Audiometric Testing of School Children

SAMUEL M. WISHIK, M.D., ELIZABETH R. KRAMM, M.A., M.P.H., and ELVIRA M. KOCH, R.N.

HEARING of school children in Reading, Pa., was tested biennially during the 8 school years 1946–47 through 1953–54 by the staff of the Reading School District. In 1952, results of these tests were used in a study of 1,726 children in the fifth and sixth grades conducted under the auspices of the School Health Committee of the Pennsylvania Public Health Association. These children were selected because they had been tested biennially for a 6-year period. The 6-year study included prognostic implications and the relationship of hearing to academic retardation. In a report of the 1952 findings, the effectiveness of a biennial audiometric testing routine was evaluated, procedures for sweep check and threshold audiometric tests were described, and some of the definitions used in the study were given (*1*).

The present report covers the 8-year period 1946–54. The study continues to explore the question of the optimum periodicity of routine audiometric testing, measures the apparent impact of hearing impairment on academic progress, identifies certain prognostic signs, makes observations on the audiometric patterns of children between 5 and 14 years of age. Audiograms have been analyzed and the data are presented according to the ear involved and the age of the children rather than their grade level. Since reasonably complete information on medical findings and treatment was not available, this important aspect of the problem cannot be reported. Administrative recommendations and research suggestions are offered in the light of the findings.

During the period from 1952 to 1954, 1,592, or 92 percent, of the 1,726 children previously reported on (*1*) had at least one audiometric test. Other than those who transferred out of the Reading public schools, only 36 children from the original study group who were still attending school were not tested.

Dr. Wishik is professor of maternal and child health and Miss Kramm is research associate in maternal and child health, Graduate School of Public Health, University of Pittsburgh. Miss Koch is a school nurse with the Reading School District, Reading, Pa.
This paper was presented in part at the annual meeting of the American Public Health Association in Atlantic City, N. J., November 14, 1956.

Method

Frequencies on the audiogram were divided into low, middle, and high ranges. Frequencies 128 and 256 were included in the low range; 512, 1,024, and 2,048 in the middle range; and 4,096 and 8,192 in the high range. Frequencies 2,896 and 5,792, not done routinely, were included in the high range. Frequency 11,584 was not used in this study although it was included in the test procedure. Overlapping of frequency ranges was avoided in order to facilitate the drawing of statistical conclusions. In the remainder of the paper, frequencies will be referred to in round numbers.

To pass the threshold test, a child was expected to hear frequencies 250–4,000 at 20 decibels, frequencies 125 at 25 decibels, and frequencies above 4,000 at an average of 30 decibels. He was considered to have failed the test if his hearing fell below the standard in two or more frequencies in either ear. The average of frequencies above 4,000 was counted as one frequency.

The scale of severity of hearing impairment was: average hearing at 20 decibels or less, normal; 21–30 decibels, slight hearing loss; 31–40 decibels, moderate loss, and over 40 decibels, severe loss. Despite differences in passing standards, the same scale was applied to all three frequency ranges, in order to give full consideration to the possible significance of the very low and the very high ranges.

Periodicity of Testing

A routine biennial testing program should reach 50 percent of the total school enrollment each year. This was accomplished by routinely testing all children in the first, third, and fifth grades. More than 50 percent of the children were tested each year except in 1946–47 and 1947–48, the first 2 years of the study, when 48.1 and 46.7 percent, respectively, were tested. In addition to the routine tests in the odd grades, children were tested whenever special indications existed. Therefore, more than 50 percent were usually tested in any year. The largest number tested in any one year during the study period was 69 percent.

A tally of the number of children given an audiometric test in a particular year does not give a complete picture of the extent to which a given child is tested during his school career. When a testing routine is administratively organized by school grades, the goal of biennial testing of a given child can be disrupted by late admission to school, early dropout from school, or repetition of grades. The age groups studied were 5–7, 8–9, 10–11, 12–13, and 14 years and over (table 1). Sixty-nine percent of the children were tested over the desired span of four or more 2-year intervals. Among the 116 children who failed a test at any time during the study, 70, or 60 percent, had this span of test coverage, and all but 3 of the remaining children were carried through 3 age groups.

The span of coverage by age groups indicates the time from beginning to end of the testing of any given child but does not imply that there was continuity or completeness of testing within that period. Table 1 indicates the longitudinal extent of the study and demonstrates that, despite the greater administrative problem, any routine program of periodic audiometric testing should be scheduled for individual children by age group rather than by academic grade.

Effectiveness of Periodic Retesting

Of the 1,726 children in the study, 116, or 6.7 percent, failed an audiometric test one or more times. These children are designated as "ever

Table 1. Age span of audiometric test coverage of total study population and of children who ever failed a test

Age-group span	Number age groups spanned	Children					
		Number		Percent			
		Tested	Ever failed	Tested	Ever failed	Tested	Ever failed
Total		1, 726	116	100. 0	100. 0	100. 0	100. 0
5–7 through 14 and over	5	29	8	1. 7	6. 9	1. 7	6. 9
5–7 through 12–13	4	1, 075	50	62. 3	43. 1	67. 7	53. 4
8–9 through 14 and over		93	12	5. 4	10. 3		
5–7 through 10–11	3	221	17	12. 8	14. 6	27. 7	37. 0
8–9 through 12–13		206	17	11. 9	14. 6		
10–11 through 14 and over		51	9	3. 0	7. 8		
5–7 through 8–9	2	11		. 6		3. 0	2. 6
8–9 through 10–11		22	1	1. 3	. 9		
10–11 through 12–13		15	2	. 9	1. 7		
12–13 through 14 and over		3		. 2			

failed." The failures were fairly evenly distributed within each age group (table 2). The high percentage of failures among children 14 years old and older should be disregarded since these are an atypical group. Sixty-five, or 7.5 percent, of 869 boys failed an audiometric test at some time during the study compared with 51, or 6.0 percent, of 857 girls.

