Aging and Middle Ear Resonance

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Abstract

Tympanograms for probes ranging from 250 through 2000 Hz were evaluated for 467 older adults. Measures of middle ear resonant frequency were compared across age groups (48-59, 60-69, 70-79, 80-90 years) and gender. No significant age group trends were observed for middle ear resonant frequency. Middle ear resonant frequencies were significantly higher for older women than for older men, but the differences were small.

Key Words: Admittance, aging, immittance, middle ear, presbyacusis, resonance, tympanometry

Earlier tympanometric studies of changes in middle ear function with age in older adults have produced conflicting reports. The results of some investigations (e.g., Jerger et al, 1972; Blood and Greenberg, 1977; Hall, 1979) indicated lower compensated acoustic admittance values for older adults, consistent with stiffening of the middle ear transmission system, and the results from other studies (e.g., Nerbonne et al, 1978; Osterhammel and Osterhammel, 1979; Thompson et al, 1979; Wilson, 1981) suggested little or no change in acoustic admittance measures with advancing age. A limitation in most of these earlier studies was the small number of participants examined. In an effort to resolve these equivocal findings from earlier studies, the issue of changes in middle ear function with advancing age was recently re-evaluated based on tympanometric data for a large sample of older adults (Wiley et al, 1996). Specifically, peak compensated static acoustic admittance (Peak $Y_{tm}$) at a probe frequency of 226 Hz was evaluated for age and gender effects in 1240 adults ranging in age from 48 to 90 years. Relative to published data for young adults, Peak $Y_{tm}$ values for older adults extended to lower admittance values. The authors noted, however, that the observed differences in the distributions of Peak $Y_{tm}$ values for older and younger adults, although statistically significant, were small. Mean Peak $Y_{tm}$ values did not differ for younger and older adults. Within the same analysis, there were significant differences in mean Peak $Y_{tm}$ values for men and women; men evidenced higher Peak $Y_{tm}$ values than those observed for women.

The vast majority of the acoustic immittance studies in aging, including the one just reviewed, have been restricted to tympanometric measures for a single, low-frequency probe (typically 220 or 226 Hz). Although tympanometry using a low-frequency probe is effective in identifying some disorders of the middle ear system, such as middle ear effusion, it is limited in its sensitivity to disorders of the ossicular chain (Lilly, 1984; Colletti et al, 1997). Tympanometric changes in middle ear characteristics due to ossicular abnormalities are more distinctive for higher probe frequencies that approximate the resonant frequency of the middle ear (Shanks and Shelton, 1991). Accordingly, restricting tympanometric measures to a single, low-frequency probe may limit the sensitivity of derived compensated acoustic-immittance measures in observing aging effects. Indeed, this restriction may account, at least in part, for the equivocal reports and large variability observed across earlier investigations.

In spite of this limitation for tympanometric measures obtained with a single, low-frequency probe, there are few tympanometric data
available in older adults for multiple and higher probe frequencies that enable estimation of changes in middle ear function with age. Holte's report (1996) in male veterans is an exception. Holte reported multifrequency tympanometry findings and estimates of middle ear resonant frequency in 136 men ranging in age from 20 through 90 years. Based on her tympanometric findings, Holte reported no significant changes in middle ear resonant frequency with advancing age.

The present study provides middle ear resonance measures in a larger sample of older adults, including both men and women. The issue of gender is important because tympanometric measures differ for both younger and older men and women (Wiley et al, 1996; Roup et al, 1998). The primary interest in the present study was delineation of any functional correlates of the earlier reported anatomic and physiologic alterations in the middle ear transmission system with age. If multifrequency tympanometry indeed offers a more sensitive evaluation of the middle ear ossicular system than tympanometric measures for a low-frequency probe, multifrequency tympanometry and estimates of middle ear resonance also may offer a more sensitive means of evaluating aging effects on the middle ear transmission system. Accordingly, the purpose of the present study was to evaluate differences in middle ear resonance with age and gender in older adults.

