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Tympanometric and Acoustic Stapedius Reflex Measures in Older Adults: The Blue Mountains Hearing Study

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Abstract

Tympanometric peak pressure, peak compensated static acoustic admittance (peak Y_{tm}) and acoustic stapedius reflex (ASR) thresholds were obtained for a representative sample of 1565 older Australians who were participants in the Blue Mountains Hearing Study (BMHS). No significant age or gender effects were found for tympanometric peak pressure. Peak Y_{tm} measures, however, decreased with age in the left ear only across all age groups and were consistently higher for men than for women. After allowing for hearing loss, the effect of age on ASR thresholds was inconsistent. An increase in ASR thresholds with age was observed at selected frequencies but only when measured contralaterally, and these changes were not clinically significant. Overall, our findings suggest that current normative data for peak Y_{tm} is too restricted for application in the older population, but there is insufficient evidence to warrant alternative normative data for the ASR threshold range in this same population.

Key Words: Acoustic stapedius reflex, aging, Blue Mountains Hearing Study, immittance, tympanometry

Abbreviations: AC = air-conduction thresholds; ASR = acoustic stapedius reflex; BBN = broadband noise; BC = bone-conduction thresholds; BMES = Blue Mountains Eye Study; BMHS = Blue Mountains Hearing Study; EHLS = Epidemiology of Hearing Loss Study; Peak Y_{tm} = peak compensated acoustic admittance; PTA = pure-tone average

Sumario

Se obtuvo la presión timpanométrica pico, el pico de admitancia acústica estática compensada (pico Y_{tm}) y los umbrales de reflejo acústico estapedial (ASR), para una muestra representativa de 1565 australianos viejos que participaban en el Estudio Auditivo de las Montañas Azules (BMHS). No se encontraron efectos significativos de la edad o género en los picos de presión timpanométrica. Las mediciones de pico Y_{tm}, sin embargo, disminuyeron con

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la edad sólo en el oído izquierdo, en todos los grupos, y fue consistentemente mayor en hombres que en mujeres. Luego de corregir de acuerdo a la pérdida auditiva, el efecto de la edad sobre los umbrales de los ASR fue inconsistente. Se observó un aumento con la edad en los umbrales de los ASR en frecuencias seleccionadas, aunque sólo cuando se medía contralateralmente, y estos cambios no fueron clínicamente significativos. Globalmente, nuestros hallazgos sugieren que los datos normativos actuales para el pico Y_{tm} son muy restrictivos para aplicar a las poblaciones más viejas, aunque existe evidencia insuficiente para garantizar datos normativos alternativos para el rango de umbrales de los ASR en esta misma población.

Palabras Clave: Reflejo acústico estapedial, envejecimiento, Estudio Auditivo de las Montañas Azules, impedancia, timpanometría

Abreviaturas: AC = umbrales de conducción aérea; ASR = reflejo acústico estapedial; BBN = ruido de banda amplia; BC = umbrales de conducción ósea; BMES = Estudio Ocular de las Montañas Azules; EHLS = Estudio de Epidemiología de Trastornos Auditivos; Peak Y_{tm} = pico de admitancia acústica compensada; PTA = promedio tonal puro

Immittance testing, which generally consists of tympanometry, measurements of acoustic stapedius reflex (ASR) thresholds, and acoustic stapedius reflex decay, is a routine clinical investigation that provides information to both audiologists and otologists regarding the conductive mechanism of the ear. Conflicting evidence exists concerning the effects of age and gender on these assessment tools.