The age distribution shown in table 2 is of no help in assessing the case-finding effectiveness of the biennial test program in children of different ages since it does not indicate how many new cases of hearing impairment were discovered in each age group. Nor would data on age at first discovery of hearing impairment give information on the increment resulting from a biennial test program unless all new cases had been tested in the biennium immediately prior to their first failure and had passed that test. Only these children can correctly be defined as "candidates for first failure by biennial retest."

Table 2. Number children tested and number and percentage who failed a test, according to age group at time of test

Age group (years)	Number tested	Failed	
		Number	Percent
5–7	1, 336	31	2. 3
8–9	1, 595	64	4. 0
10–11	1, 661	52	3. 1
12–13	1, 467	45	3. 1
14 and over	176	18	10. 2

The percentage of such candidates who failed the test drops progressively with age, from 2.3 percent in the age group 8–9 years to 1.0 percent in the group 10–11 years old, to 0.8 percent in the next higher age group (table 3). In other words, the returns from routine biennial retesting become progressively smaller as the test program continues through the age groups.

In sharp contrast, the percentage of children who failed the first audiometric test increased with age (table 4). Obviously, delayed first testing occurred in a selected group of children who had a high rate of failure in the audiometric test. This kind of experience has contributed to the impression that newly developed hearing impairment occurs rather often among older children, whereas hearing loss probably existed for an unknown time prior to the time of the first audiometric test and prior to discovery of hearing impairment in many instances.

Data on longitudinal observations of the entire study group indicate that the results of the first tests given to a group of children make it possible to identify the majority of those who will fail an audiometric retest (table 5). Among the 1,305 children who passed the hearing test in the first age group, 43 (3.3 percent) failed a subsequent test, and only 12 (1.1 percent) of the 1,062 children tested in the group aged 12–13 years showed a failure at that time. On the other hand, among the 31 children in the first age group who failed the test, 15 (48.4 percent) failed again later, and 9 (29.0 percent) failed at 12–13 years of age.

Even though subsequent test histories of those passing and those failing the first audiometric test differ greatly, a subsequent failure

Table 3. Number of candidates for first failure at biennial retest, according to age group, and number and percentage of new cases found

Age group (years)	Candidates for first failure, at biennial retest[1]	New cases	
		Number	Percent
8–9	1, 243	28	2. 3
10–11	1, 449	14	1. 0
12–13	1, 329	10	. 8

[1] "Candidates" are defined as children who had never previously failed an audiometric test and who had been tested in the immediately preceding age group.

Table 4. Number of children taking audiometric test for first time and number and percentage of new cases discovered, according to age group

Age group (years)	Children taking test for first time	New cases	
		Number	Percent
5–7	1, 336	31	2. 3
8–9	321	23	7. 2
10–11	66	6	9. 1
12–13	3	--------	--------

Table 5. Sequence of results of audiometric retests, according to first test findings on 1,726 children, by age group

5–7 years		8–9 years		10–11 years		12–13 years: Pass	12–13 years: Fail	12–13 years: Not tested
Pass	1,305	Pass	1,215	Pass	1,167	965	4	198
				Fail	11	5	3	3
				Not tested	37	26	------	11
		Fail	28	Pass	18	17	------	1
				Fail	10	1	5	4
				Not tested	------	------	------	------
		Not tested	62	Pass	61	55	------	6
				Fail	------	------	------	------
				Not tested	1	1	------	------
Fail	31	Pass	18	Pass	16	8	------	8
				Fail	1	1	------	------
				Not tested	1	------	1	------
		Fail	13	Pass	4	3	------	1
				Fail	9	1	8	------
				Not tested	------	------	------	------
Not tested	390	Pass	298	Pass	271	246	1	24
				Fail	4	2	2	------
				Not tested	23	22	1	------
		Fail	23	Pass	12	9	2	1
				Fail	11	2	9	------
				Not tested	------	------	------	------
		Not tested	69	Pass	60	53	5	2
				Fail	6	3	3	------
				Not tested	3	3	------	------

rate of 3.3 percent in the passing group is still too high to discontinue retesting. But the justification for discontinuing testing grows stronger with each retest. Children who have passed all tests while in the first two groups are unlikely ever to fail subsequently. Eleven of 1,215 children in this category failed the test at 10–11 years, a failure rate of 0.9 percent, and only 7 out of 1,003, or 0.7 percent, of those tested failed in the group aged 12–13 years. When children miss taking a test in 1 of the first 3 age groups but pass in the other 2 groups, a similarly favorable pattern is present; only 1 out of 327, or 0.3 percent, failed after passing both tests done in the first 3 groups.

If routine audiometric testing had been discontinued for children successively passing the audiometric test in two early age groups without a history of any test failures, only approximately half the routine tests reported would have been done. If such a restricted procedure had been followed and if reliance had rested entirely on the routine testing program, 16, or 13.7 percent, of the failing children would have been missed. The suggestion that the age span of the routine part of the test program be restricted will be modified later in the light of other findings.

