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16-year Change in Acoustic Admittance Measures Among Older Adults: Data from a Population-based Study

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Abstract

Purpose—The primary purpose of this study was to measure the 16-year change in peak compensated static acoustic admittance (Peak Y_{tm}) in a population-based cohort of older adults, and to determine whether age was associated with any observed change in Peak Y_{tm} . Other tympanometric measures also were taken and analyzed.

Method—Data from two examinations (1993–95, and 2009–10) of the population-based Epidemiology of Hearing Loss Study ($n = 1439$ with data at both examinations, ages 48–84 years at baseline) were utilized to assess 16-year change. Tympanometric measures were taken using a 226 Hz probe tone, a positive-to-negative direction of pressure change, and a measured pump speed of 600/200 daPa/sec.

Results—During the 16-year period, Peak Y_{tm} declined an average of 0.009 mmho/year (0.009/year for women, 0.007/year for men). Among women, older baseline age was associated with greater decline in Peak Y_{tm} . Among men, baseline age was associated with change in Peak Y_{tm} , but in a non-linear pattern. Other tympanometric measures demonstrated little change after 16 years.

Conclusions—These results demonstrate a small degree of middle-ear stiffening after 16 years among these older adults, but not enough to affect function in a manner that would influence clinical decisions.

Keywords

Acoustic-admittance; Aging; Middle ear; Tympanometry

Introduction

For decades, tympanometry has been used to help with the diagnosis of middle-ear disorders. The most commonly used form is vector tympanometry, which typically involves the use of one low-frequency probe tone (usually 226 Hz) (Wiley and Fowler, 1997). With this form of tympanometry, ear canal pressure is varied from a positive pressure to a negative pressure, and the resulting changes in acoustic admittance are plotted as a tympanogram. The peak compensated static acoustic admittance (Peak Y_{tm}), the amplitude of the tympanogram measured at the plane of the tympanic membrane, is often of interest because various disease processes (e.g., middle ear effusion, tympanic membrane perforation, ossicular discontinuity) can affect the height of the tympanometric peak. Other characteristics that may be measured to help determine if the tympanogram is normal include equivalent ear-canal volume (V_{ea}), tympanogram peak pressure (TPP), and tympanogram width (TW). These measures were discussed in more detail in earlier work (Nondahl et al, 1996; Wiley et al., 1996).

Previous studies that addressed the relation between age and Peak Y_{tm} often involved small samples (Blood and Greenberg, 1977; Nerbonne et al, 1978; Thompson et al, 1979; Stenklev et al, 2004; Feeney and Sanford, 2004), utilized varying screening criteria (Blood and Greenberg, 1977; Thompson et al, 1979; Osterhammel and Osterhammel, 1979; Hall, 1979; Holte, 1996; Stenklev et al, 2004; Feeney and Sanford, 2004), or provided no statistical inference tests (Jerger et al, 1972; Hall, 1979; Uchida et al, 2000), making it difficult to compare studies or draw conclusions. Some of these studies have suggested that acoustic admittance may decline with age (Jerger et al, 1972; Blood and Greenberg, 1977), while others found mixed results (Thompson et al, 1979; Hall, 1979) or no such relation at all (Osterhammel and Osterhammel, 1979; Holte, 1996; Uchida et al, 2000; Feeney and Sanford, 2004).

In one larger study, Gates et al (1990) reported tympanometric results from 1656 participants of the Framingham cohort. Averaged across ears, mean Peak Y_{tm} decreased significantly with age at the rate of -0.0035 acoustic mmho per year of age ($p = .039$). There was no significant gender difference in Peak Y_{tm} . In addition, Golding et al (2007) reported tympanometric measures from 1565 participants of the Blue Mountains Hearing Study. Mean Peak Y_{tm} measures decreased with age in the left ear only ($p = .002$), and were consistently higher for men than for women ($p = .001$ for both ears).