Many studies have looked at potential changes to the ear's conductive mechanism with age. While no age-related changes to the middle ear resonance frequency (Holte, 1996; Wiley et al, 1999; Uchida et al, 2000) or to eustachian tube function have been reported (Chermak and Moore, 1981), conflicting results exist regarding the effect of aging on tympanometric outcomes. Several investigations have found no significant changes in acoustic admittance values with increasing age (Nerbonne et al, 1978; Osterhammel and Osterhammel, 1979; Thompson et al, 1979; Wilson, 1981; Holte, 1996; Uchida et al, 2000; Stenklev et al, 2004), while others report that acoustic admittance values decrease with age (Jerger et al, 1972; Blood and Greenberg, 1977; Hall, 1979; Gates et al, 1990; Wiley et al, 1996), suggesting a stiffening of the middle ear conductive mechanism in older adults (Jerger et al, 1972; Blood and Greenberg, 1977; Hall, 1979; Feeney and Sanford, 2004). While an age effect may exist for acoustic admittance measures, recent studies have demonstrated no age-related changes to middle ear pressure (Uchida et al, 2000; Stenklev et al, 2004).

Differences in the ear's conductive mechanism may exist for men and women although the differences appear to be small. Men appear to have higher acoustic admittance values than women (Jerger et al, 1972; Nerbonne et al, 1978; Hall, 1979; Wiley et al, 1996), but this difference may no longer be evident after the age of 60 (Hall, 1979) or 70 years (Nerbonne et al, 1978).

Age-related changes to ASR thresholds have been reported in some but not all studies. Some studies have reported that there are no changes in ASR thresholds with age (Thompson et al, 1980; Margolis et al, 1981), while others have found that they either decrease with age (Jerger et al, 1972;

Jerger et al, 1978) or increase with age (Wilson, 1981; Gates et al, 1990). With one exception (Silverman et al, 1983), those that reportedly tested at 4000 Hz found an age-related increase in the ASR threshold at that frequency (Osterhammel and Osterhammel, 1979; Wilson, 1981), but as Jerger et al (1972) noted, ASR results at 4000 Hz are atypical and often absent even in otherwise normal ears. Irrespective of age, ASR thresholds appear similar in men and women although there have been few studies performed (Jerger et al, 1972; Gates et al, 1990).

Wilson and Margolis (1991) attribute apparent inconsistencies between studies of ASR thresholds to several factors including the use of differing measurement procedures, variations in participant selection criteria such as level of hearing loss and age groupings, and whether tonal or other stimuli were used to elicit the ASR. Jerger et al (1978) found that aging affects the reflex threshold for tonal but not broadband noise (BBN), but others have reported an increase in thresholds for BBN with age (Osterhammel and Osterhammel, 1979; Silman, 1979; Gelfand and Piper, 1981; Silman and Gelfand, 1981; Wilson, 1981; Silverman et al, 1983).

Previous population-based studies have either examined tympanometric data (Wiley et al, 1996; Wiley et al, 1999) or used immittance results for other diagnostic purposes without reporting the immittance results obtained (Ostri et al, 1986; Ostri and Parving, 1991), or have omitted immittance testing altogether (Megighian et al, 2000). Gates et al (1990) was an exception and reviewed tympanometric data and ASR thresholds to 1000 Hz tonal stimuli only. The purpose of the present population-based study of older adults was, therefore, (1) to provide further insight into the effect of age and gender on tympanic membrane admittance, tympanometric peak pressure, and ASR thresholds for a range of tonal stimuli presented both ipsilaterally (at 500 and 1000 Hz) and contralaterally (at 500, 1000, and 2000 Hz) to the probe ear and (2) to determine if existing normative data used for assessing adults is suitable for use with an older population. This paper reports acoustic immittance results obtained as part of the Blue Mountains Hearing Study (BMHS).

METHOD

Subjects

The BMHS was conducted during the period 1997 to 2003. It is a population-based survey of age-related hearing loss in a representative community of older Australians. The BMHS was conducted among participants of the Blue Mountains Eye Study (BMES), a longitudinal study that looked at eye and health-related changes in an older population. The first BMES study, known as "BMES-1," was conducted during 1992–1994, and 3654 people aged 49 or older were assessed. Participants were residents of two suburban postcode areas in a region west of Sydney, Australia. The results of these initial assessments and a description of this population have been widely reported in the literature since 1996 (Attebo et al, 1996; Mitchell et al, 1997; Mitchell et al, 1998; Wang et al, 2000). The participants in BMES-1 were invited to attend five-year follow-up examinations in 1997, known as "BMES-2," as well as a hearing assessment (BMHS). Of the 3654 original participants, 575 (15.7%) had died and 383 (10.5%) had moved away from the study area, leaving 2696 subjects eligible for participation. Of these, 2015 (74.7%) participated in the hearing exams during 1999–2000. This group, who were 98% Caucasian, were aged 54–99 years (mean: 69.84 years; SD: 8.56) and consisted of 859 men (mean age: 69.73 years; SD: 8.34) and 1156 women (mean age: 69.92 years; SD: 8.67).