Chronicity of Hearing Loss

A more detailed analysis of the longitudinal pattern of test results among the 116 children who ever failed a hearing test gives additional clues to answer the question, What is the best timing and frequency of routine audiometric testing? Most of these children did not have continuous hearing loss. They failed the audiometric test 275 times, or 49.3 percent of the 558 tests they took. The extent of "chronicity" among them and in their 177 ears whose hearing was ever affected is shown in table 6. The distribution of chronicity of hearing loss among pupils and among ears was similar. About half the audiometric test failures, those in the "temporary short" and "indeterminate" groups, were not repeated. There were other nonpermanent types of hearing loss; only 29 percent of the failing pupils and 24 percent of the failing ears fell into the definition of "continuous hearing defect" after failure of an audiometric test had first occurred.

In view of the common occurrence of a short duration of hearing loss, is the biennial test interval too long? How many new cases would be discovered by an annual testing program? On 427 occasions, 302 children who had never failed a hearing test were retested 1 year after a previous test. In a sense, these children were "candidates for first failure by annual retest." Fourteen, or 3.2 percent, failed. The failure rate was 4.7 percent for the children under 10 years of age and 2.2 percent for those 10 years old or older.

Valid conclusions on the effectiveness of annual retesting of hearing cannot be drawn from a biennial testing program. In this study, some children were tested after a 1-year interval because of suspected hearing loss or repetition of a grade. However, appreciable numbers of children, particularly in the younger age groups, show hearing impairment some of the time within a 2-year interval. The only way to determine the value of annual retesting is to study the number of new cases found in an annual testing program.

Hearing Impairment on Entering School

An appreciable amount of hearing loss undoubtedly starts in the preschool years. Therefore, in the age group 5–7 years, children who had hearing impairment at the time of the first audiometric test were compared with children who had normal hearing in the early school years but subsequently failed a hearing test. Criteria selected for comparison were continuity and severity of hearing impairment and involvement of one or both ears.

The 31 young children who had hearing difficulty when they entered school had the lowest proportion of "temporary-short" impairment of hearing, that is, no audiometric test failures after the first failure. Their percentage of temporary-short involvement was 36 compared with 63, 42, and 50, respectively, among the children who had normal hearing on admission but first failed a test in the later age groups (28 children in the 8–9 group, 15 in the 10–11 group, and 11 in the 12–13 group). The moderate difference between the entering pupils and older pupils is more noteworthy because it is directly contrary to the relatively common occurrence of temporary loss of hearing in the younger children as a whole. Four-fifths of the temporary-short failures in the study group occurred before 10 years of age. This tends to support the belief that the hearing impairment in entering pupils was not an acute transient episode but had been present prior to admission to school.

The same young children showed other evidence of having greater hearing damage than the older groups. At the time of first failure of

Table 6. Number and percentage distribution of children and separate ears ever failing an audiometric test, according to chronicity of hearing defect

[In rank order of frequency]

Chronicity	Number		Percent	
	Children	Ears	Children	Ears
Total	116	177	100. 0	100. 0
Temporary short [1]	47	81	40. 5	45. 8
Continuous [2]	33	42	28. 5	23. 7
Temporary extended [3]	20	26	17. 2	14. 7
Indeterminate [4]	8	10	6. 9	5. 6
Intermittent ending in failure [5]	4	10	3. 4	5. 6
Intermittent ending in pass [6]	4	8	3. 4	4. 5

[1] Failing 1 test only and passing subsequently.
[2] Failing all tests after first failure.
[3] Failing consecutive tests more than once but ending in a pass.
[4] Passing all tests except the last.
[5] Passing a test between failures and ending with a failure.
[6] Passing a test between failures and ending with a pass.

an audiometric test, the children in the youngest age group had a much higher percentage of bilateral involvement (71 percent) than those in the other three age groups (38, 47, and 45 percent, respectively), as well as greater severity of hearing loss in the middle frequency range. Average weighted scores of severity of hearing impairment for the four age groups were 150, 136, 86, and 50, respectively. Weights of 100, 200, and 300 were given for slight, moderate, and severe involvement of the middle frequency range. Poorer audiometric scoring in the youngest group is all the more meaningful in the face of the greater average acuity of hearing that is believed to be normally present in the early years.

Bilaterality and severity of hearing impairment may be related to age differences alone. One demonstrable age correlation in the total study population was the finding that younger children who fail an audiometric test show loss of hearing over a wider spread of frequencies than do the older children, whose hearing impairment is more likely to be focused on a narrower range of frequencies. The decrease in involvement of ranges with increasing age took place in the lower and middle frequencies rather than in the high tones. Age differences did not apply when hearing loss exceeded 40 decibels.

The extent to which a child suffers from his hearing impairment is greatly influenced by whether one or both ears are affected. Among the 116 children who ever failed an audiometric test, laterality of involvement was known for 111. Half of these had bilateral loss of hearing at the time of first failure of an audiometric test. Among the group 5–7 years old, 69 percent of all failures were bilateral compared with 45–47 percent in each of the three older age groups.

Table 7. Total number of children and number and percentage with unfavorable audiometric test history, according to age at admission to first grade

Age level at time of admission to first grade	Total children [1]	Ever failed test	
		Number	Percent
Total	1, 724	116	6. 7
Normal [2]	1, 480	88	5. 9
1 year behind	166	20	12. 0
2 years behind	52	7	13. 5
3 and 4 years behind	26	1	3. 8

[1] Excludes 2 children whose age at time of admission was unavailable.
[2] Below 7 years.

