Acoustic-Immittance Screening for Detection of Middle-Ear Effusion in Children

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Abstract

The purpose of this investigation was to evaluate the sensitivity and specificity of the following acoustic-immittance protocols and their constituent measures for detection of middle-ear effusion in children: (a) tympanometric width; (b) absent ipsilateral acoustic reflex; (c) ASHA guidelines; (d) tympanometric peak pressure; and (e) static-acoustic middle-ear admittance. The middle-ear sample was composed of 82 ears of 54 subjects ranging in age from 3 to 11 years. The control (normal-hearing, normal middle-ear) sample was composed of 53 ears of 53 subjects ranging in age from 3 to 10 years. Each subject was given a complete otolaryngologic evaluation (including pneumotoscopy and/or microtoscopy) and audiologic (including acoustic-immittance) evaluation. In the group of middle ears with normal-hearing sensitivity, the sensitivity and specificity of the ASHA guidelines were 63 percent and 79 percent, respectively. An acoustic-immittance screening protocol, based on all of the individual acoustic-immittance measures, and characterized by high sensitivity and specificity, is proposed.

Key Words: Acoustic-immittance screening, middle-ear effusion, tympanometric gradient, acoustic reflex, tympanometric peak pressure, static-acoustic admittance

The problem of developing an accurate acoustic-immittance screening protocol for detection of middle-ear effusion (MEE) in children has been the focus of extensive research (Melnick et al, 1964; Renvall et al, 1975; Paradise et al, 1976; Bluestone et al, 1979; Paradise and Smith, 1979; Tos and Poulsen, 1980; Lous, 1982; Fiellau-Nikolajsen, 1983; Roush and Tait, 1985; Margolis and Heller, 1987).

The American Speech-Language-Hearing Association (ASHA, 1979) published guidelines for acoustic-immittance screening of middle-ear (ME) function. Their criteria were based on tympanometric peak-pressure (TPP) and acoustic-reflex threshold results. Studies that employed the ASHA (1979) guidelines for acoustic-immittance screening were characterized by high false-positive rates (Lous, 1982; Roush and Tait, 1985). Because of the high false-positive rates associated with the ASHA (1979) guidelines, ASHA (1990) issued new guidelines for acoustic-immittance screening.

The ASHA (1990) acoustic-immittance screening criteria for detection of MEE in children were as follows: (a) static-acoustic ME admittance below the 90 percent range in a normative sample (with the ear-canal admittance calculated at +200 daPa), and (b) tympanometric width (TW) 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 is greater than the 95th percentile. The guidelines specified the use of an absolute acoustic-admittance device with a 226-Hz probe-tone frequency, a pump speed of 200 daPa/s, and a positive-to-negative direction of pressure change. ASHA (1990) recommended that if other measurement parameters are employed, appropriate normative data should be used.
No published data on the sensitivity and specificity of the ASHA (1990) acoustic-immittance guidelines for detection of MEE in children are available. Also, no published studies have compared the sensitivity and specificity of the individual ASHA (1990) constituent measures (i.e., tympanometric gradient and static-acoustic ME admittance) with those for the ASHA (1990) protocol.

As mentioned earlier, some investigators (Lous, 1982; Roush and Tait, 1985) reported that the ASHA (1979) protocol, based on the TPP and acoustic-reflex measures, was associated with high false-positive rates. Factors relating to the effects of maturation and minor ME abnormalities on the acoustic reflex may have contributed to the high false-positive rates associated with the ASHA (1979) protocol.

For example, the effect of maturation on the acoustic-reflex threshold was not considered when the acoustic-reflex criterion was established in the ASHA (1979) protocol. Several investigators have shown that the mean contralateral acoustic-reflex thresholds decrease as age increases from 1 to 12 years of age (Robertson et al, 1968; Jerger et al, 1974; Osterhammel and Osterhammel, 1979). The results of these investigations suggest that many normal-hearing children have contralateral acoustic-reflex thresholds for tonal activators and the 220-Hz probe tone that exceed the criterion levels proposed in the ASHA (1979) guidelines. These findings also suggest that the possibility of a maturation effect for the ipsilateral as well as the contralateral acoustic reflex cannot be ruled out. If there is a maturation effect for the ipsilateral acoustic reflex (IAR) or the intersubject variability for the IAR threshold is large, then the ASHA (1979) screening level of 105 dB SPL may be too low.