A repeat door-to-door census of the same area in 1999 identified further eligible permanent residents who moved into the area or were then aged 50 or older. At the time hearing exams of this second group were conducted, 1218 were still alive and living in the area; 941 (77.3%) participated in hearing exams during 2000–2003. This gave an overall response of 2956/3914 (75.5%) for the cross-section of persons aged 50 years or older. Of this group, 1565 (875 women and 690 men) met rigorous selection criteria for inclusion in the present report although four participants did not provide their age. The remaining BMHS participants were excluded using a cumulative set of criteria as follows: if they had an air-bone gap ≥15 dB HL at 500, 1000, 2000, or 4000

Hz in either ear (N = 403); if they reported suffering a middle ear condition diagnosed by a medical practitioner in the last ten years (N = 255); if they had experienced earache in the last year (N = 360) or a "blocked" feeling in the last year (N = 255) or discharge other than wax in the past year (N = 47); if they had a history of ear surgery (N = 58), or mastoiditis (N = 9), or otosclerosis (N = 2). BMHS participants were also excluded if they met all other selection criteria but immitance testing was not performed (N = 2).

Procedures

The BMHS involved an extensive questionnaire along with a battery of behavioral and physiologic auditory measures that included pure-tone audiometry and acoustic immittance tests.

Audiological tests were conducted by experienced master's-level audiologists in sound-treated facilities using standard TDH-39 earphones and a Madsen OB822 audiometer (Madsen Electronics, Copenhagen, Denmark) calibrated regularly during the study period to Australian Standards. Audiometric thresholds for air-conducted (AC) stimuli (right and left ears) were established for 250, 500, 1000, 2000, 4000, 6000, and 8000 Hz with 3000 Hz added if a 20 dB difference existed between 2000 and 4000 Hz thresholds. Bone-conduction (BC) thresholds were evaluated whenever AC thresholds were greater than 15 dB HL for frequencies of 500, 1000, 2000, and 4000 Hz. Masking was applied to reestablish AC thresholds whenever an air/bone gap ≥40 dB HL was observed at any frequency, and BC thresholds were reestablished whenever an air-bone gap of ≥15 dB HL was observed at 500, 1000, 2000, and 4000 Hz. The ears were examined for wax occlusion using a handheld otoscope, and participants were rescheduled for their assessment following intervention by their general practitioner. The four-frequency pure-tone average (PTA) (for 500, 1000, 2000, and 4000 Hz) was 14.72 dB HL (SD: 11.79) in the left ear and 13.83 dB HL (SD: 11.83) in the right ear for participants ≤59 years; 21.42 dB HL (SD: 14.52) in the left ear and 20.44 dB HL (SD: 14.40) in the right ear for participants aged 60–69 years; 30.30 dB HL (SD: 15.59) in the left ear and 28.59 dB HL (SD: 16.05) in the right ear for participants aged 70–79 years; 41.90 dB HL (SD: 17.20) in the left ear and 40.63 dB HL (SD: 18.50) in the right ear for participants ≥80 years.