NOTE: Chi-square based on 2 x 2 table for normal age level and 1 year behind, $\chi^2 = 11.73$ $P < .001$; and for normal age level and 2 years behind, $\chi^2 = 5.85$ $P < .02$.

Impact Upon Academic Progress

The possible effect of hearing impairment on a child's school work was studied in three ways: by age on admission to school, by repetition of academic grades, and according to grade at the end of observation.

Age of Admission to School

Among the children admitted to school at the normal age level (below 7 years), 5.9 percent ever failed a hearing test during the study period compared with 11.5 percent of those whose admission to school had been delayed. This is a statistically significant difference ($\chi^2 = 11.8$ $P < .001$), which may connote that undiscovered hearing loss was associated with and may have contributed to delay in acceptance at school. Also, 16 of the 28 children whose admission to school was delayed and who failed an audiometric test at some time failed the first time they were tested.

Intermittent hearing loss may exist prior to as well as after admission to school. Among the children who entered school late but passed the first audiometric test, the failure rate in the group aged 8–9 years was 3½ times the rate among children who were admitted to school at 5–7 years of age and passed their first audiometric test.

Gross delay in admission to school probably results from causes other than hearing defect. Among 218 children who entered school 1 and 2 years late, 12.0 and 13.5 percent, respectively, ever failed an audiometric test whereas, among the 26 children admitted to school 3 or more years late, only one instance of hearing loss was then or subsequently discovered (table 7).

The delay in receiving the first audiometric test was appreciably greater than usual among

Table 8. Total number of children and number and percentage who repeated one or more grades, according to audiometric test history

Audiometric test history	Total children	Repeated one or more grades [1]	
		Number	Percent
Total	[2] 1, 722	333	19. 3
Never failing	[2] 1, 606	294	18. 3
Ever failing	116	39	33. 6

[1] Excludes children admitted to first grade under 6 years of age who repeated the first grade only.
[2] Excludes 4 children whose record of grade repetition was unavailable.

NOTE: $\chi^2=14.89 \quad P<.001$.

children who entered school late. Because these children often deviated from the routine grade placement, they tended to miss the scheduled tests for their group and to have recognition of their hearing impairment still further postponed.

Repetition of Academic Grades

Children who ever had hearing impairment during their school lives were twice as likely to repeat a grade as were other children (table 8). The magnitude of the impact of hearing impairment on academic status can also be sought through the grade repetition ratio, or the total number of grades repeated per 100 children. This ratio was 46 among children who ever failed an audiometric test compared with 20 among those who never showed hearing impairment. Thus, a child with a hearing defect not uncommonly repeats more than one academic grade during his school career.

In the present study it was not possible to examine the time relationship between hearing loss and school work because the data gave time of recognition of hearing loss rather than time of onset and time of repetition of a grade rather than time of the beginning of poor academic work. Comparison of age of grade repeaters with nonrepeaters at first audiometric test failure and separate comparison of audiometric test failers with nonfailers at first repetition of a grade showed no meaningful differences. There was no significant pattern of time relationship between first audiometric failure and first repetition of a grade in the 39 children who had both. Furthermore, there was greater delay in the time of audiometric testing of children who repeated grades than in the testing of other children, again apparently due to their falling out of step with the grades of their fellow pupils and being missed by the routine biennial testing program.

Grade at End of Observation

A combination of factors determines a child's academic status at the end of his school career. Therefore, the grade-age relationship at the end of the observation period was set up as the third index of possible impact of hearing impairment upon school work. Among the 114 children who ever failed an audiometric test, 38.6 percent had not reached their normal academic grade level at the terminal point of the study, whereas only 24.4 percent of the 1,609 children who had not shown hearing impairment at any time in their school career were behind their expected grade at the end ($\chi^2=13.66 \quad P<.001$). The audiometric failure rate was far greater among children 2 years behind their age group than among those 1 year behind, and 3 times as high as among children at

Table 9. Number and percentage distribution of children with unfavorable audiometric test history, according to age-grade relationship at last observation

Age-grade relationship	Number tested [1]	Ever failed a test	
		Number [2]	Percent
Total	1, 723	114	6. 6
Normal age level	1, 286	70	5. 4
1 year behind	246	17	6. 9
2 years behind	124	21	16. 9
3 and 4 years behind	67	6	9. 0

[1] Excludes 3 children whose grade classification was unavailable.
[2] Excludes 2 children whose grade classification was unavailable.

NOTE: Chi-square based on 2 x 2 table for normal age level and 2 years behind, $\chi^2=28.94 \quad P<.001$; 1 and 2 years behind, $\chi^2=9.08 \quad P<.01$; normal age level and 3 and 4 years behind, $\chi^2=1.12 \quad P<.30$.

normal grade level. In the group with 3 or 4 years of total academic retardation, however, the proportion with hearing impairment dropped, suggesting that other factors, such as mental retardation, entered more fully into the picture (table 9).

Detailed analysis of the longitudinal history of the children revealed a number of characteristic pictures. One group had hearing loss from the beginning and consistently thereafter. Half of these had fallen 2 or more years behind their normal academic level at the end of the study. These children usually had severe bilateral hearing impairment.