The effect of minor ME abnormalities on the acoustic-reflex threshold also was not considered when the acoustic-reflex criterion was established in the ASHA (1979) protocol. Hall and Weaver (1979) reported slightly higher mean contralateral acoustic-reflex thresholds in children without MEE who had Type A tympanograms than in children without MEE with Type A tympanograms. Their 95th percentile contralateral acoustic-reflex threshold for the 1000-Hz tonal activator was 107 dB HL as compared with the ASHA (1979) screening level of 100 dB HL. This finding suggests that many normal-hearing children without MEE but with only minor ME abnormalities such as a Type A tympanogram have contralateral and ipsilateral acoustic-reflex thresholds higher than the criterion levels set by ASHA (1979).

Other reasons for the high false-positive rates associated with the ASHA (1979) guidelines for acoustic-immittance screening include the following:

1. The status of the earphone ear affects whether a contralateral acoustic reflex will be monitored in the probe ear.
2. Collapsed ear canals are associated with absent or elevated contralateral acoustic reflexes.
3. The ASHA (1979) cutoff level of 105 dB SPL for the ipsilateral acoustic reflex is excessively low. This level was selected by ASHA (1979) to avoid possible artifacts and because commercial instrumentation available then had low maximum output intensities for ipsilateral acoustic-reflex assessment.

Perhaps the predictive accuracy of a protocol based on the use of the traditional acoustic-immittance measures—acoustic-reflex in conjunction with the TPP—may be enhanced by the use of an acoustic-reflex measurement technique and criterion level that takes into account the effects of maturation and minimal eardrum abnormalities and the advantage of ipsilateral over contralateral stimulation. That is, the acoustic-reflex should be measured for ipsilateral stimulation and the presence versus absence of the acoustic reflex should be determined at 110 dB HL using an acoustic-immittance device with a multiplexing circuit to control for additive and subtractive artifacts.

The TPP criterion associated with MEE, following several investigators (Jerger, 1970; Jerger et al, 1972, 1974; Fiellau-Nikolajsen, 1983) should be ≤−100 daPa. If these substantive revisions of the traditional acoustic-reflex measures do enhance the predictive accuracy of an acoustic-immittance protocol based on the traditional acoustic-reflex and TPP measures, then research is needed to evaluate the sensitivity and specificity of these individual, constituent measures and a protocol based on these traditional measures. Research would also be needed to compare the sensitivity and specificity of this "sensitized" traditional protocol with those for the ASHA (1990) protocol.

The purpose of this study was to evaluate the sensitivity and specificity of the following acoustic-immittance protocols and their constituent measures for detection of MEE in chil-
METHOD

Subjects

The MEE sample was composed of 82 ears of 54 subjects (30 boys and 24 girls) ranging in age from 3 to 11 years (X = 6.3 years). (All ears from these 54 subjects were included in the study if they had MEE.) The control (normal-hearing, normal ME) sample was composed of 53 ears of 53 subjects (34 boys and 19 girls) ranging in age from 3 to 10 years (X = 6.1 years). Subjects were drawn from one otolaryngologic clinic in New York City.

MEE was established based on the results of pneumotoscopy and/or microtoscopy performed by an otolaryngologist with more than 10 years of otolaryngologic experience. The experimental and control subjects were referred to the otolaryngologist because of one or more of the following reasons: (a) the child failed the school hearing-screening test; (b) audiologic and otologic examinations were required by the New York City Board of Education prior to entering school; or (c) parent suspicion of ME problems. Experimental and control 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.

The criterion levels for the TW and static-acoustic ME admittance employed by ASHA (1990) were based on interim norms. ASHA (1990) suggested that if measurement parameters other than those in the guidelines were to be used, then criterion levels for the TW and the static-acoustic ME admittance should be based on the 90 percent range in appropriate normative data. For this study, pump speed was chosen to be 50 daPa/s rather than the 200 daPa/s employed by ASHA (1990). Therefore, normative TW and static-acoustic ME admittance were obtained based on 42 ears of 42 normal-hearing children between 3 and 10 years of age meeting the following criteria for normalcy: (a) air-conduction (AC) thresholds not exceeding 10 dB HL at 250 to 8000 Hz and air-bone gaps not exceeding 10 dB; and (b) negative findings for a pneumotoscopic and/or microtoscopic examination performed by an otolaryngologist.

Instrumentation

Audiologic assessment was carried out in a single-room sound suite meeting ANSI S3.1 (1960, R1977) standards for audiometric environments.

Acoustic-immittance measurements were accomplished using the Grason-Stadler 1723 middle-ear analyzer with a multiplexing circuit to control for additive and subtractive artifacts during ipsilateral acoustic-reflex assessment. The maximum output for the ipsilateral acoustic-reflex activator at 1000 Hz was 110 dB HL. The acoustic-immittance device was calibrated as specified by the manufacturer's manual. Acoustic-immittance meter linearity was calibrated using a microsyringe (Gilmont Model S-1200).