Acoustic immittance measures were obtained using a GSI-33 Middle Ear Analyzer (Grason-Stadler) calibrated regularly during the study period to Australian Standards. Tympanograms were obtained for both ears with order of testing selected pseudorandomly. A 226 Hz probe frequency was used with a single positive-to-negative direction of pressure change from +200 to 200 daPa, or -400 daPa if the tympanometric peak was not found. Peak compensated acoustic admittance (peak Y_{tm}) measures were calculated using the admittance value at +200 daPa as a reference for compensated calculations, and tympanometric peak pressure was measured at the point of maximum admittance. ASR testing using ipsilateral and contralateral stimulation was performed immediately following tympanometry without repositioning the probe. The order of stimulation was pseudorandom. The ASR thresholds were measured at the point of maximum admittance on contralateral stimulation of both ears at 500, 1000, and 2000 Hz, and on ipsilateral stimulation of both ears at 500 and 1000 Hz. ASR measures obtained using contralateral stimulation at 4000 Hz have been reported as being unreliable (Jerger et al, 1972) and were therefore not included in this study. Starting at 85–90 dB, a bracketing approach was used to determine the ASR thresholds that were defined as the lowest stimulus level (dB HL) producing a minimum decrease in admittance of at least 0.02 mmho on at least two occasions as per the GSI-33 manufacturer's recommendations.

Data management and tabular analysis was undertaken using SPSS version 12.01. Descriptive statistics including mean, standard error of the mean, median, and percentiles were used to describe interval scale variables such as peak Y_{tm} and ASR thresholds. Dichotomous variables such as the presence/absence of ASR thresholds were expressed proportionally. Analysis of variance (ANOVA) was used to test differences between means of interval scale variables with other variables entered to the model as covariates where appropriate. Post-hoc comparisons (Bonferroni) were used to test pair-wise differences. Logistic regression modeling was used to determine factors that were significantly associated with absent ASR thresholds. P values of 0.05 were used to denote statistical significance.

RESULTS

While an attempt was made to carry out the full immittance test battery on all included participants, it was not always feasible to do so. In some cases, it was not possible to maintain an airtight seal for the duration of the test, and it was not always possible to obtain ASR thresholds at all test frequencies in each ear. Consequently, variability in the number of participants per test occurred.

Tympanometry

Tympanometric Peak Pressure

Table 1 shows the summary data and statistics for tympanometric peak pressure by age group, gender, and ear. Using ANOVA and entering age and gender as covariates, the average tympanometric peak pressure (in daPa) in the right ear was 5.6 (SE = 0.8) and in the left ear was 5.9 (SE = 0.9). When ANOVA was used for the right ear (without covariates), neither age nor gender had a significant impact on tympanometric peak pressure (gender: $F = 0.06$, $p = 0.81$; age: $F = 0.50$, $p = 0.68$), and this was consistent for men and women and across all ages ($F = 0.21$, $p = 0.89$). Similarly, for the left ear, there was no significant effect of gender ($F = 0.07$, $p = 0.80$) or age ($F = 0.68$, $p = 0.56$), and this was also consistent for men and women and across all ages ($F = 0.06$, $p = 0.98$). When the right ear was compared with the left ear using a repeated measures ANOVA (and age group and gender were entered to the model as covariates), there was no significant difference between the ears ($F = 0.12$, $p = 0.73$) in the tympanometric peak pressure.

Peak Y_{tm}

Table 2 shows the summary data and statistics for peak Y_{tm} (in mmho) by age group, gender, and ear. Using ANOVA and entering age and gender to the model as covariates, the average peak Y_{tm} was 0.9 (SE = 0.02) in the right ear and 0.8 (SE = 0.02) in the left ear. When ANOVA (without covariates) was used for the right ear, there was no age effect ($F = 1.74$, $p = 0.16$), but there was a significant gender effect for the peak Y_{tm} ($F = 31.05$, $p = 0.001$) where men of all ages had higher TM admittance than women of all ages (gender and age interaction [$F = 0.78$, $p = 0.51$]). For the left ear, peak Y_{tm} decreased significantly with age ($F = 5.12$, $p = 0.002$). There was also a gender effect ($F = 39.05$, $p = 0.001$) where men of all ages had significantly higher admittance than women of all ages (gender and age interaction [$F = 0.30$, $p = 0.83$]). When the right ear was compared with the left ear using a repeated measures ANOVA

