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Pure-Tone Assessment and Screening of Children with Middle-Ear Effusion

Shlomo Silman*†
Carol A. Silverman†‡
Daniel S. Arick§

Abstract

The purpose of this prospective investigation was to evaluate the sensitivity of pure-tone screening of children with middle-ear effusion (MEE) and to describe the short-term audiometric and otologic follow-up of children with MEE who pass versus fail a pure-tone screen. Eighty-two ears of 54 children with MEE based on pneumotoscopy/microtoscopy were investigated. A complete otolaryngologic evaluation, pure-tone screen, then complete audiologic evaluation were performed at the initial test. Retesting was done at 6–8 weeks post initial test. The sensitivity of the ASHA (1985) pure-tone screen to MEE was 54 percent when 500 Hz was excluded, 85 percent when 500 Hz was included, and 89 percent when 250 Hz was also included. Significant air-bone gaps were present in 100 percent of the MEE group that failed and in 92 percent of the MEE group that passed the screen (excluding 500 Hz). Of the cases with MEE at the initial test that returned for the retest, 53 percent to 54 percent continued to show MEE. The mean speech-recognition threshold (SRT) was in best agreement with the hearing-threshold levels at the low frequencies, regardless of the pure-tone screen outcome. The results suggest that 500 Hz, as well as 1000–4000 Hz, should be used in a pure-tone screen at 20 dB HL for detection of MEE. The results also question the assumption in the ASHA (1985) screening guidelines that passing a pure-tone screen at 1000–4000 Hz puts one at low risk for hearing impairments that "interfere with or have the potential for interfering with communication" (ASHA, 1985).

Key Words: Audiometry, conductive hearing impairment, hearing assessment in children, middle-ear effusion (MEE), pure-tone screening, serous otitis media, speech audiometry

The American Speech-Language-Hearing Association (ASHA, 1990) published guidelines for screening children for hearing impairment and middle-ear disorders such as middle-ear effusion (MEE). The ASHA (1990) guidelines were to be used in conjunction with the previous ASHA (1985) guidelines for identification audiometry. Specifically, the ASHA (1985) guidelines for a pure-tone screen performed together with an acoustic-immittance screen require screening at 20 dB HL at 1000, 2000, and 4000 Hz (excluding 500 Hz). However, when a pure-tone screen is performed without an acoustic-immittance screen, the ASHA (1985) guidelines require screening at 20 dB HL at 500, 1000, 2000, and 4000 Hz (including 500 Hz), provided the ambient level does not exceed ANSI S3.1-1977. (ANSI S3.1-1977 has been revised as ANSI S3.1-1991.)

The ASHA (1990) acoustic-immittance screen criteria for detection of middle-ear disorders in children include: static-acoustic middle-ear admittance below the 90 percent range in a normative sample (with the ear-canal admittance calculated at +200 dapa) and tympanometric width such that the pressure interval corresponding to 50 percent reduction in peak static-acoustic admittance from the peak to the tail value in the admittance-pressure function exceeds the 95th percentile.

*Department of Speech, Brooklyn College, CUNY, Brooklyn, New York; †Department of Speech and Hearing Sciences, Doctoral Program, Graduate School and University Center, CUNY, New York, New York; ‡ Communication Sciences Program, Hunter College, CUNY, New York, New York; and §Department of Otolaryngology, Long Island College Hospital, Brooklyn, New York

Reprint requests: Carol A. Silverman, 625 Main St., Apt. 1041, New York, NY 10044

In a prospective investigation, Silman et al (1992) evaluated the accuracy of the ASHA (1990) acoustic-immittance criteria for detection of MEE in children. The MEE sample was composed of 82 ears of 54 children ranging in age from 3 to 11 years, whereas the control (normal hearing, normal middle ear) sample was composed of 53 ears from 53 children ranging in age from 3 to 10 years. The sensitivity and specificity of the ASHA (1990) acoustic-immittance criteria were only 81.5 percent (for the total MEE sample) and 79.0 percent, respectively. The hit rate for the ASHA (1985) pure-tone screen (excluding 500 Hz) for the total MEE sample was poorer, at 54 percent, than the ASHA (1990) acoustic-immittance screen. In contrast, the sensitivity and specificity for the acoustic-immittance screen developed by Silman et al (1992), based on static-acoustic middle-ear admittance, tympanometric width, tympanometric peak pressure, and the ipsilateral acoustic-reflex threshold, were 90 percent and 92.5 percent, respectively. In conclusion, the acoustic-immittance screen using the Silman et al (1992) screen was more effective than both the ASHA (1990) acoustic-immittance screen and ASHA (1985) pure-tone screen for detecting MEE.