Early in their school careers, the children who probably had had a hearing defect prior to admission to school were grossly retarded academically. They were delayed in being admitted to school, missed their audiometric tests for varying lengths of time after admission, and repeated one or more grades before their hearing impairment was recognized. Strangely enough, half of them had only unilateral hearing defect. The nature of the hearing loss and its tendency to eventual improvement suggested an infectious etiology rather than that organic brain damage was the common basis for a nerve type of hearing impairment associated with mental retardation. Unfortunately, information on clinical findings and intelligence testing was not consistently available. In a number of slow-learning children, superimposed mild or moderate hearing impairment seemed to constitute a considerable handicap.

Prognosis

In order to make a retrospective appraisal of the prognostic implications of early audiometric test findings, the following indexes of the course of hearing impairment and its end results were established: chronicity; severity of hearing loss at the last audiometric test in different frequency ranges, especially the middle frequencies; and impairment of hearing in one or both ears at the last test. These indexes were analyzed in relation to (*a*) hearing impairment in frequency ranges at first test failure, (*b*) hearing impairment in combinations of frequency ranges at first failure, (*c*) severity of hearing impairment in the three frequency ranges at first failure, (*d*) greatest severity of involvement in the three frequency ranges during the period of observation, and (*e*) consistency of laterality of hearing impairment.

Frequency Ranges

Among the children followed for 3 or more years after failure of an audiometric test, there was general correlation in the group as a whole between the number and severity of hearing impairments in any one of the three frequency ranges at the time of first test failure and the persistence and degree of loss in that same range at the time of the last test. The correlation held more strongly for high tones than for middle tones and for middle tones than for low tones.

Combinations of Ranges

Table 10 gives the percentage distribution of frequency ranges and combinations of ranges at the time of first failure of the ears that ever failed an audiometric test. Table 11 shows that among the 148 ears for which data on chronicity of hearing impairment were available, 25 percent had continuous audiometric test failure. The direct correlation between height of early hearing impairment on the frequency range scale and tendency of hearing deficit in that same frequency range to persist also was evident when combinations of two frequency ranges were affected at the first failure of a test. The rank order of percentage of continuous failure after early dual range involvement

Table 10. Distribution of combinations of frequency ranges affected at time of first failure of audiometric test by an ear

[Arranged in rank order of percentage distribution]

Combinations of frequency ranges	Number [1]	Percent
Total	158	100.0
Low, middle, and high	71	44.9
Low and middle	23	14.6
Middle and high	22	13.9
High only	20	12.7
Low and high	8	5.1
Low only	8	5.1
Middle only	6	3.8

[1] Excludes 19 ears for which audiogram of first audiometric test failed was unavailable.

Table 11. Number and percentage of classes of chronicity [1] of hearing impairment, according to combinations of frequency ranges affected at time of first failure of an ear

[Arranged in rank order of percentage distribution of continuous impairment]

Combinations of frequency ranges	Total [2]	Number		Percent	
		Continuous	Temporary and intermittent	Continuous	Temporary and intermittent
Total	148	37	111	25. 0	75. 0
Middle and high	22	14	8	63. 6	36. 4
High only	17	7	10	41. 2	58. 8
Low and high	5	1	4	20. 0	80. 0
Low and middle	23	4	19	17. 4	82. 6
Middle only	6	1	5	16. 7	83. 3
Low, middle, and high	67	9	58	13. 4	86. 6
Low only	8	1	7	12. 5	87. 5

[1] See footnotes to table 6.

[2] Excludes 10 ears with "indeterminate impairment" and 19 ears for which audiogram of first audiometric test failed was unavailable.

was: high plus middle, high plus low, and middle plus low.

With one exception, hearing impairment in two ranges increased the tendency to continuous hearing failure, as follows:

High plus middle was more chronic than high alone.

High plus middle was more chronic than middle alone.

High plus low was less chronic than high alone (the exception).

High plus low was more chronic than low alone.

Middle plus low was more chronic than middle alone.

Middle plus low was more chronic than low alone.

When hearing impairment existed in all three frequency changes, however, continuous failure was least likely.

Since the middle frequencies are the ones essential to functional hearing of speech, it is important that the prognostic significance of early loss of hearing in any frequency range must be assessed in relation to the end point of hearing impairment for the middle frequency range. Detailed analysis helps to explain the rank order of the frequency ranges in respect to their seeming prognostic significance for continuity of hearing impairment (table 11). Although the numbers of ears tested are small, the differences in chronicity of hearing impairment in the middle frequency range are striking.

Four possible patterns of combination of frequency ranges include the high range. The highest percentages of continuous hearing impairment occurred when hearing impairment at the time of first audiometric test failure had been found in 3 of these 4 combinations (table 11). At first glance, this would suggest that any loss of hearing in the high range at the time of first failure of an audiometric test has great significance for continuity of hearing impairment. From a practical viewpoint, however, this is not so. The correlation existed only with the definition used for failing a threshold test, not with ultimate functional hearing as judged chiefly by middle frequency range loss.

End-point middle frequency range loss of hearing evidently related back to early middle range loss and did not occur to more than a slight extent when no loss of hearing in the middle frequency range had existed at the time of first failure of an audiometric test (table 12). Observation of these children over a longer period of time is necessary to determine whether the slight impairment of hearing in the middle frequency range that sometimes occurred ever becomes more significant. When the first test failure consisted of loss of hearing in the high frequency range only, the high proportion of continuing failure of the audiometric test was made up almost entirely of persistent failure in the high range exclusively. Only 3 of the 13 ears in this group whose continuous failure of audiometric tests spanned 3 or more years developed even a slight degree of hearing loss in the middle frequency range. As an added check, audiograms were studied of 20 ears in 15 children which had been labeled "borderline" rather than test failures. These children had shown some loss of hearing at the 6,000 or 8,000 frequency at one time or another but the loss was not enough to drop the high frequency range average below the passing standard. The majority of these children were 8 years of age when hearing loss was first noted and 13 of them were boys. The amount of loss was usually less than 50 decibels, in which case it disappeared within 1 or, at most, 2 years.