The activating signals for ipsilateral acoustic-reflex testing were calibrated with a sound-level meter (B & K 4150), 2-cc coupler, and frequency counter (Allison 402). All SPL values were the total rms values of the signal and are in dB re: 2 x 10^-5 Pa.

Procedure

Data were collected prospectively. Each subject was seen first for a complete otolaryngologic evaluation including (a) examination of the oropharynx, nasopharynx, larynx, neck, ears, and nose, and (b) pneumotoscopy and/or microtoscopy and a complete audiologic assessment including (a) pure-tone air- and bone-conduction thresholds, (b) speech-recognition threshold and suprathreshold monosyllabic word-recognition assessment whenever possible, (c) static-acoustic ME admittance, (d) acoustic-admittance pressure function, and (e) IAR testing for the 1000-Hz tonal activator.

Following ASHA (1990), static-acoustic ME admittance was calculated by subtracting an ear-canal admittance at +200 daPa from the peak admittance and the acoustic-admittance pressure function was obtained using a positive-to-negative direction of pressure change. The 226-Hz probe tone was employed for all acoustic-immittance assessment.
Acoustic-immittance change was visually monitored on the meter of the acoustic-immittance device for the determination of the presence versus absence of the IAR. The criterion for a response was an observation of needle deflection on the meter that could be differentiated from background activity and was time-locked to the stimulus presentation.

A blind design was employed whereby the otolaryngologic diagnosis was made without knowledge of the audiologic findings and the audiologic testing was done without knowledge of the otolaryngologic findings.

The following measurements were analyzed from each subject: (a) ASHA (1990) TW, (b) static-acoustic ME admittance, (c) TPP, and (d) presence versus absence of the IAR at 110 dB HL.

RESULTS

The 90 percent range for the ASHA (1990) TW in our normative sample was 55 to 180 daPa. Therefore, for this study, TW greater than 180 daPa was considered to be abnormal. The 90 percent range for the static-acoustic ME admittance in our normative sample was 0.35 to 1.25 mhmhos. Therefore, for this study, static-acoustic ME admittance less than 0.35 mhmho was considered to be abnormal.

Table 1 shows the pass and fail rates for the ASHA (1990) TW, static-acoustic ME admittance, IAR, and TPP for the total MEE group (N = 82); the MEE subgroup with AC thresholds exceeding 20 dB HL at 1000, 2000, and/or 4000 Hz (N = 44); the MEE subgroup with AC thresholds not exceeding 20 dB HL at 1000, 2000, and/or 4000 Hz (N = 38); and the normal, control group (N = 53).

In the total MEE group, sensitivity was highest (93%) for the IAR and was lowest (61%) for the static-acoustic ME admittance. The TPP measure also had a high sensitivity (89%). In the MEE subgroup with AC thresholds exceeding 20 dB HL at 1000, 2000, and 4000 Hz, the sensitivity ranged from 86 percent to 98 percent across all the measures; it was highest for the TPP and was lowest for the static-acoustic ME admittance. In the MEE subgroup with AC thresholds not exceeding 20 dB HL at 1000, 2000, and 4000 Hz, the sensitivity exceeded 90 percent only for the IAR and the sensitivity for the IAR greatly exceeded that of the other measures; the sensitivity was extremely low (32%) for the static-acoustic ME admittance. In the control group, specificity was highest (84%) for the IAR; specificity for the TPP was nearly as high as that for the IAR. In this group, specificity was lowest (77%) for the static-acoustic ME admittance. In summary, the measure with the highest sensitivity in the normal-hearing, MEE subgroup and the highest specificity was the IAR.

Table 2 shows the pass and fail rates for the following protocols: (a) ASHA (1990) protocol, (b) sensitized protocol based on the TPP and IAR, (c) protocol based on failing the ASHA (1990) guidelines as well as having an absent IAR, and (d) proposed protocol based on failing the sensitized protocol or, on the other hand, failing the ASHA (1990) guidelines as well as having an absent IAR.