Table 1. Tympanometric Peak Pressure Data (daPa) by Gender, Age, and Ear

Gender and Age (yrs)	Right Ear			Left Ear		
	n	Mean (SD)	Median (5th–95th Percentile)	n	Mean (SD)	Median (5th–95th Percentile)
All						
≤59	345	6.1 (24.2)	5.0 (-18.8 to 30)	349	7.8 (21.8)	5.5 (-15 to 33.8)
60–69	500	6.3 (23.1)	5.0 (-26 to 35)	508	6.5 (28.2)	10.0 (-36 to 35)
70–79	472	5.7 (30.3)	5.0 (-43.8 to 45)	476	5.9 (31.9)	5.0 (-45 to 45)
≥80	152	3.2 (27.2)	5.0 (-62.3 to 32.3)	156	3.7 (37.9)	10.0 (-74 to 35)
Male						
≤59	150	5.7 (25.2)	5.0 (-24 to 30)	154	7.4 (22.5)	5.0 (-15 to 37.3)
60–69	210	7.0 (23.4)	5.0 (-22.8 to 35)	217	6.8 (29.5)	10.0 (-40 to 45)
70–79	218	5.2 (33.9)	5.0 (-55 to 50)	222	6.4 (35.5)	10.0 (-65 to 52)
≥80	62	4.4 (27.0)	5.0 (-28.5 to 39)	63	4.2 (28.4)	10.0 (-83 to 30)
Female						
≤59	195	6.3 (23.5)	5.0 (-5 to 20)	195	8.0 (21.3)	10.0 (-15 to 30)
60–69	290	5.8 (23.0)	10.0 (-10 to 20)	291	6.3 (27.3)	5.0 (-30 to 30)
70–79	254	6.2 (26.9)	5.0 (-15 to 25)	254	5.4 (28.5)	5.0 (-45 to 45)
≥80	90	2.4 (27.6)	5.0 (-35 to 25)	93	3.3 (43.3)	10.0 (-75 to 37.5)

Table 2. Tympanic Membrane Admittance Data (Peak Y_{tm} in mmho) by Gender, Age, and Ear

Gender and Age (yrs)	Right Ear			Left Ear		
	n	Mean (SD)	Median (5th–95th Percentile)	n	Mean (SD)	Median (5th–95th Percentile)
All						
≤59	345	0.85 (0.65)	0.6 (0.3 to 2.2)	349	0.87 (0.66)	0.7 (0.3 to 2.3)
60–69	501	0.86 (0.70)	0.7 (0.3 to 2.1)	508	0.85 (0.62)	0.7 (0.3 to 2.2)
70–79	471	0.87 (0.77)	0.7 (0.2 to 2.2)	476	0.80 (0.60)	0.7 (0.2 to 1.9)
≥80	152	0.81 (0.78)	0.6 (0.2 to 2.5)	156	0.74 (0.63)	0.6 (0.2 to 1.7)
Male						
≤59	150	0.98 (0.76)	0.7 (0.3 to 2.8)	154	1.03 (0.76)	0.8 (0.3 to 2.9)
60–69	210	0.92 (0.71)	0.7 (0.3 to 2.2)	217	0.97 (0.73)	0.7 (0.3 to 2.4)
70–79	218	0.99 (0.88)	0.8 (0.3 to 2.6)	222	0.89 (0.68)	0.7 (0.3 to 2.1)
≥80	62	0.96 (0.94)	0.6 (0.2 to 3.1)	63	0.88 (0.86)	0.7 (0.2 to 2.9)
Female						
≤59	195	0.75 (0.52)	0.6 (0.3 to 1.7)	195	0.75 (0.54)	0.6 (0.3 to 1.6)
60–69	291	0.81 (0.68)	0.6 (0.3 to 2.1)	291	0.75 (0.51)	0.6 (0.3 to 1.9)
70–79	253	0.76 (0.65)	0.6 (0.2 to 1.8)	254	0.72 (0.51)	0.6 (0.2 to 1.7)
≥80	90	0.70 (0.63)	0.5 (0.2 to 2.1)	93	0.64 (0.39)	0.5 (0.2 to 1.55)

(and age group and gender were entered to the model as covariates), there were no significant ear differences ($F = 0.28$, $p = 0.59$) in the peak Y_{tm}.