Audiometric School Testing Program

ADMINISTRATIVE RECOMMENDATIONS

The administrative recommendations listed below are based upon the findings of the study as they seem to fit together with other experiences, observations, and reports in the field of audiology and in school health programs. The word "school" applies to all grades through high school, without regard to structural or organizational separation. It is not intended that elementary, junior high, and high schools should treat their entering students as entirely new to an audiometric testing program but that continuity in testing should be attained by effective coordination of programs and prompt transfer of health records with the students.

1. School systems and health departments should work jointly for the development of comprehensive routine hearing screening programs among children of preschool age.

2. Organization of the audiometric test programs in schools should be based on ages of children rather than on grade grouping.

3. Screening tests should be given routinely:

a) To all students entering school for the first time. (Highest priority for prompt testing should be given to this group.)

b) Annually to all children under 10 years of age, except those who have ever had hearing impairment.

c) Possibly to all children just prior to their leaving school, especially among those who terminate their schooling before graduation.

4. Screening tests should be limited to the middle frequency range (500, 1,000, 2,000 decibels).

5. A makeup test should be arranged as soon as possible when children miss taking their routine tests, especially if these children fall into one of the special referral categories listed immediately below.

6. On referral, screening tests should be given to school children of any age when:

a) The teacher, parent, or child himself, suspects hearing is not normal.

b) Infections or allergic involvement of ear, nose, or throat are frequent or excessive.

c) Absenteeism is marked. (Criteria in terms of frequency, length, number, and type of absences, and ages of children should be established by the school health service.)

d) Academic work is poor. (Criteria should be established by the school according to its pattern of instruction and grading.)

7. Special effort should be made to obtain a test of hearing whenever a child has not entered school at the usual starting age.

When hearing impairment could be a contributing factor, no child should be denied admission or delayed in admission to school for supposed mental retardation or other reason without attempting a test of hearing.

8. When a child fails a first screening test, the audiometric test should be repeated the same day, possibly with partial threshold testing in the middle frequencies. If he fails a second time:

a) His classroom teachers should be informed immediately of the possibility of hearing impairment.

b) A questionnaire on his earlier and recent hearing history should be filled out by the parents and child.

c) He should be given a threshold test covering frequencies 250–8,000 approximately 3 weeks afterwards, or later if respiratory infection is present.

9. When a child fails a threshold test:

a) The school health service should arrange to have him examined by an otologist.

b) He should be referred to the family physician or to the family's usual resource for medical care, and the parents should be given an interpretation of the audiometric test results and the otologist's findings.

c) Attempt should be made to send reports to the physician who treats the child.

d) Prompt and persistent follow-up steps should be taken by the school and the school health service to assure adequate care. Frequent threshold retesting may help to motivate the family toward medical care as well as to measure the child's progress.

The six children who had 50 decibels or more of loss retained this loss with minor fluctuations throughout the period of observation but never developed any other impairment sufficient to fail an audiometric test.

In the small group of five cases with the pattern of loss of hearing in the low plus high frequency ranges at the first failure of an audiometric test, the one ear that did not ultimately pass the test showed only slight loss of hearing in the middle range frequency (table 12). Among the infrequent cases of initial loss of hearing in the low range only, one ear showed slight hearing deficit after 3 or more years.

It seems safe to conclude that if a child has or is likely to develop appreciable difficulty in hearing speech, this can usually be detected by audiometric testing of the middle frequency range only. Therefore, in sweep check screening tests time should not be spent on the low and

---

10. Once a child has been found to have hearing impairment:

a) He should be removed from the screening program and thereafter be given appropriate supervision and his hearing threshold should be tested as frequently as indicated by his clinical and academic progress.

b) Mild hearing impairment in a child becomes more handicapping when it is associated with some degree of mental retardation. Such a child should have as complete audiologic and psychological appraisal as possible so that an appropriate program can be planned for him.

c) Decision on modification of any child's education because of hearing impairment should first be based on his immediate needs rather than on the prognosis and thereafter on careful observation and frequent reappraisal of the child rather than on the mere nature of his audiometric score. This works in two directions. On the one hand, mild loss of hearing on the audiogram with a clinical picture that usually bears a good prognosis does not preclude prompt aggressive treatment, possibly the temporary use of a hearing aid, and adaptations in the child's educational program. On the other hand, when the prognosis seems poor, definitive acceptance of that prognosis should be postponed and long-term educational and vocational plans should not be made until longitudinal observation and treatment for at least 2 years have permitted a more valid estimate of the ultimate outcome.

SUGGESTIONS FOR RESEARCH

A variety of audiometric screening methods deserve comparative studies.

1. The increment of new cases found by an annual retest should be studied in a school screening program in which such annual testing is done routinely.

2. The effects on meaningful case finding of narrowing the span of screening to the middle frequencies and to the younger ages, as here recommended, should be studied in additional school programs.

3. If the pure tone sweep check method is used, studies should be done on the advisability of moving the screening decibel level closer to the so-called zero line in the middle frequency range. The greater artifact of ambient noise in the low frequency range has heretofore been the major deterrent to establishing a more rigid passing standard for audiometric tests.

