Solving Audiometric Masking Dilemmas With an Insert Masker

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Acoustic isolation between ears is generally only 45 to 65 dB with standard audiometric earphones, depending on stimulus frequency, earphone seal, and subject head dimensions. Assuming a good earphone seal, interaural attention (IA) is not limited by air conduction transmission, but by the level at which sound is transmitted to the opposite ear by head vibration. Limited IA is clinically relevant in the case of "masking dilemma" (Fig 1), where the masking necessary to isolate the two ears cannot be presented to the non-test ear without risking crossover to the test ear canal. The overmasking that occurs when the masker intensity exceeds the IA plus the real bone threshold of the test ear leads to an erroneous estimate of the amount of sensorineural hearing loss.

Masking dilemmas are encountered in patients with significant bilateral conductive hearing loss, for whom appropriate case management and surgical candidacy are often dependent on the amount of estimated cochlear reserve. In such cases, we can now increase IA sufficiently to obtain accurate bone conduction thresholds by presenting masking through the type of insert earphones shown in Fig 2.

We know from the work of Zwislocki (among others) that there are ways of increasing IA over that afforded by standard earphones. He varied measurement methods and coupler systems (earplug in bony or cartilaginous external auditory meatus, small rubber earphone cushion, doughnut cushion), and showed that the amount of IA was inversely related to the surface areas exposed to acoustic or mechanical force. Inserting a perforated earplug in the ear canal rather than covering the ear with a standard cushion reduces the vibrated area, resulting in a decreased bone-conducted signal and increased IA, especially in the 250-1,000-Hz range. When sound radiation around the head and the effective vibrating surface were minimized, Zwislocki obtained IA values in excess of 90 dB at 2,000 Hz and below.

Few clinical data have been published on the use of insert devices for audiometric masking. As early as 1952, Littler et al reported IA values of 70 to 80 dB with an insert device and recommended that inserts be used clinically for masking purposes. These results were replicated by Feldman, who further reported IA values greater than 90 dB for one patient. Studebaker obtained an average of only 12.7 dB of additional IA with his insert, compared with standard earphones, and attributed the difference to poor device design that allowed both sound radiation around the head and a larger effective vibrating surface for bone conduction.

Despite the increased masker isolate-
With an insert earphone demonstrated by these researchers, few audiometers come equipped with such a device. For those audiometers that do have insert earphones, there are no data published on their relative masking efficiency. In the present study, we measured the amount of IA obtained with four different insert devices at three frequencies. Two devices were homemade and two are commercially available. In addition, we explored the efficacy of one of the devices in determining bone conduction thresholds in a group of patients with significant conductive or mixed hearing losses.

SUBJECTS AND METHODS

The four insert devices (Fig 2) were as follows: (1) an adapted metal shank portion of an acoustic immittance probe assembly, snapped onto the transducer and fitted with a standard impedance probe tip (device 1); (2) a soft plastic ear nubbin fitted around the transducer—the standard insert device available on several commercially available audiometers (device 2); (3) a piece of tubing inserted into device 1 between the metal shank and probe tip, separating them by 1.0 cm (device 3); and (4) the ER-3 insert earphone (device 4). The frequency response characteristics in a 2-cc coupler of the Stanton button-style hearing aid transducer, used for the first three devices, and for the ER-3 are shown in Fig 3. When masking with these transducers, it is important to match the impedance to the output impedance of the audiometer to ensure maximum signal output at each test frequency. In a pilot study with ten normal listeners, masker linearity at 500, 1,000, and 2,000 Hz was checked by mixing the test tone and narrow-band noise centered at the tone frequency in the same earphone and obtaining tone thresholds at three masker levels (30, 50, and 70 dB SL). The results are shown in Fig 4.

To determine whether the insert maskers provided additional acoustical isolation between ears, IA was measured in 22 normal hearing ears under two conditions: (1) with a TDH 49 phone in an MX41AR cushion and (2) with each insert masker. The procedure for measuring IA was adapted from procedures described by Sanders' and Wegel and Lane. The experimental subject's thresholds were first obtained for tones in quiet. Next, the tone and narrow-band noise at a 30-dB masker level were mixed into the same earphone and the shift in tone threshold was determined. Tone threshold was then remeasured with the noise presented contralaterally. Given the amount of ipsilateral threshold shift with 30 dB of masking at a frequency, IA was designated as the additional amount of contralateral noise in decibels required to shift tone threshold by an equal amount. Values were extrapolated in those cases where IA was so large that contralateral noise could not shift threshold by an equivalent amount. In pilot work, an additional control test was performed on a monaurally deaf patient by comparing the contralateral threshold levels of narrow-band noise presented through device 1 to the deafened ear.