### Table 1 Results for ASHA (1990) TW, Static-Acoustic ME Admittance, IAR, and TPP Measures in MEE and in Control Ears

<table>
<thead>
<tr>
<th>Group</th>
<th>ASHA (1990) TW</th>
<th>Static-Acoustic ME Admittance</th>
<th>IAR</th>
<th>TPP</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>P</td>
<td>F</td>
<td>P</td>
<td>F</td>
</tr>
<tr>
<td>MEE (N = 82)</td>
<td>23</td>
<td>77</td>
<td>39</td>
<td>61</td>
</tr>
<tr>
<td>MEE having 1kHz, 2kHz, and/or 4kHz &gt; 20 dB HL (N = 44)</td>
<td>7</td>
<td>93</td>
<td>14</td>
<td>86</td>
</tr>
<tr>
<td>MEE having 1kHz, 2kHz, and 4kHz ≤ 20 dB HL (N = 38)</td>
<td>42</td>
<td>58</td>
<td>68</td>
<td>32</td>
</tr>
<tr>
<td>ME without effusion having normal-hearing thresholds (N = 53)</td>
<td>81</td>
<td>19</td>
<td>77</td>
<td>23</td>
</tr>
</tbody>
</table>

P = pass rate (%); F = failure rate (%).

* > 180 daPa (pump speed 50 daPa/s); † < 0.35 mhmhos (pump speed 50 daPa/s); ‡ Absent at 110 dB HL at 1000 Hz; § ≤ -100 daPa.
Table 2  Results for Various Testing Protocols in MEE and in Control Ears

<table>
<thead>
<tr>
<th>Group</th>
<th>ASHA (1990)</th>
<th>TPP + IAR*</th>
<th>ASHA (1990) + IAR†</th>
<th>[ASHA (1990) + IAR] or [TPP + IAR]†</th>
</tr>
</thead>
<tbody>
<tr>
<td>MEE (N = 82)</td>
<td>P</td>
<td>F</td>
<td>P</td>
<td>F</td>
</tr>
<tr>
<td></td>
<td>19.5</td>
<td>81.5</td>
<td>16.0</td>
<td>84.0</td>
</tr>
<tr>
<td>MEE having 1kHz, 2kHz, and/or 4kHz &gt; 20 dB HL (N = 44)</td>
<td>7.0</td>
<td>93.0</td>
<td>9.0</td>
<td>91.0</td>
</tr>
<tr>
<td>MEE having 1kHz, 2kHz, and 4kHz ≤ 20 dB HL (N = 38)</td>
<td>37.0</td>
<td>63.0</td>
<td>21.0</td>
<td>79.0</td>
</tr>
<tr>
<td>ME without effusion having normal-hearing thresholds (N = 53)</td>
<td>79.0</td>
<td>21.0</td>
<td>92.0</td>
<td>8.0</td>
</tr>
</tbody>
</table>

P = pass rate (%); F = failure rate (%).

*Sensitized traditional protocol; † Modified ASHA (1990) protocol; † Proposed protocol.

In Table 2, the pass and fail rates for these protocols are shown for the total MEE group, MEE subgroup with AC thresholds exceeding 20 dB HL at 1000, 2000, and/or 4000 Hz, MEE subgroup with AC thresholds not exceeding 20 dB HL at 1000, 2000, and 4000 Hz, and control group. Graphic comparisons of the overall sensitivity and specificity of each protocol for the total MEE group, for the normal-hearing MEE subgroup, and for the control group are provided in Figures 1 and 2.

Inspection of Table 2 and Figure 1 reveals that in the total MEE group, sensitivity reached 90 percent only for the proposed protocol; sensitivity was moderately high for the ASHA (1990) protocol and sensitized traditional protocol. Sensitivity was lowest (75.5%) for the protocol based on the ASHA (1990) guidelines and IAR. In the MEE subgroup with AC thresholds exceeding 20 dB HL at 1000, 2000, and/or 4000 Hz, sensitivity was very high (88% or more) for all protocols. Inspection of Table 2 and Figure 2 reveals that in the MEE subgroup with AC thresholds not exceeding 20 dB HL at 1000, 2000, and 4000 Hz, sensitivity reached approximately 90 percent only for the proposed protocol and was only 63 percent for the ASHA (1990) protocol; the sensitivity for the other protocols was also low, ranging between 58 percent and 79 percent. In the control group, specificity exceeded 90 percent for all protocols except the ASHA (1990) protocol; the specificity was low (79%) for the ASHA (1990) protocol. In summary, the protocol with the best combination of sensitivity (based on the normal-hearing, MEE subgroup) and specificity was the proposed protocol. Although specificity was slightly higher for the protocol based on both the ASHA (1990) guidelines and IAR than for the proposed protocol, the former protocol had markedly lower sensitivity than the latter.

Figure 1  Specificity and sensitivity comparison of the tested protocols: new proposal [ASHA (1990) + IAR] or [TPP + IAR], modified ASHA (1990) [ASHA (1990) + IAR], sensitized traditional (TPP + IAR), and ASHA (1990), in the total MEE group and control group.