Change in the passing standard would also be in keeping with the greater acuity of hearing that is normally present in young children. Audiometers have been calibrated to fit the hearing of adults, not children. The case-finding and prognostic value of a more rigid passing standard in the middle frequency range should be checked by comparative studies.

4. In a routine screening program limited to as few as three frequencies, it may be desirable and feasible to do a threshold test rather than a sweep check test. The threshold test might detect changes in a child's hearing in successive years even within the usual passing level, and it would establish for each child his own individual norm rather than pegging all children at the same norm.

With the use of antibiotics, otologists have been reporting the common occurrence of nonpurulent collections of fluid in the middle ear chambers, producing an initial drop in hearing of as little as 10 decibels. Prompt recognition of this relatively minor degree of impairment might lead to early and aggressive therapy and to prevention of permanent damage.

5. In the opposite direction to moving from a sweep check to a threshold test, there may be effective shortcuts to case finding. Comparative studies should be made on the use of a single frequency, such as 1,000, or of some sound other than a pure tone but composed primarily of the middle frequencies. Verbal tests need further analysis. These have been discussed by Lee Meyerson in Hearing for Speech in Children: A Verbal Audiometric Test (Supplementum 128 to *Acta Oto-Laryngologica* 1956).

6. Evaluation should be done of the case-finding effectiveness of the several special referral criteria suggested in this paper.

7. Time and cost studies of the various audiometric screening methods are essential to help determine the most practicable procedures for testing large numbers of children.

Table 12. Combinations of frequency ranges affected at time of first failure of an ear, according to middle range involvement at time of last test

[Frequencies arranged in rank order of total percentage with middle range loss]

Frequency ranges affected at time of first failure		Ears having middle range loss at last test					
		Number			Percent of column (2)		
Combinations of ranges	Number of ears [1]	Total	Moderate and severe	Slight	Total	Moderate and severe	Slight
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Total	135	28	15	13	20. 7	11. 1	9. 6
Middle and high	21	12	9	3	57. 1	42. 9	14. 2
High only	13	3	----------	3	23. 1	----------	23. 1
Middle and low	19	4	3	1	21. 1	15. 8	5. 3
Low and high	5	1	----------	1	20. 0	----------	20. 0
Low only	8	1	----------	1	12. 5	----------	12. 5
Middle, low, and high	64	7	3	4	10. 9	4. 7	6. 2
Middle only	5	--------	----------	--------	--------	----------	--------

[1] Number of ears with a 3-year span of test coverage after first failure. For observed differences in column (7), $\chi^2=18.76$ $P<.001$.

high frequency ranges. When, however, one moves from finding new cases by screening tests to assessing, treating, and educating children with known hearing impairment, knowledge concerning any associated impairment of hearing in the low and high frequencies is important. A number of findings indicate that low and high frequency ranges should be included when threshold tests are done on children with known or suspected loss of hearing.

The severity of end-point middle frequency range loss of hearing depended on early impairment of hearing in the middle frequency range in combination with 1 or 2 other frequency ranges (table 12) in the same rank order as the tendency of such combinations of ranges to persist (table 11), as follows: middle plus high, middle plus low, and middle plus high plus low.

Severity of Hearing Impairment

The mere presence at the time of first audiometric test failure of loss of hearing in either the low or high frequency range combined with impairment of hearing in the middle frequency range was more significant than the severity of early impairment in the low or high range. Among the ears with loss of hearing in the middle range plus high range at the first failure of an audiometric test, the group with the highest proportion of persistence of hearing impairment (63.6 percent, table 11), there was no relationship between the severity of loss of hearing in the high range at the first test failure and loss of hearing in the middle range at the last test. There was, however, striking correlation between the severity of hearing impairment in the middle frequency range at the first and last tests.

Among the 19 ears with loss of hearing in the middle plus low frequency ranges at first failure of an audiometric test, the extent of first impairment of hearing in either the middle or low range had no relationship to whether an ear later passed or failed the audiometric test or to the severity of end-point middle frequency range loss of hearing when the ear did fail the test. Four ears showed audiometric test failure after the first test. In none of the rare instances of initial loss of hearing in the middle frequency range only was there any hearing impairment after a span of 3 or more years.

Of particular interest is the large group of ears that showed "across the board" loss of hearing in all three frequency ranges at the first failure of an audiometric test. Only 11 percent of these ears followed for 3 or more years had more than slight middle range loss at the last test. Even among 10 children who had severe loss of hearing in all 3 frequency ranges at the first failure of an audiometric test, 9 finally passed the sweep check test. Therefore, among children attending day school, "across the board" loss of hearing on audiometric test usually is the result of acute rather than chronic hearing impairment.

In this study, loss of hearing in some of these children may have been due to impacted wax, although case histories indicated the frequent existence of nasopharyngeal infection. This finding is in keeping with the experience of clinicians that there is a general "flattening" of hearing level associated with acute middle ear infection and that this flattening moves either toward recovery or toward persistent loss of hearing of a less even nature. The broad span of frequencies affected in the flattening gives a favorable rather than an unfavorable prognosis as long as the impairment is not excessive.