ASR Thresholds

Contralateral ASR Thresholds

Tables 3, 4, and 5 show the summary data and statistics for ASR thresholds obtained using contralateral stimulation at 500, 1000, and 2000 Hz, respectively, by age group, gender, and ear under stimulation. The mean (in dB HL) and SE for contralateral ASR thresholds in the right and left ears were 94.7 (SE = 0.28) and 94.2 (SE = 0.28) for 500 Hz, 90.2 (SE = 0.27) and 89.7 (SE = 0.27) for 1000 Hz, and 89.7 (SE = 0.25) and 89.5 (SE = 0.25) for 2000 Hz respectively. Using ANOVA and entering gender as a covariate together with the hearing level at the relevant frequency for the ear under stimulation, there was a significant increase in the ASR threshold with age in some contralateral ASR thresholds, namely 500 and 1000 Hz in the left ear and 1000 Hz in the right ear (p values 0.03, 0.01, and 0.11; p values for linear trend 0.04, 0.03, and 0.03, respectively). This age effect was consistent across age groups and stimuli, irrespective of gender (p values ranged from 0.15 to 0.30), except for contralateral ASR thresholds at 1000 Hz in the left ear, which decreased in men but increased in women (p value 0.03). A closer examination of this data using Bonferroni pair-wise comparisons showed that the youngest age group had significantly lower contralateral ASR thresholds at 1000 Hz in the left ear than the 60–69 and 70–79 age groups (p values 0.02, 0.03, respectively), but not the ≥80 age group. There were no significant differences for other pairs (p values > 0.05). By contrast, there was no gender effect on contralateral ASR thresholds at 500, 1000, and 2000 Hz, in the right or left ears (p values range from 0.19 to 0.66) when age and hearing loss were entered to the model as covariates. When the right ear contralateral ASR thresholds were compared with the left using a repeated measures ANOVA (and age group, gender, and hearing loss at the relevant frequency were entered to the model as covariates), no significant differences between the ears were found for 500, 1000, or 2000 Hz (p values 0.90, 0.68, and 0.87, respectively).

Ipsilateral ASR Thresholds

Tables 6 and 7 show the summary data and statistics for ASR thresholds obtained using ipsilateral stimulation at 500 and 1000 Hz, respectively, by age group, gender, and stimulus ear. The mean (in dB HL) and SE for ipsilateral ASR thresholds in the right ear was 87.8 (SE = 0.24) at 500 Hz and 87.1 (SE = 0.25) at 1000 Hz, and in the left ear it was 87.6 (SE = 0.24) and 86.5 (SE = 0.24), respectively. Using ANOVA and entering gender as a covariate together

Table 3. Contralateral ASR Thresholds (dB HL) for a 500 Hz Stimulus Tone by Gender, Age, and Stimulus Ear