METHOD

Subjects

Data in this report are based on 404 participants in the Epidemiology of Hearing Loss Study (EHLS) who were examined between May 1994 and July 1995. Of the 1055 participants eligible for multifrequency tympanometry, data were not obtained on 185 due to the following reasons: presence of excessive cerumen in the ear canal at the time of examination (76), participant refusal or fatigue (53), lack of time available on the day of examination (48), or equipment failure (8). Multifrequency tympanometry data also were not obtained for another 403 participants because an adequate seal could not be obtained or maintained for all or some of the probe frequencies using the acoustic immittance probe unit supplied with the instrument. These seal failures are discussed further in the next section (Procedures). Accordingly, multifrequency tympanometry was attempted with 467 participants. Finally, excluded from analyses were data for participants (63) who evidenced abnormal middle ear function based on otoscopy or screening tympanometry (Wiley et al, 1996), had an air–bone gap ≥15 dB based on tone audiometry, or had no middle ear resonant frequency less than 2000 Hz. The measurement system was restricted to probe frequencies of 2000 Hz or less. The final 404 participants included in the analyses presented here were similar in age, gender, and education to the total group of 1055 eligible participants. Participants were classified by age in years (48–59, 60–69, 70–79, 80–90). Approximately 99 percent of the subjects were non-Hispanic white.

Procedures

Otoscopy was performed in each ear at the start of each examination session (see Nondahl et al, 1996). Behavioral air-conduction and bone-conduction thresholds for tones at audiometric frequencies 250 through 8000 Hz were obtained using a diagnostic audiometer (Virtual, 320). Acoustic admittance measures were taken in one test session on the same day as the hearing tests. Sweep-frequency tympanograms for probe frequencies from 250 through 2000 Hz were obtained in one ear (randomly assigned) of each participant using a computer-based measurement system (Virtual, Model 310) and the standard probe tips supplied by the manufacturer. Tympanometric measures were collected over a pressure range from 250 to −300 daPa using a positive-to-negative direction of pressure change and a pump speed of 100 daPa/sec. Measures of middle ear resonant frequency were derived from peak compensated acoustic susceptance and admittance phase angle measures. Specifically, the frequency at which acoustic susceptance approximated 0 acoustic mmhos and the frequency at which the acoustic admittance phase angle approximated 0 degrees were determined. Resonant frequencies were determined using both the positive and negative tail of tympanograms as compensation referents. Raw data for pressure, acoustic admittance, and admittance phase angle at each probe frequency were directed via an RS-232 interface to a separate Macintosh (IIci) computer for file management and analyses. As a check on the reliability of resonant frequency calculations, resonant frequencies based on both phase angle and acoustic susceptance measures were compared. The audiometer and acoustic immittance system were calibrated in accordance with appropriate
In a substantial number of participants, tympanometry across all probe frequencies could not be completed due to the lack of an adequate seal for portions of the experimental run. Because the multifrequency tympanometry project was a portion of a larger epidemiologic research program, limited protocol time was available for completion of the tympanometric measures. Accordingly, a three strikes and out rule was used for completion of multifrequency tympanometry for each participant. Specifically, if an adequate probe seal was not obtained or maintained (for all probe frequencies) on the first run, the probe was repositioned and a new trial attempted. If judged appropriate by the tester, a different probe tip (typically the next larger size) was used for the second trial. This same process was repeated for a third trial if necessary. If, after three trials, an adequate seal was not maintained for tympanometry throughout the probe frequency range, the multifrequency tympanometry procedure was terminated.

RESULTS

Measures of middle ear resonant frequencies for all participants are summarized in Table 1. Resonant frequencies based on acoustic susceptance measures and on admittance phase angle are included for both positive- and negative-tail compensation techniques. Resonant frequencies based on acoustic susceptance measures were very similar to those based on acoustic admittance phase angle measures. The largest difference in mean resonant frequency for susceptance-derived measures and phase-derived measures across both compensation techniques for any age group was 3 Hz. Accordingly, except where noted, resonant frequencies based on acoustic admittance phase angle were used for all data analyses that follow.

