for samples of normal-hearing and hearing-impaired preschoolers.

Before concluding, it should be noted that the clinical utilization of the taped filtered environmental sound test was found by the present investigators to be somewhat more complex than conventional pure tone audiometry since one examiner is always needed to manipulate the tape recorder/ speech audiometer instrumentation in a control room while a second person is needed in the test area to shape and maintain the child's response behavior. In contrast, it is possible in many instances for one examiner to complete pure tone measurements of children while using conditioned play audiometry or tangible reinforcement audiometry when a portable audiometer is placed in the test room. However, the fact that one person can not administer the filtered environmental sound test does not appear to be a serious limitation since the evaluation of preschool children with suspected hearing loss is already undertaken as a team endeavor in many clinical settings.

A review of the available literature in pediatric audiology suggested that selected environmental sounds might prove to be more effective auditory test signals with young children than pure tones since listening to environmental sounds apparently represents a more familiar and concrete experience. Yet, when used as the test stimuli, filtered environmental sounds did not yield better (lower) thresholds than pure tones with the three research groups included in the present study. However, it must be kept in mind that all audiometric data contained in the present report were collected from cooperative children who could be conditioned for audiological testing with relative ease. For this reason, the applicability of the findings from the present investigation to certain pediatric test situations is open to question. For example, it is possible that taped filtered environmental sounds, such as developed and evaluated in this investigation, may prove to be effective as alternate stimuli when conditioning some preschool children for hearing tests who could not be conditioned to respond to pure tone stimuli. In such instances, minimal response levels established with filtered environmental sound stimuli should serve as a solid basis for predicting auditory sensitivity at 500, 1000 and 2000 Hz. Another area of uncertainty, at present, is whether or not filtered environmental sounds may yield better estimates of threshold than pure tones when minimal response levels to auditory signals are obtained with distraction audiometry for those children who can not be successfully conditioned for formal testing. It is strongly suspected that filtered environmental sounds may prove to be more effective test signals in such instances.

It is apparent from the preceding comments that further study and clinical application of filtered environmental sound stimuli is necessary. The full potentials and limitations of such an approach can only be realized after systematic investigation with large and varied samples of children suspected of having auditory disorders.

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