Data are lacking on the sensitivity of the ASHA (1985) pure-tone screen (incorporated in the ASHA [1990] guidelines), which is performed without an acoustic-immittance screen (i.e., including 500 Hz), especially in comparison with those for the ASHA (1990) and Silman et al (1992) acoustic-immittance screens. Perhaps the sensitivity of the ASHA (1985) pure-tone screen performed without an acoustic-immittance screen (i.e., excluding 500 Hz) can be improved by including other test frequencies or other pure-tone measures (e.g., air-bone gaps).

The need for a more sensitive pure-tone screen for detection of MEE is strengthened when considering the limitations of an acoustic-immittance screen and the findings of Silman et al (1992). Obstacles to performing an acoustic-immittance screen for detection of MEE include the cost of acoustic-immittance devices and cost/availability of personnel with the expertise to perform an acoustic-immittance screen. On the other hand, pure-tone screening audiometers are considerably lower in cost than acoustic-immittance screening devices. Also, the personnel level of expertise required for performing a pure-tone screen is considerably lower than that required for performing an acoustic-immittance screen. Silman et al (1992) also reported that 46.4 percent of their total sample of children with MEE would have passed the ASHA (1985) pure-tone screen (excluding 500 Hz); of this "normal-hearing" subgroup, only 63 percent would have been detected with the ASHA (1990) acoustic-immittance screen as compared with 89.5 percent detection with the Silman et al (1992) screen.

If a pure-tone screen is performed to detect MEE, then research is also needed to investigate the effectiveness of such a screen in detection of MEE, which is present upon a retest 6–8 weeks after the initial test. An interval of 6–8 weeks between test and retest is typical of screening programs. Also, the ASHA (1990) guidelines specify retesting of audiometric failures on site or at a later evaluation. Therefore, what proportion of cases with MEE that pass versus fail a pure-tone screen at the initial test have MEE 6–8 weeks later? Such information would shed light on whether children with MEE who initially pass versus fail a pure-tone screen show recovery from MEE upon the retest 6–8 weeks later.

The ASHA (1990) audiometric guidelines are based on the ASHA (1985) guidelines, which stated that pure-tone screen criteria were developed for rapid and efficient detection of hearing impairments that "interfere with or have the potential for interfering with communication." Does pure-tone screening of children with MEE meet this goal? The ASHA (1990) pure-tone screen guidelines specify audiologic follow-up only for those who fail but not those who pass the pure-tone screen, suggesting that those who pass the pure-tone screen are at low risk for potential hearing impairment upon a retest performed at 6–8 weeks post initial test.

Another related question concerns the determination of the frequency of the air-conduction threshold that best agrees with the speech-recognition threshold (SRT) in children with MEE who pass versus fail the ASHA (1985) pure-tone screen (excluding 500 Hz). Perhaps the answer to this question could help identify the frequency of the air-conduction threshold that best predicts interference with communication in children with MEE.

The purpose of this investigation was to evaluate the sensitivity of pure-tone screening of children with MEE and to describe the short-term audiometric and otologic follow-up of children with MEE who pass versus fail a pure-tone screen. The specific research questions included:

1. What is the sensitivity of the ASHA (1985) pure-tone screen when 500 Hz is excluded versus included for the detection of MEE in children?
2. What is the sensitivity of significant air-bone gaps and a pure-tone screen that includes 250 Hz as well as 500 Hz at 20 dB HL for detection of MEE in children?
3. What is the sensitivity of the ASHA (1985) pure-tone screen that includes or excludes 500 Hz, as compared with the ASHA (1990) acoustic-immittance screen, for detection of MEE in children?
4. What proportion of cases with MEE at the initial test that pass or fail the ASHA (1985) pure-tone screen (excluding 500 Hz) have MEE at a retest performed 6–8 weeks later?
5. In children with MEE at the initial test and retest, do the mean air-conduction thresholds at the retest for those who passed the ASHA (1985) initial pure-tone screen (excluding 500 Hz) differ from those who failed the initial pure-tone screen?
6. At which frequency does the mean air-conduction threshold best agree with the SRT in children with MEE who pass versus fail the ASHA (1985) pure-tone screen (excluding 500 Hz)?

METHOD

Subjects

Eighty-two ears of 54 subjects (30 boys and 24 girls) with MEE ranging in age from 3 to 11 years (M = 6.3 years) were investigated. The subjects with MEE in this study were drawn from an otolaryngologic clinic in New York City. Their characteristics were previously described in the report by Silman et al (1992). The diagnosis of MEE was established using pneumotoscopy. Microtoscopy was also employed whenever the diagnosis of MEE based on pneumotoscopy was at all questionable. Pneumotoscopy and microtoscopy were performed by an otolaryngologist with more than 15 years of pediatric otolaryngologic experience. The subjects were referred because they failed the school hearing screen, audiologic and otolaryngologic examinations required by the New York City Board of Education prior to entering school, or because the parent suspected a middle-ear problem. Subjects were excluded from the study if the bone-conduction threshold exceeded 20 dB HL at one or more frequencies between 250 and 4000 Hz, inclusive.