We also tested masked bone conduction with the device 1 semi-insert masker in 22 patients (32 ears) with air-bone gaps of 30 dB or greater in the 500- to 2,000-Hz range. Average audiometric thresholds and conductive components are shown in Table 1 for all patients. Bone conduction masking was performed by initially presenting noise at a minimum effective masking level, as defined by Lidén et al. By their formula, this level equals the unmasked bone conduction threshold plus the air-bone gap in the masked ear. The bone conduction threshold was noted in this condition and masking was then increased.
in 5-dB steps, using a plateau masking method in which bone conduction threshold was reassessed for each masking increment until a threshold “plateau” was reached where additional masking increments did not change the threshold. Masking was then increased further to determine the level at which masking occurred, as denoted by resumption of bone conduction threshold shifts. The lower and upper noise levels of the plateau were designated as minimum and maximum masking levels. Interaural attenuation was calculated as the difference between the maximum masking level and the masked bone conduction threshold at each test frequency.

**RESULTS**

Interaural attenuation results for the four insert devices and for TDH-49 phones are shown in Fig 5, and statistical comparisons between insert devices are shown in Table 2. All of the insert devices significantly improved IA compared with the TDH-49 earphones at 500 and 1,000 Hz; however, only devices 3 and 4 had statistically superior IA at 2,000 Hz compared with TDH-49 performance ($P < .001$). Device 4 provided the best IA overall (16 to 30 dB), and four subjects had IAs of 85 to 95 dB with this device. Devices 1, 2, and 4 were frequency dependent, providing more than 10 dB greater IA at low than high frequencies, while device 3 was not frequency dependent and therefore provided as much IA as device 4 at 1,000 and 2,000 Hz.

The superiority of device 4 is due to the large distance separating the transducer and the ear insert, effectively minimizing the vibrating surface for bone conduction. Conversely, the comparatively poor performance of device 1 is due to the direct coupling of the metal shank to the ear canal, resulting in an effective increase in the vibrating surface. To a lesser extent, the direct coupling problem also occurred with device 3: the 1-cm tubing separating the metal shank and ear tip was too short to reduce transducer vibration sufficiently.

The pattern of frequency effects observed with devices 1, 2, and 4 is

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**Table 1.**—Average Thresholds of Hearing-Impaired Subjects (32 Ears) for Air Conduction and Bone Conduction Signals, and Average Air-Bone Gaps

<table>
<thead>
<tr>
<th>Frequency, Hz</th>
<th>500</th>
<th>1,000</th>
<th>2,000</th>
<th>4,000</th>
</tr>
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<tr>
<td><strong>Air conduction, dB</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>58.4</td>
<td>57.7</td>
<td>55.8</td>
<td>63.4</td>
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<tr>
<td>SD</td>
<td>22.0</td>
<td>16.5</td>
<td>20.2</td>
<td>25.8</td>
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<tr>
<td><strong>Bone conduction, dB</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Mean</td>
<td>18.9</td>
<td>20.0</td>
<td>25.2</td>
<td>29.0</td>
</tr>
<tr>
<td>SD</td>
<td>12.2</td>
<td>16.6</td>
<td>19.1</td>
<td>20.7</td>
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<tr>
<td><strong>Air-bone gaps, dB</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>39.5</td>
<td>38.1</td>
<td>30.8</td>
<td>35.5</td>
</tr>
<tr>
<td>SD</td>
<td>13.8</td>
<td>16.1</td>
<td>14.4</td>
<td>15.8</td>
</tr>
</tbody>
</table>

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**Table 2.**—Paired Comparison t Scores for Four Insert Masker Interaural Attention Values at Different Frequencies

<table>
<thead>
<tr>
<th>Devices</th>
<th>500</th>
<th>1,000</th>
<th>2,000</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 X 2</td>
<td>-1.8</td>
<td>-0.15</td>
<td>0.46</td>
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<td>1 X 3</td>
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<td>-5.70t</td>
<td>-8.50t</td>
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<td>1 X 4</td>
<td>-7.11ft</td>
<td>-11.14t</td>
<td>-7.93t</td>
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<tr>
<td>2 X 3</td>
<td>-1.09</td>
<td>-4.16t</td>
<td>-8.43t</td>
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<tr>
<td>2 X 4</td>
<td>-6.86t</td>
<td>-5.46t</td>
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</tr>
<tr>
<td>3 X 4</td>
<td>-6.35t</td>
<td>-2.11t</td>
<td>1.44t</td>
</tr>
</tbody>
</table>

* Negative values occur when second device of pair had larger interaural attention value ($df = 21$).