Gender and Age (yrs)	Right Ear			Left Ear		
	n	Mean (SD)	Median (5th–95th Percentile)	n	Mean (SD)	Median (5th–95th Percentile)
All	1028	94.7 (9.1)	95 (85 to 105)	1027	94.2 (9.0)	95 (85 to 105)
≤59	277	92.8 (9.1)	95 (80 to 105)	280	92.6 (8.9)	90 (80 to 105)
60–69	357	95.0 (9.0)	95 (85 to 105)	372	94.7 (8.8)	95 (85 to 105)
70–79	314	95.5 (8.9)	95 (85 to 105)	294	94.3 (9.3)	95 (80 to 105)
≥80	80	96.9 (9.0)	100 (85 to 110)	81	97.2 (8.9)	95 (85 to 110)
Male	450	94.5 (8.6)	95(85 to 105)	451	94.0 (8.4)	95 (85 to 105)
≤59	114	93.8 (8.0)	95(85 to 105)	117	93.3 (8.1)	95 (84 to 105)
60–69	151	94.4 (9.0)	95(81 to 105)	158	94.4 (8.0)	95 (85 to 105)
70–79	149	94.7 (8.4)	95(85 to 105)	139	94.0 (8.9)	95 (85 to 105)
≥80	36	96.4 (9.5)	100(80 to 110)	37	94.7 (9.1)	95 (85 to 106)
Female	578	94.9 (9.5)	95(85 to 105)	576	94.4 (9.5)	95 (80 to 105)
≤59	163	92.2 (9.8)	90(80 to 105)	163	92.1 (9.4)	90 (80 to 105)
60–69	206	95.5 (9.1)	95(85 to 105)	214	95.0 (9.4)	95 (85 to 108)
70–79	165	96.1 (9.3)	95(85 to 110)	155	94.5 (9.6)	95 (80 to 105)
≥80	44	97.3 (8.8)	100(85 to 110)	44	99.2 (8.3)	100 (90 to 110)

Table 4. Contralateral ASR Thresholds (dB HL) for a 1000 Hz Stimulus Tone by Gender, Age, and Stimulus Ear

Gender and Age (yrs)	Right Ear			Left Ear		
	n	Mean (SD)	Median (5th–95th Percentile)	n	Mean (SD)	Median (5th–95th Percentile)
All	1077	90.2 (8.7)	90 (80 to 100)	1084	89.7 (8.8)	90 (80 to 100)
≤59	283	88.7 (8.5)	90 (80 to 100)	284	87.9 (8.2)	85 (78 to 100)
60–69	380	90.1 (8.4)	90 (80 to 100)	396	90.1 (8.1)	90 (80 to 100)
70–79	331	91.0 (8.7)	90 (80 to 105)	319	90.5 (9.5)	90 (80 to 105)
≥80	83	92.7 (10.0)	95 (80 to 105)	85	90.9 (9.7)	90 (78 to 105)
Male	470	90.3 (8.4)	90 (80 to 100)	466	89.5 (7.9)	90 (80 to 100)
≤59	116	89.1 (7.7)	90 (80 to 100)	117	88.9 (7.5)	90 (80 to 100)
60–69	163	90.7 (8.6)	90 (80 to 100)	166	90.0 (7.5)	90 (80 to 100)
70–79	155	90.4 (8.6)	90 (80 to 100)	143	89.0 (8.2)	90 (80 to 100)
≥80	36	91.9 (9.1)	95 (80 to 101.5)	40	90.3 (9.7)	90 (76 to 105)
Female	607	90.2 (9.0)	90 (80 to 104.5)	618	89.9 (9.4)	90 (80 to 105)
≤59	167	88.4 (9.0)	90 (75 to 100)	167	87.2 (8.7)	85 (75 to 100)
60–69	217	89.7 (8.3)	90 (80 to 100)	230	90.2 (8.6)	90 (80 to 100)
70–79	176	91.6 (8.8)	90 (80 to 105)	176	91.6 (10.4)	90 (80 to 105)
≥80	47	93.2 (10.8)	90 (80 to 110)	45	91.6 (9.8)	90 (78 to 105)

Table 5. Contralateral ASR Thresholds (dB HL) for a 2000 Hz Stimulus Tone by Gender, Age, and Stimulus Ear