Age and Gender Effects

Mean middle ear resonant frequencies across age group and gender are displayed in Figures 1 and 2 for positive-tail compensation and for negative-tail compensation, respectively. Across age groups and gender, middle ear resonant frequencies based on negative-tail compensation were higher than those based on positive-tail compensation. There were no significant age group trends for middle ear resonant frequency in men (positive tail, $F[1, 178] = 0.01, p = .91$; negative tail, $F[1, 174] = 0.01, p = .92$) women (positive tail, $F[1, 222] = 0.15, p = .70$; negative tail, $F[1, 216] = 1.13, p = 0.29$), or after adjusting for gender differences (positive tail, $F[1, 40] = 0.15, p = .70$; negative tail, $F[1, 39] = 0.63, p = .43$).

After adjusting for age group differences, middle ear resonant frequencies were higher

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Middle Ear Resonant Frequencies (Hz) Based on Measures of Acoustic Susceptance and Acoustic Admittance Phase Angle for All Participants</th>
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<tr>
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<td>Negative Tail Compensation</td>
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<td></td>
<td>Phase Derived</td>
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<td>Participants</td>
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<td>48-59 yrs</td>
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<td>60-69 yrs</td>
<td>127</td>
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<td>70-79 yrs</td>
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<td>80-90 yrs</td>
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<td>Women</td>
<td>218</td>
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<td>48-59 yrs</td>
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<td>80-90 yrs</td>
<td>10</td>
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<td>Men</td>
<td>176</td>
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<td>48-59 yrs</td>
<td>81</td>
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Resonant frequencies based on ear canal compensation for both negative and positive tympanogram tails are provided.
for women than for men. This was the case for both positive tail \( F[1, 399] = 15.90, p < .05 \) and negative tail \( F[1, 389] = 8.11, p < .05 \) compensation methods. With the exception of the 80 to 90 years age group, mean middle ear resonant frequencies within each age group were higher for women than for men in the present study (see Figs. 1–2). The significance of differences in means for men and women, however, differed with the compensation method. Specifically, gender differences were significant for participants 48 to 59 years of age (positive tail, \( t[195] = 2.51, p < .05 \); negative tail, \( t[191] = 2.42, p < .05 \)) and for participants 60 to 69 years of age with positive-tail compensation (positive tail, \( t[115] = 2.99, p < .05 \); negative tail, \( t[125] = 1.35, p = .18 \)). Gender differences were not significant for participants 70 to 79 years of age (positive tail, \( t[55] = 1.68, p = .10 \); negative tail, \( t[54] = 1.62, p = .11 \)) or 80 to 90 years of age (positive tail, \( t[16] = -0.16, p = .87 \); negative tail, \( t[16] = -0.91, p = .38 \)).

As a final age comparison, middle ear resonant frequencies for older adults in the present study were compared with resonant frequencies reported for younger adults (Margolis and Goycoolea, 1993). Because Margolis and Goycoolea reported resonant frequencies based on acoustic susceptance measures, resonant frequencies derived in the same manner for the present study were used for comparison. Mean and 90 percent ranges for resonant frequencies in each data set are displayed as Figure 3. The data of Margolis and Goycoolea were based on multifrequency tympanometry in 28 adults (14 men, 14 women) aged 19 to 48 years. This specific database was chosen for comparisons based on the use of the same acoustic immittance instrument and similar measurement procedures and because gender was considered in the analysis of findings. Margolis and Goycoolea observed no significant differences in resonant frequencies for men and women; data were collapsed across gender. As indicated in Figure 3, resonant frequencies for older adults in the present study were lower than those reported by Margolis and Goycoolea for younger adults. These differences were significant for resonant frequencies based on the positive tympanogram tail \( (t[55] = -6.43, p < .05) \) and for resonant frequencies based on the negative tympanogram tail \( (t[55] = -5.27, p < .05) \). The 90 percent ranges for older adults were smaller than those reported by Margolis and Goycoolea (1993) for younger adults. Also, as illustrated in Figure 3, 90 percent ranges for positive-tail resonant frequencies were noticeably smaller for both data sets relative to the
DISCUSSION