All of the aforementioned studies of the association between age and tympanometric measures were cross-sectional in nature. That is, each study participant was assessed only one time. To our knowledge, our previous study (Wiley et al, 2005) is the only one that has examined change in these measures in the same individuals over time. In that study, we examined 5-year change in measures of Peak Y_{tm} , V_{ea} , and TW among 2366 participants of the Epidemiology of Hearing Loss Study (EHLS). Peak Y_{tm} increased by an average of 0.04 acoustic mmho during the five-year interval ($p < .0001$ for both right and left ears). Mean Peak Y_{tm} values for men increased more than those for women (0.06 vs 0.02 acoustic mmho). V_{ea} increased an average of 0.05 cm³ in the right ear, and 0.09 cm³ in the left ear, with larger increases for men than women. TW increased an average of 3.0 daPa in the right

ear and 3.9 daPa in the left ear. These changes, while reaching statistical significance, were small and would not be likely to influence clinical decisions regarding middle ear function.

The primary purpose of this study was to expand on the earlier study by assessing 16-year change in peak compensated static acoustic admittance (Peak Y_{tm}) in a population-based cohort of older adults, and determine whether age was associated with any observed change. Other tympanometric measures also were examined.

Methods

Subjects

The Epidemiology of Hearing Loss Study (EHLS) is a population-based study of hearing impairment in adults 48 to 92 years of age at baseline (Cruickshanks et al. 1998). During 1987 to 1988, residents of the city or township of Beaver Dam, Wisconsin who were 43 to 84 years of age ($n = 5924$) were identified through a private census and invited to participate in a study of age-related ocular disorders (The Beaver Dam Eye Study, 1988–1990, $n = 4926$) (Klein et al. 1991). All who participated in the baseline eye examination and were alive as of March 1, 1993 were eligible to participate in the baseline examination of the hearing study (EHLS, $n = 4541$). Of those eligible, 3753 (82.6%) participated (1993–1995). Some participants ($n = 182$) refused the hearing testing but completed an interview.

A five-year follow-up examination was conducted during 1998–2000 ($n=2800$), followed by a ten-year (2003–2005; $n = 2395$) and 16-year follow-up examination (2009–2010; $n = 1812$). Comparisons between participants and non-participants have been reported elsewhere for the baseline examination (Cruickshanks et al. 1998), five-year examination (Cruickshanks et al. 2003), and the 10-year examination (Cruickshanks et al. 2010). The primary reason for non-participation in follow-up examinations was death.

Study approval was granted by the Human Subjects Committee of the University of Wisconsin-Madison. Informed consent was obtained from each participant.

Procedure

The same standardized methods were used in all examinations. The audiometric examination included otoscopic evaluation (Nondahl et al, 1996), screening tympanogram (Wiley et al, 1996), and pure-tone air- and bone-conduction audiometry (Cruickshanks et al, 1998). In addition, an extensive questionnaire was administered that included information on hearing and medical history and related exposures.

Acoustic-admittance measures were obtained on the same day as the hearing tests. Measures of Peak Y_{tm} , V_{ea} , TPP, and TW were obtained accordance with ASHA guidelines (ASHA, 1990). The screening tympanometer (GSI-37 Autotymp, Grason-Stadler, Inc., Madison, WI) used a probe frequency of 226 Hz, a positive-to-negative direction of pressure change, and a measured pump speed of 600/200 daPa/sec. The acoustic-admittance value at 200 daPa was used as the ear-canal referent for compensated admittance calculations. The tympanometer was calibrated in accordance with ANSI standards (ANSI, 1987).

Statistical methods

All data analyses were completed with the SAS System (SAS Institute, Inc., Gary, NC). Paired t-tests were used to assess the significance of mean 16-year change. Gender differences in mean change were assessed with t-tests. Three age groups were established (48–59 y, 60–69 y, and 70–84 y) based on the subjects' age at baseline. Unadjusted age group trends were tested using least squares linear regression (LSLR) models with age group modeled as an ordered factor. For Peak Y_{tm} , LSLR models were also used to model and test the association between continuous baseline age and 16-year change, using higher-ordered age terms when needed to improve model fit. The predicted values were plotted by year of age to better visualize the data. The p-values shown in the subsequent figure represent a joint test for all age terms combined. Additional subset analyses were performed. Since results from right ears and left ears were very similar, we focused the present study primarily on right-ear data for brevity.