The prognostic importance of "across the board" loss of hearing was borne out by a look at another group of children. This group was composed of seven children who were in the same age group as the study population and whose families resided in the Reading School District but who attended the State residential school for the deaf. All of these children had consistent "across the board" impairment of hearing from first to last tests, with much greater decibel loss than the children in the study. No child in the study population, for example, ever had an audiogram with every frequency reading at 60 decibels or more. Although severity and duration of "across the board" hearing impairment are of some assistance, it is not always possible to distinguish between the child whose hearing will clear up partially or completely and the child who will remain seriously handicapped. What is vital is the fact that the prognosis for many children with considerable hearing loss covering a wide spectrum of frequencies need not be a pessimistic one.

An attempt was made to derive prognostic significance from the greatest degree of hearing impairment in each frequency range in any ear during the study period. Continuity of failure of audiometric tests or intermittency of hearing impairment ending in failure of the test correlated directly with increasing severity of the poorest test result in the middle frequency range. The correlation was even greater with poor test results in the high frequency range. On the other hand, the ears that remained normal in the low frequency range despite failing one or more audiometric tests had the poorest prognosis for chronicity of hearing impairment. Evidently, unevenness in audiometric test score is more indicative of probable persistence of hearing impairment than is "across the board" homogeneous severity of hearing loss. This applies not only to irregular impairment of hearing in the three frequency ranges but to uneven severity of hearing loss from one frequency to another within any range.

Laterality of Impairment

Some interesting prognostic inferences may be drawn from the data on consistency of hearing impairment of one or both ears in the same children. Among the 58 children who failed the audiometric test in more than 1 year, 38 percent had unilateral involvement only, 24 percent had bilateral involvement only, and 38 percent fluctuated between unilateral and bilateral involvement. In almost no instance did unilateral failure move from one ear to the other, and very rarely did hearing loss progress from unilateral to bilateral involvement. The change, if any, was usually in the other direction. In general, a better prognosis for hearing status at the last audiometric test was suggested when there was fluctuation between bilateral and unilateral hearing loss during a child's school career than if the loss was always unilateral or always bilateral (table 13).

At the end of the observation period, 13 children, or 8 per 1,000, had bilateral hearing loss of more than 30 decibels in the middle frequency range. Seven were in the school for the deaf; six were from the Reading School District biennial audiometric test program. These six children were the ones with a definite deficit for hearing speech. Four had had hearing difficulty when they entered school; two developed hearing difficulty later. In the entire study population, there was only one child who had had the same degree and type

Table 13. Number of children who failed more than one audiometric test and number and percentage of failures at time of last test, according to laterality of impairment in all test failures

Laterality of ear involvement when failing tests	Children failing more than 1 test	Failed last test	
		Number	Percent
Total	58	36	62. 1
Always unilateral	22	17	77. 3
Always bilateral	14	10	71. 4
Mixed laterality	22	9	40. 9

of hearing loss for 2 or more years but whose hearing at the last observation was no longer impaired to the same extent as at the beginning of the study. Information was not available on homebound children with other handicaps that could affect their hearing.

Summary

During an 8-year study of 1,726 school children aged 5–14 years in Reading, Pa., 116, or 6.7 percent, ever failed an audiometric test.

The increment of new cases of hearing impairment found by a biennial retest routine was 2.3 percent among "candidates" 8–9 years old, 1.0 percent in the group aged 10–11 years, and 0.8 percent in those 12–13 years old.

Among children 5–7 years of age who passed their first audiometric tests, 3.3 percent failed a subsequent test. Among children in this age group who failed their first audiometric test, 48.4 percent failed later tests. When children passed all their tests before 10 years of age, less than 1 percent failed thereafter.

Hearing impairment persisted without interruption in 28 percent of the children and in 24 percent of the ears that ever failed an audiometric test.

Young children whose hearing impairment was discovered about the time they entered school had more severe types of hearing impairment than other children, suggesting that the condition had probably existed for some time prior to admission to school.

Rates of delayed admission to school, delay in receiving audiometric tests, repetition of academic grades, and retarded grade status at the end of the observation period were higher for children who ever failed an audiometric test than for other children. Moderate unilateral impairment of hearing as well as severe or bilateral loss of hearing seemed to constitute an educational handicap, especially during the early years of learning language, reading, and spelling, when missing parts of the sounds might almost completely prevent a child from grasping the meaning of what he hears.

Ultimate loss of hearing in the middle frequency range after failure of an audiometric test did not often occur unless there had been initial impairment of hearing in the middle frequency range. With initial middle frequency range loss of hearing alone, the prognosis was good; initial middle range plus low frequency range loss signified a poorer prognosis, and initial middle plus high frequency range loss, the least favorable prognosis.

Initial "across the board" loss of hearing in all three frequency ranges at 40 decibels or less usually denoted a good prognosis. More severe and early "across the board" impairment of hearing occurred in cases of persistent deafness.

Unevenness of audiograms in severity of hearing impairment and in frequency ranges gave a poorer prognosis than evenness except for the most severely affected ears.

Hearing impairment in 38 percent of the children who failed the audiometric test in more than one year was unilateral whenever they failed the tests, almost always in the same ear; in 24 percent, always bilateral; and in 38 percent, impairment fluctuated between unilateral and bilateral involvement. Such fluctuation gave a better prognosis than when hearing loss was always unilateral or always bilateral.

Eight children per 1,000 studied had an end point of bilateral hearing impairment of more than 30 decibels in the middle frequency range.

REFERENCE

(*1*) Wishik, S. M., and Kramm, E. R.: Audiometric testing of hearing of school children. J. Speech & Hearing Disorders 18: 360–365, December 1953.