In terms of the primary focus of the study, there were no significant age group (48–59, 60–69, 70–79, 80–90 years) trends for mean middle ear resonant frequency in older adults. After adjusting for age group, middle ear resonant frequencies in the older adults were higher for females than for males. The significance of gender differences varied with compensation technique (positive vs negative tail), but mean middle ear resonant frequencies were generally higher for females than for males with the exception of the 80 to 90 years age group. The lack of a clear gender effect for this oldest age group could have been due to the small number of subjects in the group. Finally, middle ear resonant frequencies were lower for older adults in the present study than those reported for younger (19–48 years) adults (Margolis and Goycoolea, 1993). Resonant frequencies for older men in the present study were similar to those reported by Holte (1996). Holte reported no significant age trends for resonant frequency in older men. The mean resonant frequencies for older men reported by Holte were 905.7 Hz and 1000.5 Hz for positive-tail and negative-tail compensation methods, respectively. Comparable mean resonant frequency values for men in the present study were 827 Hz (positive tail) and 993 Hz (negative tail). In both data sets, resonant frequencies based on the positive tympanogram tail were lower than those based on the negative tail. This difference in resonant frequencies for the two tympanogram tails is predictable from tympanogram characteristics at extreme pressures and has been documented earlier by Shanks et al (1993), Margolis and Goycoolea (1993), Shahnaz and Polka (1997), and Hanks and Mortensen (1997) for younger adults. It should be noted that the exact procedures and ear canal compensation technique differed across these studies in younger adults. The differences in means for Holte’s older group and older men in the present study are likely due in large part to differences in the sample size, age distribution, and other specific participant characteristics across the two studies. Taken together, however, the results of both studies suggest little change in the resonant frequency of the middle ear with age in older adults.

In terms of compensation techniques, the variance in resonant frequency across older participants in the present study was noticeably smaller for resonant frequencies based on the positive tympanogram tail (see Table 1 and Fig. 3). Given the observed variance in measures of resonant frequency for all participant groups, this reduction in measurement variability is important in terms of comparison measures. The reduced variability for positive-tail measures improves the sensitivity of measures in terms of differentiating resonant measures for older and younger adults (see Fig. 3). This same sensitivity advantage would likely be important for any clinical application of middle ear resonance measures.

The differences in resonant frequencies for older men and women observed in the present study is in contrast to the report of Margolis and Goycoolea (1993) for younger adults. Margolis and Goycoolea reported that there were no significant gender differences in measures of middle ear resonant frequencies for their participants aged 19 to 48 years. In the present study, mean resonant frequencies for older participants, aged 48 to 90 years, were higher for women than for men. This difference was significant after adjusting for age group. The actual differences in mean resonant frequency for men and women in each age group, however, were small, ranging from 13 to 106 Hz across age groups and compensation methods (see Table 1). These are relatively small differences relative to the observed variance in resonant frequency across the same variables. Nevertheless, the slightly higher middle ear resonant frequency for women is consistent with the slightly lower peak compensated static acoustic admittance values typically observed for adult women relative to adult men in both younger (Roup et al, 1998) and older (Wiley et al, 1996) age groups.

Relative to resonant frequencies in young adults (Margolis and Goycoolea, 1993), resonant frequencies for older adults in the present study were lower. This difference was significant after accounting for gender differences observed for older adults. The 90 percent ranges for resonant frequencies based on both the positive and negative tympanogram tail were smaller in the case of older adults than those reported by Margolis and Goycoolea (1993) for younger adults. This reduced variability may be related to the lower peak compensated static acoustic admittance (Peak $Y_{cm}$) observed in older adults relative to that for younger adults (Wiley et al, 1996). Specifically, the reduced dynamic range
between the tympanogram peak and the positive tympanogram tail associated with reduced Peak $Y_{tm}$ measures in older adults will restrict the range of possible $Y_{tm}$ values. This, in turn, will restrict the range of possible resonant frequencies and may account, in part, for the reduced variability observed in resonant frequencies based on the positive tympanogram tail for the same participants.