Results

There were 3,235 participants with right-ear measurements at baseline, and 1439 with right-ear data at both baseline and the 16-year follow-up examination (Table 1). The average time of follow-up was 15.8 years (range of 14.0–17.5 years). Flat tympanograms, where Peak Y_{tm} is labeled “NP” on the GSI-37 autotym, were assigned a Peak Y_{tm} value of zero. V_{ea} , however, is still displayed for flat tympanograms. Since TPP and TW are not displayed by the GSI-37 autotym for cases of flat or unusually-shaped tympanograms, these two measures have more missing values than do Peak Y_{tm} and V_{ea} .

Peak Y_{tm}

Mean change in Peak Y_{tm} after 16 years is shown by gender and baseline age group in Table 2. Among 1,439 participants aged 48–84 years of age at baseline, Peak Y_{tm} declined an average of 0.14 acoustic mmho ($p < .001$), or 0.009 acoustic mmho/year. The decline was somewhat greater for women than for men (0.15 vs 0.11 acoustic mmho, $p = .04$). Overall, the mean decline was greater for older age groups ($p = .002$). This linear age trend was significant for women ($p < .001$) but not for men ($p = .99$). Decline in the left ear was similar (0.13 acoustic mmho).

Interactions between gender and 1) age, and 2) age-squared were statistically significant ($p = .037$ and $.029$, respectively), so the fitted values from the LSLR models were plotted separately for men and women in Figure 1. Fitted results from the models reveal a decline in Peak Y_{tm} for all baseline ages among women, with slightly greater decline for older baseline ages compared to younger. For men, 16-year decline reached its maximum for those aged 63 years at baseline (declining 0.16 acoustic mmho during the next 16 years), after which the 16-year decline slows to zero. The dotted lines in the figure represent the outer age range that includes less than five participants at each year of age contributing to the model.

In a subset analysis excluding participants 70 years of age and older from the LSLR model, 16-year change decreased slightly with age (0.004 acoustic mmho per year of age, $p = .01$), but there were no differences in change by gender and no age/gender interaction.

Focusing only on the 1213 participants who had right-ear Peak Y_{tm} data from all four examinations, the mean Peak Y_{tm} values were 0.67 acoustic mmho at baseline, 0.71 at 5-years, 0.62 at 10-years, and 0.53 at 16-years.

Finally, with the same 1213 participants, we used the generalized estimating equations (GEE) approach of Liang and Zeger (1986) to incorporate the right-ear Peak Y_{tm} data from all four examinations ($n=4852$ measures) into one linear model. This is essentially a cross-sectional analysis that accounts for the correlation within person over time as a nuisance parameter. The results showed that Peak Y_{tm} decreased an average of 0.009 acoustic mmho per year of age ($p < .0001$), and men had values 0.15 higher on average than did women ($p < .0001$).

Other measures

V_{ea} declined an average of 0.06 cm^3 during the 16-year interval (Table 3), a small but statistically significant change ($p < .001$). This translates to a rate of decline of about 0.004 cm^3 per year. There was no difference in mean decline by gender ($p = .55$), and no significant age group trends in the pattern of decline ($p = .66$, $.46$ and $.85$ for all participants, women, and men, respectively). The average left ear decline in V_{ea} (0.02 cm^3) was not statistically significant ($p = .13$).