Instrumentation

Audiologic assessment was carried out in an audiometric test room meeting ANSI S3.1-1991 maximum permissible ambient noise levels for ears uncovered testing from 125 through 8000 Hz. See Silman et al (1992) for a description of the acoustic-immittance instrumentation and calibration.

Procedure

The data were collected prospectively (Silman et al, 1992). Each subject was seen for a complete otolaryngologic evaluation immediately prior to a pure-tone screening and complete audiologic evaluation at the same visit. The otolaryngologic evaluation included pneumotoscopy/microtoscopy. The audiologic evaluation included pure-tone air- and bone-conduction thresholds, SRTs and suprathreshold monosyllabic word-recognition assessment whenever possible, static-acoustic middle-ear admittance assessment, acoustic-admittance pressure function, and ipsilateral acoustic-reflex threshold testing (1000-Hz tonal activator).

A blind design was employed. The otolaryngologic diagnosis was made without knowledge of the audiologic findings, and the audiologic testing was done without knowledge of the otolaryngologic findings at both the initial test and retest. The subjects were not treated with medication at the initial test as the philosophy of the otolaryngologist in this investigation was not to provide medication in cases with MEE unless bacterial infection was present. Retest pure-tone screening and audiologic and otolaryngologic re-evaluations were performed at 6–8 weeks post initial test.

RESULTS

ASHA Pure-Tone Screening Protocol

Table 1 shows the frequency distribution of cases with MEE that passed or failed the ASHA (1985) pure-tone screen at 20 dB HL that excluded 500 Hz. It also shows the frequency distribution of cases with MEE that passed or failed a pure-tone screen at 250 and 500 Hz, in addition to passing or failing the screen at 1000

Table 1 Frequency Distribution of MEE Cases that Passed versus Failed Pure-Tone Screening at 250 Hz and 500 Hz and the ASHA (1985) Pure-Tone Screen*

Group	*Number of Ears*	*Percentage*
Passed screen based on 1, 2, and 4 kHz	38	46
Passed 250 & 500 Hz	9	24
Passed 250 Hz, failed 500 Hz	3	8
Failed 250 Hz, passed 500 Hz	3	8
Failed 250 & 500 Hz	23	60
Passed ASHA (1990) immittance screen	14	37
Failed ASHA (1990) immitance screen	24	63
Failed screen based on 1, 2, and 4 kHz	44	54
Passed 250 & 500 Hz	0	0
Passed 250 Hz, failed 500 Hz	0	0
Failed 250 Hz, passed 500 Hz	1	2
Failed 250 & 500 Hz	43	98
Passed ASHA (1990) immittance screen	3	7
Failed ASHA (1990) immitance screen	41	93

Based on 1000, 2000, and 4000 Hz at the initial test.

through 4000 Hz, at the initial test. Table 2 shows the frequency distribution of cases with MEE that passed or failed the ASHA (1985) pure-tone screen that included 500 Hz. Table 2 also shows the frequency distribution of cases with MEE that passed or failed a pure-tone screen at 250 Hz, in addition to passing or failing a pure-tone screen at 500 through 4000 Hz, at the initial test.

Inspection of Table 1 reveals that of the 82 cases with MEE, 46 percent passed, whereas 54 percent failed the ASHA (1985) pure-tone screen that excluded 500 Hz. Tables 1 and 2 show that when 500 Hz was included as part of the pure-tone screen, only 15 percent (9 ears that passed both 250 and 500 Hz, and 3 ears that failed 250 Hz but passed 500 Hz) of the 82 cases with MEE passed, whereas 85 percent failed. Thus, the sensitivity was 54 percent for the ASHA (1985) pure-tone screen protocol that excluded 500 Hz and was 85 percent when 500 Hz was included.

Further inspection of Table 1 reveals that of the 38 cases with MEE that passed the ASHA (1985) pure-tone screen excluding 500 Hz, 8 percent (3 ears) failed 500 Hz and passed 250 Hz, and 60 percent (23 ears) failed both 250 and 500 Hz. These 26 ears account for the increase of sensitivity in the pure-tone screen from 54 percent when 500 Hz is excluded to 85 percent when 500 Hz is included. Note from Table 1 that

Table 2 Frequency Distribution of MEE Cases that Passed versus Failed a Pure-Tone Screen at 250 Hz and the ASHA (1985) Pure-Tone Screen*