The comparison of resonant frequencies for younger and older adults does not support the position that the middle ear transmission system stiffens with age in older adults. Although the differences were not large, resonant frequencies were nonetheless lower for older adults compared with those for younger adults. This difference may or may not be verified in other studies of younger and older adults. Our comparisons were based on the single study by Margolis and Goycoolea (1993) in younger adults. This study was chosen because Margolis and Goycoolea used procedures similar to those in the present study and provided analyses that accounted for gender. Comparisons of middle ear resonant frequencies for older adults in the present study with other studies of middle ear resonant frequencies in younger adults using the same instrument and similar compensation methods as those used in the present study, however, suggest smaller differences in observed resonant frequencies. Shahnaz and Polka (1997), for example, reported resonant frequencies for 36 young adults (20-43 years of age) with normal hearing. Although they did not provide an analysis of resonant frequency by gender, their reported mean resonant frequencies for young adults were 894 Hz and 1043 Hz for positive-tail and negative-tail compensation methods, respectively. These values compare closely with the overall means (across age and gender) of 866 Hz and 1039 Hz from the present study in older adults for the same respective compensation methods. Similarly, Shanks et al (1993) reported median resonant frequencies of 800 Hz (positive tail) and 1100 Hz (negative tail) for a group of younger (20-40 years) men. Relative to the data comparisons for older adults in the present study and the younger adults of Margolis and Goycoolea (1993), comparisons with these other studies in younger adults suggest little or no difference in resonant frequencies for younger and older adults. In general, the differences in resonant frequencies between older and younger adults presented in the present study were not large and should be viewed with caution, particularly given the range of published values for middle ear resonant frequency for younger adults. Differences in sample sizes, specific procedures, participant characteristics, and other methodologic issues compromise direct comparisons of data across studies.

An important instrumental limitation observed in the current study was the number of measurement failures due to the lack of an adequate hermetic seal for the probe unit in the ear canal. Of 870 participants for whom multifrequency tympanometry was attempted, an adequate seal was not maintained throughout the probe frequency range for 403 (46%). As illustrated in Figure 4, the failure rate was higher for older age groups. As noted earlier (under Procedures), a maximum of three trials was attempted because of the limited test time available within the experimental protocol. The failure rate due to seal problems may have been somewhat lower if additional time had been available for repeated trial attempts with changes in probe tips and repositioning of the probe. With the exception of the work by Holte (1996), no rates of failure for obtaining an hermetic seal with the available probe unit have been reported. Holte, using the same instrument and probe system, noted that she did not obtain a necessary airtight seal for 6 of her 22 recruited participants aged 79 years and older. This represented a failure rate of 27 percent for her oldest group of participants. For the 80 to 90 years age group in the present study, failure rates were 56 percent and 65 percent for men and women, respectively (see Fig. 4). The difference in seal failures for the two studies could be related to multiple factors, including the participant sample and the number of attempts made to obtain the seal. The seal failures in the

![Image](image_url)

**Figure 4** Percent of participants for whom an adequate hermetic seal (probe unit) could not be obtained or maintained for completion of multifrequency tympanometry. Separate percentages are provided for age groups and gender.
oldest participants (80–90 years) from the present study were higher for women than for men; the Holte sample was limited to men. Holte did not report the number of trials or time required for achieving a hermetic seal in successful cases. Although our limit to three attempts may have contributed to the number of seal failures, it could be argued that the time available for measures in this epidemiologic study is not unlike the time demands that would be at issue in a busy diagnostic clinic.

Consistent with Holte’s (1996) report, a frequent observation in the current study was that the ear canal shape, particularly at its entrance, for many older adults often was not circular in cross-sectional area. Indeed, the ear canal opening was often slit-like or oval in shape. Thus, the rather firm, circular probe tips supplied with the instrument were not well suited for obtaining a hermetic seal for the probe unit. In a number of cases, a hermetic seal initially was obtained but was lost during the sweep-frequency tympanometry trials.

In summary, results of the present study indicated no significant age group trends for middle ear resonant frequency in older adults. One of the initial research questions was concerned with the potential sensitivity of multifrequency tympanometry and measures of middle ear resonant frequency in demonstrating any stiffening of the middle ear transmission system with age. In this regard, findings of the present study revealed no unique middle ear aging effects using multiple tympanometric probe frequencies and derived measures of middle ear resonant frequency. Overall, these findings suggest little evidence of any substantial stiffening of the middle ear transmission system with age in older adults.

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REFERENCES