TPP declined an average of 2 daPa during the 16-year interval (Table 4). This was not a statistically significant change ($p = .14$). There was no difference in mean change by gender ($p = .88$). There were no significant age group trends in the pattern of change overall ($p = .29$) or for women ($p = .86$). For men, however, there was a significant age trend ($p = .02$), with mean change of -4 , 0 and 13 daPa for age groups 48–59, 60–69, and 70–84 years, respectively. On average, there was no change in the left ear (average = 0 daPa).

TW also declined an average of 2 daPa during the 16-year interval (Table 5), a very small but statistically significant change ($p < .001$). There was no difference in mean change by gender ($p = .11$) and no significant age group trends ($p = .84$, $.48$ and $.39$ for all participants, women, and men, respectively). Decline in the left ear was similar (3 daPa).

Discussion

Peak Y_{tm}

Peak Y_{tm} decreased during the 16-year interval, both for men and women. Among women, there was a greater decrease as baseline age increased. The age relation was more curvilinear among men, with men in their early 60s experiencing the most change after 16 years. Restricting the analysis to participants less than 70 years of age at baseline, the relation between age and 16-year change was similar for men and women, suggesting that selective mortality may play a role in the diverging patterns observed in Figure 1. Both analyses suggested that age may play a role in how acoustic admittance changes further over time. Overall, our study suggested a small amount of stiffening of the middle-ear system during the 16-year interval. Consistent with this, we also demonstrated a small amount of stiffening with age.

The mean decline of 0.14 acoustic mmho over 16 years (from 0.66 to 0.52) can be viewed within the context of suggested norms for younger adults. ASHA (1990), based on Margolis and Heller's (1987) work with adults aged 19–61 years (mean = 32 years), suggested a 90% range of 0.3 – 1.4 acoustic mmho as normative for adults. More recent work from the Epidemiology of Hearing Loss Study (Wiley et al, 1996) suggested a similar 90% range (0.2 – 1.5 acoustic mmho) for normal older adults. These wide ranges of normative values suggest that, on average, the decline observed in the present study still results in values well within the normal range and would not be enough to affect function in a manner that would influence clinical decisions.

Results from the present study contrast to our earlier report showing a small increase in Peak Y_{tm} after only five years (Wiley et al, 2005). In that study, Peak Y_{tm} in the right ear increased an average of 0.06 acoustic mmho for men and 0.02 for women. However, we noted at the time that “the five-year examination interval may have been too brief for the observation of longitudinal changes in middle ear function.” With 16 years of data it is likely that a more accurate representation of change in Peak Y_{tm} has been obtained than was possible with a shorter follow-up time.

The observed stiffening of the middle-ear system after 16 years is consistent with a report from Ruah et al (1991) who conducted microscopic examinations of 54 tympanic membranes from persons in infancy to 91 years of age and found that they became less vascular, less cellular, more rigid and less elastic with increasing age. In addition, Etholm and Belal (1974) reported moderate to severe arthritis in both the incudomalleal and incudostapedial joints of all 34 temporal bones examined from individuals older than 70 years.

Other measures

After 16 years, V_{ea} had decreased about 0.06 cm^3 in the right ear; this average decrease was relatively stable across age groups and gender. The even smaller decrease in the left ear did not reach statistical significance. These small decreases are of little clinical significance. TPP remained virtually unchanged after 16 years, as did TW.

Comments

This is the largest study of long-term change in these measures. Data for the present study were limited to those for participants aged 48 to 84 years at baseline; observed age and gender patterns may not apply to younger adults. Study participants were 99% non-Hispanic White, so generalizability to other ethnicities is unknown. However, the population-based study design, without any exclusionary criteria, makes it the most generalizable study to date. In summary, we found a tendency for the middle-ear system to slightly stiffen during a 16-year interval. These results add an important and unique contribution to the available literature on the relation between age, middle-ear function, and tympanometric measures among older adults.

Acknowledgments

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Abbreviations

daPa	Decapascal
EHLS	Epidemiology of Hearing Loss Study
LSLR	Least squares linear regression
Peak Y_{tm}	Peak compensated static acoustic admittance
TPP	Tympanogram peak pressure
TW	Tympanogram width
V_{ea}	Equivalent ear-canal volume

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Figure 1.