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Fig 3.—Frequency response characteristics of Stanton button transducer used in devices 1, 2, and 3 (top), and of ER-3 (bottom). Frequency responses were obtained by presenting broad-band noise from audiometer (Saico SC6) into transducer and measuring output in 2-cc coupler. One-third octave band analysis of output was performed on hearing aid analyzer.

Fig 4.—Effective ipsilateral masking for 500-, 1,000- and 2,000-Hz tones at 30-, 50-, and 70-dB sensation level narrow-band noise levels. Results are average for ten pilot subjects.

Fig 5.—Interaural attenuation values for four insert devices and TDH49 earphone (triangle). Average and SD shown (N = 22). Devices designated as follows: 1, open circle; 2, solid circle; 3, open square; and 4, solid square.

Fig 6.—Masking dilemma unsolved by insert masker: Maximum masking available is insufficient due to profound air conduction sensitivity loss. Circles indicate air conduction in right ear; X, left ear; wedges, bone conduction.
similar to that found by Zwislocki for a nonradiating, mechanically isolated probe in the cartilaginous portion of the ear canal. The absolute values of IA are less than those proposed by Zwislocki, due to device-dependent differences in effective vibrating surface. In the case of device 4, IA could probably have been increased further if a perforated earplug was substituted for the impedance probe tip. Frequency-specific differences in acoustic radiation of devices 1, 2, and 4 were also noted, although the contribution of this effect to IA was probably minimal. With the tone or masking level at 500 Hz set just below detection level for an observer standing next to the subject, it became easily detectable and then increased in loudness when the frequency was changed to 1,000 and 2,000 Hz, respectively. This effect was attributed to acoustic radiation since no frequency effect was observed for either tone or noise thresholds. The effect did not occur with device 3.

Interaural attenuation values for device 1 in the monaurally deaf subject at 500, 1,000, and 2,000 Hz were greater by 25, 15, and 5 dB, respectively, compared with measurements obtained with the standard earphone. For this subject, the relative increase in IA with this device was better than average at 500 Hz and similar to average values at 1,000 and 2,000 Hz.

Even with device 1, which was one of the poorest insert devices, average IA for the 32 hearing-impaired ears ranged from 57 to 71 dB. These values were in good agreement with the normative data for device 1 and were significantly better than would be expected and standard masking equipment. The IA calculations in hearing-impaired subjects are conservative and have increased variance compared with normative data, as some of the patients with mixed losses did not show bone conduction threshold shifts even at maximum effective masking levels (100 dB HL).

With the standard earphone, over-masking was a significant risk at most test frequencies in our hearing-impaired subjects. However, using even the poorer, homemade insert device raised IA sufficiently so that cochlear reserve could be accurately measured in each ear in almost all cases.

**COMMENT**

Even though the use of an insert masker decreases the number of potential problems, it will not solve all masking dilemmas. An example is shown in Fig 6, where the air conduction loss is so great that maximum masking levels are inadequate. In such patients, assessment of middle ear status by stimulation of the nonacoustic middle ear muscle reflex is recommended.

One other precaution that must be observed is that the tip of the insert masker must be firmly coupled in the canal. Whereas in normal-hearing subjects the large airborne leakage from a poorly coupled masker results in unwanted masking of the test ear and, therefore, decreased IA values, this is not the case with bilaterally hearing-impaired subjects. In one of our hearing-impaired patients with very small and tortuous canals, the insert masking coupling was very poor, but airborne leakage levels were below the subject's air conduction thresholds. The result was little if any masking, thereby producing inflated and erroneous IA values at all frequencies and a potential underestimation of the amount of sensorineural hearing loss in the test ear. This is especially important when using device 2, where adequate coupling of the plastic nubbin was frequently a problem. It is less of a problem when the device is coupled to the canal with an immittance probe tip, since the ear canal seal can be easily checked on a standard acoustic immittance meter.

In summary, our results indicate that an insert masker coupling system can dramatically reduce masking dilemma problems if used carefully and appropriately. Use of an inexpensive homemade insert masker increases IA by at least 10 to 20 dB and use of the commercially available ER-3 further increases IA. Both approaches allow extended assessment of cochlear reserve and better treatment planning in most hearing-impaired listeners.

Etytomic Research provided ER-3 earphones free for this study.

**References**