Figure 2  Specificity and sensitivity comparison of the tested protocols: new proposal [ASHA (1990) + IAR] or [TPP + IAR], modified ASHA (1990) [ASHA (1990) + IAR], sensitized traditional (TPP + IAR), and ASHA (1990), in the normal-hearing MEE subgroup and control group.
DISCUSSION

The purpose of acoustic-imittance screening in children is to detect ME problems, primarily MEE. The results of this study showed that the ASHA (1990) TW and static-acoustic ME admittance, the constituent measures of the ASHA (1990) protocol, are characterized by very low sensitivity (58% and 32%, respectively) in the normal-hearing, MEE subgroup and by only fair specificity (81% and 77%), respectively. In this MEE subgroup, the sensitivity of the traditional acoustic-imittance measures, TPP and IAR, was markedly higher than that for the constituent measures of the ASHA (1990) protocol. The specificity of these traditional acoustic-imittance measures, however, was only slightly higher than that for the individual, constituent measures of the ASHA (1990) protocol. Although the IAR was characterized by very high sensitivity (95%), its specificity did not reach 90 percent. In fact, the specificity did not reach 90 percent for any of the individual acoustic-imittance measures. This suggests that mass acoustic-imittance screening with any single acoustic-imittance measure to detect MEE may be associated with an unacceptably high false-positive rate.

Our proposed protocol is based on either (a) failing the ASHA (1990) guidelines and having an absent IAR, or (b) obtaining a significantly negative TPP and having an absent IAR. Thus, the proposed protocol reflects a combination of all four acoustic-imittance measures with increased weight given to the IAR. Part (a) of the proposed protocol will fail to detect MEE in ears with abnormal TPP and absent IAR together with normal TW and static-acoustic ME admittance. Part (b) of the proposed protocol will fail to detect MEE in ears with abnormal TW or static-acoustic ME admittance together with absent IAR but normal TPP. Thus, ears with MEE undetected by part (a) of the proposed protocol will be detected by part (b) of the proposed protocol and vice-versa.

The results of this study showed that the ASHA (1990) protocol is characterized by very low sensitivity (63%) in the MEE subgroup with normal-hearing sensitivity and low specificity (79%). These findings suggest that mass acoustic-imittance screenings based on the ASHA (1990) protocol for detection of MEE in children may be characterized by unacceptably high false-positive rates as well as low hit rates.

In contrast, the sensitivity of the proposed protocol was approximately 90 percent in the normal-hearing MEE subgroup and markedly exceeded that of the ASHA (1990) protocol. Similarly, the specificity of the proposed protocol was more than 90 percent and markedly exceeded that of the ASHA (1990) protocol. In fact, the false-positive rate of the proposed protocol was approximately one third of that for the ASHA (1990) protocol. These findings suggest that the best acoustic-imittance screening protocol is that based on a combination of the TW, static-acoustic ME admittance, TPP, and IAR and that emphasizes the IAR as obtained in this study; that is, the IAR should be obtained using a criterion controlling for maturation and minimal eardrum abnormalities and using an acoustic-imittance device that uses a multiplexing circuit to control for artifacts. These findings also corroborate Jerger's (1970) conclusion that "individually, each measure has serious limitation. In combination, however, they yield patterns of great diagnostic value" (p. 322).

The results of this investigation also showed that in the MEE subgroup with hearing impairment, the sensitivity of the individual acoustic-imittance measures and protocols was high, ranging between 86 percent and 98 percent. This MEE subgroup had AC thresholds exceeding 20 dB HL at 1000, 2000, and/or 4000 Hz. This finding suggests that regardless of the acoustic-imittance individual measure or protocol employed, these MEE ears with hearing impairment would have been detected and referred for follow-up if pure-tone screening based on the ASHA (1985) guidelines for identification audiometry had been carried out. Therefore, it is for the MEE subgroup with normal-hearing AC thresholds at 1000, 2000, and 4000 Hz that acoustic-imittance screening for the purpose of detection of MEE is most important; this MEE subgroup would not have been referred for audiologic or medical follow-up based solely on the results of a pure-tone hearing screening conducted according to the ASHA (1985) guidelines for identification audiometry. Note that of the total MEE group, nearly half (46%) had normal-hearing threshold levels at 1000, 2000, and 4000 Hz. This suggests that nearly half of this total MEE group would have passed a pure-tone hearing screening based on the ASHA (1985) guidelines for identification audiometry.

We recommend that for acoustic-imittance screening, the presence versus absence of the IAR should first be evaluated at 100 dB HL; if the IAR is absent at this level, it should then be evaluated at 110 dB HL.
Further research is needed to substantiate these findings.

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REFERENCES