Fitted values from linear regression models for 16-year change in Peak Y_{tm} for each year of age, by gender. The dotted lines in the figure represent the outer age range that includes less than five participants at each year of age contributing to the model. The p-values represent a joint test for all age terms combined.

Table 1

Baseline (1993–95) characteristics of study participants in the Epidemiology of Hearing Loss Study (EHLS) with right-ear tympanometric data.

Participants with right-ear tympanometric data at baseline (n=3295) ¹			Participants with right-ear tympanometric data at both the baseline and 16-year follow-up examinations (n=1439) ²		
Baseline Characteristic	N	%	Baseline Characteristic	N	%
Gender			Gender		
Women	1993	59.8	Women	887	61.6
Men	1302	40.2	Men	552	38.4
Age group (yrs)			Age group (yrs)		
48–59	1136	35.1	48–59	811	56.4
60–69	958	29.6	60–69	464	32.2
70–91	1141	35.3	70–84	164	11.4

¹ EHLS1 (1993–95).

² EHLS1 (1993–95) and EHLS4 (2009–10).

Table 2

16-year change in Peak Y_{tm} (in acoustic mmho). Right-ear data from the Epidemiology of Hearing Loss Study, 1993–95 to 2009–10, by gender and baseline age group.

Age Group at Baseline (yrs)	N	Mean (SD) at Baseline	Mean (SD) at 16-yr Follow-up	Mean Change	90% Range of Change	p-value for Mean Change
All	1439	0.66 (0.53)	0.52 (0.47)	−0.14	−0.6 to 0.2	< .001
48–59	811	0.65 (0.45)	0.54 (0.46)	−0.11	−1.5 to 0.2	< .001
60–69	464	0.66 (0.59)	0.49 (0.45)	−0.17	−0.7 to 0.2	< .001
70–84	164	0.68 (0.68)	0.49 (0.57)	−0.19	−0.8 to 0.3	< .001
Women	887	0.61 (0.50)	0.46 (0.39)	−0.15	−0.5 to 0.2	< .001
48–59	476	0.58 (0.39)	0.47 (0.37)	−0.12	−0.4 to 0.2	< .001
60–69	288	0.65 (0.63)	0.47 (0.43)	−0.18	−0.7 to 0.1	< .001
70–84	123	0.62 (0.54)	0.39 (0.38)	−0.23	−0.8 to 0.2	< .001
Men	552	0.73 (0.56)	0.62 (0.56)	−0.11	−0.6 to 0.3	< .001
48–59	335	0.75 (0.51)	0.64 (0.55)	−0.11	−0.6 to 0.3	< .001
60–69	176	0.67 (0.50)	0.54 (0.48)	−0.14	−0.7 to 0.3	< .001
70–84	41	0.84 (0.97)	0.78 (0.88)	−0.06	−0.5 to 0.6	.329

The values in **bold face** represent statistically significant age trends in mean change. For example, the pattern −0.11, −0.17, and −0.19 for age groups 48–59, 60–69, and 70–84 is a statistically significant downward linear trend ($p < .05$).

Table 3

16-year change in V_{ea} (in cm^3). Right-ear data from the Epidemiology of Hearing Loss Study, 1993–95 to 2009–10, by gender and baseline age group.