Group	*Number of Ears*	*Percentage*
Passed screen based on 0.5, 1, 2, and 4 kHz	12	15
Passed 250 Hz	9	75
Failed 250 Hz	3	25
Passed ASHA (1990) immittance screen	9	75
Failed ASHA (1990) immitance screen	3	25
Failed screen based on 0.5, 1, 2, and 4 kHz	70	85
Passed 250 Hz	0	0
Failed 250 Hz	70	100
Passed ASHA (1990) immittance screen	8	11
Failed ASHA (1990) immitance screen	62	89

Based on 500, 1000, 2000, and 4000 Hz at the initial test.

only 8 percent (3 ears) that passed the ASHA (1985) pure-tone screen (including 500 Hz) failed at 250 Hz. Thus, if the pure-tone screen had included 250 as well as 500 Hz, its sensitivity would have improved only slightly from 85 percent (with 500 Hz included) to 89 percent (with 250 as well as 500 Hz included).

Overall, the sensitivity of a pure-tone screen (89%) at 250 through 4000 Hz, inclusive, was essentially equivalent to the sensitivity (90%) obtained for the acoustic-immittance screen for detection of MEE developed by Silman et al (1992). The high sensitivity of the ASHA (1985) pure-tone screen when 500 and 250 Hz are included exceeds the approximately 82 percent sensitivity for the ASHA (1990) acoustic-immittance screen (Silman et al, 1992).

ASHA Acoustic-Immittance Screen

Inspection of Table 1 also reveals that in the MEE group that passed the ASHA (1985) pure-tone screen excluding 500 Hz, only 63 percent failed the ASHA (1990) acoustic-immittance screen, as compared with approximately 90 percent that failed the Silman et al (1992) acoustic-immittance screen. Conversely, in the MEE group that failed the pure-tone screen excluding 500 Hz, only 7 percent passed the ASHA (1990) acoustic-immittance screen.

Note from Table 2 that in the MEE group that passed the ASHA (1985) pure-tone screen including 500 Hz, only 25 percent failed the ASHA (1990) acoustic-immittance screen. In the MEE group that failed the pure-tone screen including 500 Hz, 11 percent passed the ASHA (1990) acoustic-immittance screen.

Sensitivity of Significant Air-Bone Gaps

Table 3 shows the frequency distribution of significant (≥ 15 dB) air-bone gaps at frequencies between 250 and 4000 Hz in the MEE group that passed the ASHA (1985) pure-tone screen excluding 500 Hz at the initial test. Inspection of this table reveals that 500 Hz was the frequency with the highest number (31) of significant air-bone gaps, whereas 4000 Hz was the frequency with the lowest number (5) of significant air-bone gaps. Although a slightly higher number of significant air-bone gaps were obtained at 500 Hz than at 250 Hz, the number of large air-bone gaps (≥ 30 dB) was higher at 250 Hz than at 500 Hz. Inspection of Table 3 also reveals that air-bone gaps ≥ 25 dB were present at 250 and 500 Hz but were absent at 1000, 2000, and 4000 Hz.

Of the cases with MEE that failed the ASHA (1985) pure-tone screen (excluding 500 Hz), 100 percent had significant air-bone gaps. Of the cases with MEE that passed the ASHA (1985) pure-tone screen (excluding 500 Hz), 92 percent had significant air-bone gaps at one or more frequencies; of the three remaining ears without significant air-bone gaps, two had 10-dB air-bone gaps.

As mentioned earlier, inspection of Table 2 shows that of the 12 cases with MEE that passed the ASHA (1985) pure-tone screen including 500 Hz, 9 also passed at 250 Hz. Of these 9 ears, 6 had significant air-bone gaps as follows: (a) 1 had a significant air-bone gap only at 250 Hz; (b) 3 had significant air-bone gaps at 250 and 500 Hz; (c) 1 had a significant air-bone gap at 500 and 1000 Hz; (d) 1 had a significant

Table 3 Frequency Distribution of Significant Air-Bone Gaps in MEE Cases that Passed Initial Pure-Tone Screen (excluding 500 Hz)

	Frequency (Hz)				
Air-Bone Gap	*250*	*500*	*1000*	*2000*	*4000*
15 dB	2	5	11	15	1
20 dB	4	8	4	4	4
25 dB	9	10	0	0	0
30 dB	5	3	0	0	0
35 dB	5	3	0	0	0
40 dB	2	0	0	0	0
45 dB	1	1	0	0	0
50 dB	1	1	0	0	0
Total	29	31	15	19	5

N = 38.

air-bone gap at 1000 and 2000 Hz. Of these 6 ears, 33 percent failed the ASHA (1990) acoustic-immittance screen and 67 percent failed the Silman et al (1992) acoustic-immittance screen.

Air-Conduction Thresholds versus SRT

Table 4 shows the means and standard deviations of the air-conduction thresholds and SRTs for the MEE group that passed or failed the ASHA (1985) pure-tone screen excluding 500 Hz at the initial test. The mean SRT was in best agreement with the mean air-conduction threshold at 500 Hz in the MEE group that passed the pure-tone screen. In the MEE group that failed the pure-tone screen, the mean SRT was in best agreement with the mean air-conduction threshold at 250 Hz. The mean pure-tone average (PTA) was 18.6 dB HL and 35.04 dB HL for the cases with MEE that passed and failed, respectively, the ASHA (1985) pure-tone screen excluding 500 Hz. The mean SRT-PTA difference was 7.43 dB and 4.3 dB in the cases with MEE that passed and failed, respectively, the ASHA (1985) pure-tone screen excluding 500 Hz.

Note from Table 4 that in the MEE group that passed the ASHA (1985) pure-tone screen excluding 500 Hz, the mean air-conduction threshold at the low frequencies exceeded 25 dB HL, although the PTA was below 20 dB HL. In the MEE group that passed as well as the group that failed the ASHA (1985) pure-tone screen, the mean air-conduction thresholds at the low frequencies exceeded those at the mid-to-high frequencies. The mean SRT was 8.92–13.92 dB higher than the mean hearing threshold levels at 1000–4000 Hz in the MEE group that passed the pure-tone screen excluding 500 Hz. In the MEE group that failed the pure-tone screen (excluding 500 Hz), the mean SRT was within 3.43–9.11 dB of the mean hearing threshold levels at 1000–4000 Hz.

In conclusion, based on the results shown in Table 4, the MEE group that passed the pure-tone screen had, on average, a mild hearing impairment for speech that was reflected in the mean hearing threshold levels at the low frequencies. The MEE group that failed the pure-tone screen had, on average, a borderline moderate hearing impairment for speech that was reflected by a hearing impairment at all frequencies, particularly the low frequencies. Based on the mean hearing threshold levels at 250 through 4000 Hz and the mean SRT for the MEE group, the mean SRT appears to best reflect the low frequencies, regardless of the outcome of a pure-tone screen at 1000–4000 Hz.

Test versus Retest

Of the 38 cases with MEE that passed the ASHA (1985) pure-tone screen excluding 500 Hz at the initial test, 84 percent (32) returned for the retest performed at 6–8 weeks post initial test. For these 32 cases, 53 percent (17) had MEE at the retest as well as at the initial test. Of the 44 cases with MEE that failed the ASHA (1985) pure-tone screen excluding 500 Hz at the initial test, 89 percent (39) returned. For these 39 cases, 54 percent (21) had MEE at the retest as well as at the initial test. Thus, the percentage of cases with MEE at the initial test that also had MEE at the retest in the group that passed the initial pure-tone screen was similar to that in the group that failed the initial pure-tone screen.

Table 5 shows the test and retest means and standard deviations of the air-conduction thresholds at 250 through 4000 Hz and PTAs at

Table 4 Means and Standard Deviations of Air-Conduction Thresholds and SRTs for MEE Cases that Passed versus Failed Initial Pure-Tone Screen (excluding 500 Hz)

	Threshold (dB HL)					
Group	*250 Hz*	*500 Hz*	*1000 Hz*	*2000 Hz*	*4000 Hz*	*SRT*
Passed (N = 38)						
Mean	30.53	25.53	17.11	13.16	12.11	26.03
SD	10.19	9.85	3.41	4.71	5.77	9.36
Range	10–50	10–45	10–20	0–20	0–20	10–40
Failed (N = 44)						
Mean	39.10	36.71	35.91	32.50	30.23	39.34
SD	9.42	8.07	7.87	9.79	10.28	7.64
Range	25–60	20–55	20–55	15–50	15–50	20–55

Table 5 Test and Retest Means and Standard Deviations of Air-Conduction Thresholds and PTAs* for the MEE Group that Failed versus Passed the Initial Pure-Tone Screen (excluding 500 Hz)

	Frequency (Hz)					
Group	*250*	*500*	*1000*	*2000*	*4000*	*PTA*
Passed (N = 17)						
Test						
Mean	31.18	27.35	17.06	14.71	13.23	15.00
SD	10.08	10.48	4.35	4.83	4.31	3.64
Retest						
Mean	36.18	33.82	30.59	26.18	28.82	28.53
SD	12.06	12.57	14.67	15.96	12.44	13.35
Failed (N = 21)						
Test						
Mean	40.00	38.81	36.91	33.81	33.09	34.59
SD	10.37	8.79	9.81	12.03	13.74	10.59
Retest						
Mean	37.14	33.57	29.05	26.19	28.33	28.01
SD	10.79	10.14	10.56	11.28	11.97	9.07

*Based on 500, 1000, and 2000 Hz.

both the initial test and retest for the MEE group that passed or failed the initial ASHA (1985) pure-tone screen excluding 500 Hz. Table 6 shows the t values for the results of comparison of the mean data shown in Table 5. That is, Table 6 shows the t values for the results of comparison of the mean air-conduction thresholds and PTAs between (a) the group that passed versus failed the screen at the initial test; (b) the group that passed versus failed the screen at the retest; (c) the initial test and retest in the group that passed the initial screen; and (d) the initial test and retest in the group that failed the initial test.