Age Group at Baseline (yrs)	N	Mean (SD) at Baseline	Mean (SD) at 16-yr Follow-up	Mean Change	90% Range of Change	p-value for Mean Change
All	1439	1.33 (0.39)	1.27 (0.37)	−0.06	−0.7 to 0.5	< .001
48–59	811	1.34 (0.37)	1.27 (0.35)	−0.06	−0.7 to 0.5	< .001
60–69	464	1.34 (0.44)	1.29 (0.43)	−0.05	−0.8 to 0.5	.017
70–84	164	1.28 (0.36)	1.22 (0.32)	−0.06	−0.7 to 0.4	.040
Women	887	1.26 (0.37)	1.19 (0.34)	−0.06	−0.7 to 0.4	< .001
48–59	476	1.25 (0.32)	1.17 (0.28)	−0.07	−0.7 to 0.4	< .001
60–69	288	1.28 (0.44)	1.22 (0.42)	−0.06	−0.8 to 0.5	.048
70–84	123	1.23 (0.32)	1.19 (0.30)	−0.05	−0.7 to 0.4	.139
Men	552	1.46 (0.40)	1.41 (0.39)	−0.05	−0.7 to 0.5	.003
48–59	335	1.47 (0.39)	1.42 (0.38)	−0.05	−0.7 to 0.5	.017
60–69	176	1.44 (0.41)	1.40 (0.41)	−0.04	−0.8 to 0.6	.178
70–84	41	1.41 (0.44)	1.33 (0.38)	−0.09	−0.7 to 0.4	.139

There were no statistically significant age group trends in mean change ($p < .05$).

Table 4

16-year change in TPP (in daPa). Right-ear data from the Epidemiology of Hearing Loss Study, 1993–95 to 2009–10, by gender and baseline age group.

Age Group at Baseline (yrs)	N	Mean (SD) at Baseline	Mean (SD) at 16-yr Follow-up	Mean Change	90% Range of Change	p-value for Mean Change
All	1282	–24 (35)	–25 (42)	–2	–65 to 50	.136
48–59	744	–23 (30)	–25 (39)	–2	–70 to 45	.124
60–69	406	–24 (39)	–26 (44)	–2	–55 to 55	.302
70–84	132	–29 (40)	–26 (51)	2	–60 to 75	.440
Women	789	–25 (37)	–27 (45)	–2	–70 to 45	.224
48–59	438	–24 (31)	–25 (43)	–1	–75 to 40	.527
60–69	255	–26 (44)	–29 (46)	–3	–55 to 50	.236
70–84	96	–28 (38)	–28 (51)	–1	–85 to 60	.810
Men	493	–22 (31)	–23 (37)	–1	–60 to 60	.390
48–59	306	–21 (29)	–25 (33)	–4	–60 to 45	.077
60–69	151	–20 (29)	–21 (40)	0	–55 to 60	.891
70–84	36	–33 (45)	–20 (52)	13	–35 to 95	.077

The values in **bold face** represent statistically significant age trends in mean change. That is, for men, the pattern –4, 0, and 13 for age groups 48–59, 60–69, and 70–84 is a statistically significant upward linear trend ($p < .05$).

Table 5

16-year change in TW (in daPa). Right-ear data from the Epidemiology of Hearing Loss Study, 1993–95 to 2009–10, by gender and baseline age group.

Age Group at Baseline (yrs)	N	Mean (SD) at Baseline	Mean (SD) at 16-yr Follow-up	Mean Change	90% Range of Change	p-value for Mean Change
All	1276	70 (25)	68 (25)	–2	–35 to 25	< .001
48–59	741	69 (23)	66 (23)	–3	–30 to 25	< .001
60–69	403	71 (26)	70 (25)	–1	–30 to 30	.213
70–84	132	75 (30)	71 (28)	–4	–45 to 30	.057
Women	785	72 (26)	70 (24)	–2	–35 to 25	.011
48–59	435	72 (24)	69 (23)	–2	–30 to 20	.004
60–69	254	72 (28)	71 (26)	0	–30 to 30	.798
70–84	96	76 (30)	74 (27)	–2	–45 to 30	.334
Men	491	67 (24)	64 (24)	–3	–35 to 25	< .001
48–59	306	65 (23)	62 (24)	–3	–30 to 25	.003
60–69	149	69 (23)	67 (24)	–3	–30 to 30	.092
70–84	36	72 (30)	64 (29)	–8	–55 to 25	.048

There were no statistically significant age group trends in mean change ($p < .05$).