Inspection of Tables 5 and 6 reveals that at the initial test, the MEE group that failed the initial pure-tone screen had significantly poorer mean air-conduction thresholds at each frequency and a significantly poorer mean PTA than the MEE group that passed the initial pure-tone screen. On the other hand, further inspection of Tables 5 and 6 also reveals that at the retest, no significant differences were obtained in mean air-conduction threshold at any frequency or PTA between the MEE group that passed and the MEE group that failed the initial pure-tone screen. Also, Tables 5 and 6 indicate that the mean air-conduction thresholds at 1000–4000 Hz and PTA were significantly worse at the retest than at the initial test in the MEE group that passed the initial test. Finally, Tables 5 and 6 show that the mean air-

Table 6 T Values for Comparison of Mean Air-Conduction Thresholds and PTAs* between Pass and Fail Ears at Initial Test, Pass and Fail Ears at Retest, Initial Test and Retest Ears that Passed Initial Test, and Initial and Retest Ears that Failed Initial Test

	Frequency (Hz)						
Group	*250*	*500*	*1000*	*2000*	*4000*	*PTA*	*df*
Initial (pass vs fail)	−2.641*	−3.667‡	−7.734‡	−6.145‡	−5.724‡	−7.273‡	36
Retest (pass vs fail)	−0.260	0.068	0.376	−0.003	0.123	0.144	36
Pass initial test (initial vs retest)	−1.250	−1.620	−3.725†	−3.461†	−6.070‡	−4.824‡	16
Fail initial test (initial vs retest)	0.890	1.614	2.305*	2.235*	1.370	2.046	20

*$p \leq .05$; †$p \leq .01$; ‡$p \leq .001$.

conduction thresholds at 1000 and 2000 Hz were significantly better at the retest than at the initial test in the MEE group that failed the initial test. Thus, at the initial test, the MEE group that failed the initial screen had significantly poorer thresholds than the MEE group that passed the initial screen, although the groups had similar thresholds at the retest. Also, from initial test to retest, the thresholds at the middle and high frequencies significantly worsened in the MEE group that passed the initial screen but significantly improved at the mid-high frequencies in the MEE group that failed the initial screen.

DISCUSSION

The sensitivity of a pure-tone screen to detection of MEE in children improved from 54 percent, when it was based on a screening level of 20 dB HL at 1000, 2000, and 4000 Hz, to 85 percent, when it was based on a screening level of 20 dB HL at 500 as well as 1000, 2000, and 4000 Hz. This suggests that a pure-tone screen for detection of MEE should include 500 Hz as well as the higher frequencies. This sensitivity for the pure-tone screen (including 500 Hz) exceeds the sensitivity for the ASHA (1990) acoustic-immittance screen (81.5%) but does not quite reach the sensitivity (90%) for the Silman et al (1992) acoustic-immittance screen in the total MEE group.

Our 15 percent miss rate for pure-tone screening (including 500 Hz) is substantially lower than the 44 percent miss rate for pure-tone screening (including 500 and 6000 Hz) reported by Melnick et al (1964). The screening levels employed by Melnick et al (1964) were essentially the same (within 1.5 dB) as in the present study at 500 and 1000 Hz and were more stringent than the present study at 2000 Hz. Possible factors accounting for the higher miss rate for the Melnick et al than this investigation include the following:

1. The sample size of the MEE group was 27 for Melnick et al compared with 82 for this investigation.
2. Determination of the presence or absence of MEE was done within 1 week following pure-tone screening in the Melnick et al investigation. In contrast, in this investigation, the diagnosis regarding MEE was determined at the same time that the pure-tone screening was performed.
3. The diagnosis of MEE was based on regular otoscopy in the Melnick et al investigation compared with pneumotoscopy/microtoscopy in this investigation.

When 250 Hz as well as 500 Hz was added to the pure-tone screen, the sensitivity of the pure-tone screen increased to 89 percent, approximating that of the Silman et al (1992) acoustic-immittance screen. Nevertheless, we suggest that 250 Hz not be included as part of the pure-tone screen as (a) the gain in test sensitivity when 250 Hz is included was small (4%); and (b) problems with earphone leakage leading to false positive results are significant at 250 Hz, particularly in mass pure-tone screens. Therefore, it is suggested that 250 Hz not be included as part of the pure-tone screen protocol.

When pure-tone screening excluding 500 Hz was done in conjunction with the ASHA (1990) acoustic-immittance screen, the sensitivity to detection of middle-ear effusion was 83 percent in this investigation. (Forty-four of the 82 ears failed the pure-tone screening and 24 of the 82 ears passed the pure-tone screening but failed the ASHA [1990] screen.) Although this sensitivity is slightly improved over that (81.5%) for the ASHA (1990) acoustic-immittance screen (Silman et al, 1992), it still does not reach the sensitivity (90%) for the Silman et al (1992) acoustic-immittance screen and is slightly less than the sensitivity of a pure-tone screen including 500 Hz. Thus, our results suggest that if personnel and equipment for acoustic-immittance screening for detection of MEE in children are unavailable or infeasible, pure-tone screening should be employed at 500–4000 Hz at the screening level of 20 dB HL, provided that ambient noise levels permit testing at these levels and frequencies. If ambient noise levels do not permit testing at 500 Hz, the Silman et al (1992) acoustic-immittance protocol should be employed in place of audiometric screening. Research is needed to investigate the sensitivity of the Silman et al (1992) acoustic-immittance screen performed without audiometric screening as compared with that of the Silman et al (1992) acoustic-immittance screen performed in conjunction with pure-tone screening.

In the real world, it is unlikely that the test environment in the schools would permit doing pure-tone screening at 500 Hz without a sound-isolated booth. In such cases, the cost of a

sound-isolated booth, audiometers, and audiometric screening personnel should be weighed against the cost of acoustic-immittance devices and the cost/availability of appropriate acoustic-immittance screen personnel. Since one of the goals of hearing screening of school-aged children is the identification of MEE, sensitive and specific procedures for identification of MEE need to be developed.

Another finding was that the highest number of significant air-bone gaps occurred at 500 Hz, although the number of large air-bone gaps exceeding 30 dB was higher at 250 Hz than at 500 Hz. This finding is consistent with the presence of a stiffness-loaded middle-ear system, which is characteristic of MEE.

In this investigation, 92 percent of our sample of 82 cases with MEE that passed the ASHA (1985) pure-tone screen (excluding 500 Hz) had significant air-bone gaps. Bluestone et al's (1979) findings reveal that 81 percent of their MEE group had significant air-bone gaps. Melnick et al (1964) reported that 44 percent of their sample of 27 cases with MEE passed pure-tone screening at 10 dB HL at 500, 1000, 2000, and 6000 Hz and at 20 dB HL at 4000 Hz (referenced to ASA-1951). Based on Melnick et al's findings, one might erroneously conclude that 44 percent of their MEE group did not have air-bone gaps at 500 through 2000 Hz as they passed pure-tone screening at 10 dB HL. Although pure-tone screening at 20 dB HL (referenced to ANSI-1969) yields essentially similar SPL values as pure-tone screening at 10 dB HL (referenced to ASA-1951), significant air-bone gaps can be detected only with the former and not with the latter screening levels, assuming that bone-conduction threshold measurement is not made below 0 dB HL. The high prevalence of significant air-bone gaps in our MEE group suggests that MEE is generally accompanied by significant air-bone gaps. In our investigation, 97 percent of the MEE group had air-bone gaps of 10 dB or more. Similarly, Bluestone et al's (1979) findings also reveal that 97 percent of their MEE group had air-bone gaps of 10 dB or more.

The mean SRT for the MEE group reflected, on average, a mild hearing impairment for speech in the group that passed the ASHA (1985) pure-tone screen (excluding 500 Hz) and a moderate hearing impairment for speech in the group that failed the ASHA (1985) pure-tone screen (excluding 500 Hz). The hearing impairment for speech was best reflected by the mean hearing threshold levels at the low frequencies (500 Hz in the MEE group that passed the pure-tone screen and 250 Hz in the MEE group that failed the pure-tone screen). Thus, the children with MEE in this investigation displayed, on average, a hearing impairment that might interfere with communication. This finding indicates that further research is needed to evaluate the assumption in the ASHA (1985) identification audiometry guidelines that persons who pass the pure-tone screening (excluding 500 Hz) do not have hearing impairments that "interfere with or have the potential for interfering with communication" (ASHA, 1985). An elevated SRT generally indicates lowered sensation levels for conversation, at least when the SRT reflects hearing sensitivity in the mid frequencies. Research is needed to evaluate whether an SRT that corresponds to the low frequencies together with normal-hearing threshold levels at 1000 Hz and higher is associated with a communication handicap.

Another finding was that 84 to 89 percent of the cases with MEE at the initial test returned for a retest, and 53 to 54 percent of these retest cases continued to show MEE. This finding suggests that a child with MEE who passes a pure-tone screen excluding 500 Hz is essentially at the same risk for longstanding (over a 6- to 8-week period) MEE as a child with MEE who fails the pure-tone screen. Approximately 11 to 16 percent of the cases with MEE at the initial test did not return for a retest, despite being counseled to do so. It is unknown whether these subjects experienced recovery or went elsewhere for continued follow-up.

The mean air-conduction thresholds significantly worsened at the mid and high frequencies from initial test to retest in the MEE group that passed the initial pure-tone screen and significantly improved at 1000 Hz and 2000 Hz from initial test to retest in the MEE group that failed the initial pure-tone screen. No significant worsening of the mean air-conduction thresholds at the low frequencies from initial test to retest was observed in the MEE group that passed the initial pure-tone screen. This suggests that the effects of MEE on hearing sensitivity began at the low frequencies (as seen at the initial test) and then spread to the mid-to-high frequencies (as seen at the retest). Similarly, no significant improvement in the mean air-conduction thresholds at the low frequencies below 1000 Hz and high frequencies above 2000 Hz from initial test to retest was observed in the MEE group that failed the initial test. This suggests that recovery from

MEE was probably at the beginning stages at the retest since improvement was observed at the mid frequencies, assuming that recovery occurs first for the mid frequencies and then for the low frequencies.

At the retest, there were no significant differences in mean air-conduction threshold at any frequency between the MEE group that passed the initial pure-tone screen and the MEE group that failed the pure-tone screen. This suggests that the group with longstanding MEE over a 6- to 8-week period that passed the initial pure-tone screen developed a hearing impairment between the initial test and retest. Similarly, the group with longstanding MEE over a 6- to 8-week period that failed the initial pure-tone screen appeared to have at least partial recovery between initial test and retest. Thus, the group with MEE at the initial test and retest that initially failed the ASHA (1985) pure-tone screen (excluding 500 Hz) was not at higher risk for potential hearing impairment than the group with MEE at the initial test and retest that initially passed the pure-tone screen.

An unavoidable limitation of this investigation was the use of pneumotoscopy/microtoscopy rather than myringotomy as the "gold standard" for diagnosing MEE. Surgical treatment of MEE is generally not performed unless the MEE persists for at least 3 months along with significant hearing loss (Jung and Ku Rhee, 1991). The subjects in our investigation were seen at the initial test and at the retest 6 weeks later. From the standpoint of timespan, the subjects did not meet the criterion for surgical treatment. Also, from the standpoint of hearing loss, the subjects did not meet the criterion for surgical treatment as many of the subjects had normal hearing threshold levels at the initial test. Even if a myringotomy had been performed after persistent (for at least 3 months) middle-ear effusion with hearing impairment, the outcome can only confirm a diagnosis at the time of the surgery; the outcome cannot confirm a diagnosis made 3 months earlier (e.g, at the initial test). Therefore, surgical confirmation of the otologic diagnosis could not have been employed as the gold standard in this investigation.

Research is needed to substantiate these findings using a larger sample. Long-term audiologic and acoustic-immittance follow-up of children with recurrent MEE is needed in order to develop a screening protocol for detection of recurrent MEE.

REFERENCES

American National Standards Institute. (1960). *Criteria for Permissible Ambient Noise during Audiometric Testing.* (ANSI S3.1-1960 R 1977). New York: ANSI.

American National Standards Institute. (1991). *Maximum Permissible Ambient Noise Levels for Audiometric Test Rooms.* (ANSI S3.1-1991). New York: ANSI.

American Speech-Language-Hearing Association. (1985). Guidelines for identification audiometry. *ASHA* 40:49–52.

American Speech-Language-Hearing Association. (1990). Guidelines for screening for hearing impairment and middle-ear disorders. *ASHA* 32(2):25–30.

Bluestone CD, Beery QC, Paradise JL. (1979). Audiometry and tympanometry in relation to middle ear effusions in children. *Laryngoscope* 83:594–603.

Jerger S, Jerger J, Mauldin L, Segal P. (1974). Studies in impedance audiometry. II. Children less than 6 years old. *Arch Otolaryngol* 99:1–9.

Jung TK, Ku Rhee C. (1991). Otolaryngologic approach to the diagnosis and management of otitis media. *Otolaryngol Clin North Am* 24(4):931–945.

Melnick W, Eagles EL, Levine HS. (1964). Evaluation of a recommended program of identification audiometry with school age children. *J Speech Hear Disord* 29:3–13.

Silman S, Silverman CA, Arick DS. (1992). Acoustic-immittance screening for detection of middle-ear effusion in children. *J Am Acad Audiol* 3:262–268.