Gender and Age (yrs)	Right Ear			Left Ear		
	n	Mean (SD)	Median (10th–90th Percentile)	n	Mean (SD)	Median (10th–90th Percentile)
All	1040	89.7 (8.1)	90 (80 to 100)	1043	89.5 (8.2)	90 (80 to 100)
≤59	277	88.1 (7.6)	90 (80 to 100)	279	88.2 (7.9)	85 (80 to 100)
60–69	373	89.8 (7.8)	90 (80 to 100)	385	89.9 (8.2)	90 (80 to 100)
70–79	318	90.5 (8.5)	90 (80 to 105)	303	89.9 (8.3)	90 (80 to 100)
≥80	72	91.4 (9.1)	90 (80 to 105)	76	90.6 (9.2)	90 (80 to 105)
Male	449	90.4 (7.8)	90 (80 to 100)	453	90.3 (8.0)	90 (80 to 100)
≤59	115	89.2 (7.7)	90 (80 to 100)	115	89.1 (7.7)	90 (80 to 100)
60–69	157	91.0 (7.9)	90 (80 to 100)	162	91.1 (8.1)	90 (80 to 104)
70–79	147	90.5 (7.9)	90 (80 to 100)	139	90.7 (8.1)	90 (80 to 100)
≥80	30	91.2 (7.5)	90 (85 to 100)	37	89.6 (8.4)	90 (80 to 101)
Female	591	89.2 (8.3)	90 (80 to 100)	590	88.8 (8.3)	90 (80 to 100)
≤59	162	87.4 (7.4)	85 (80 to 98.5)	164	87.5 (8.0)	85 (80 to 100)
60–69	216	88.9 (7.7)	90 (80 to 100)	223	89.0 (8.1)	90 (80 to 100)
70–79	171	90.5 (9.0)	90 (80 to 105)	164	89.2 (8.4)	90 (80 to 100)
≥80	42	91.6 (10.2)	90 (80 to 105)	39	91.5 (9.9)	90 (75 to 105)

Table 6. Ipsilateral ASR Thresholds (dB HL) for a 500 Hz Stimulus Tone by Gender, Age, and Stimulus Ear

Gender and Age (yrs)	Right Ear			Left Ear		
	n	Mean (SD)	Median (10th–90th Percentile)	n	Mean (SD)	Median (10th–90th Percentile)
All	1104	87.8 (7.9)	85 (80 to 100)	1114	87.6 (8.0)	85 (80 to 100)
≤59	285	87.6 (7.5)	85 (80 to 97)	291	87.2 (8.0)	85 (80 to 95)
60–69	394	87.7 (7.9)	85 (80 to 100)	403	87.7 (7.6)	85 (80 to 100)
70–79	338	88.0 (8.0)	85 (80 to 100)	328	87.7 (8.2)	85 (80 to 100)
≥80	87	88.8 (8.2)	90 (80 to 100)	92	88.3 (8.7)	90 (80 to 100)
Male	479	88.3 (7.3)	90 (80 to 100)	483	88.3 (7.9)	85 (80 to 100)
≤59	117	88.3 (7.4)	90 (80 to 100)	121	88.2 (8.1)	85 (80 to 100)
60–69	168	88.7 (7.6)	90 (80 to 100)	170	88.8 (7.4)	90 (80 to 100)
70–79	156	87.9 (7.3)	90 (80 to 100)	150	87.6 (8.3)	85 (80 to 100)
≥80	38	88.3 (6.1)	90 (80 to 95.5)	42	88.8 (8.8)	90 (77 to 104)
Female	625	87.5 (8.2)	85 (80 to 100)	631	87.1 (7.9)	85 (80 to 95)
≤59	168	87.0 (7.6)	85 (80 to 95)	170	86.4 (7.9)	85 (75 to 95)
60–69	226	87.0 (8.0)	85 (80 to 100)	233	87.0 (7.7)	85 (80 to 95)
70–79	182	88.1 (8.7)	85 (77 to 100)	178	87.9 (8.1)	85 (80 to 100)
≥80	49	89.2 (9.5)	85 (80 to 105)	50	87.8 (8.6)	88 (80 to 100)

Table 7. Ipsilateral ASR Thresholds (dB HL) for a 1000 Hz Stimulus Tone by Gender, Age, and Stimulus Ear

Gender and Age (yrs)	Right Ear			Left Ear		
	n	Mean (SD)	Median (10th–90th Percentile)	n	Mean (SD)	Median (10th–90th Percentile)
All	1103	87.1 (8.3)	85 (75 to 100)	1102	86.5 (8.1)	85 (75 to 95)
≤59	284	86.0 (7.5)	85 (75 to 95)	289	85.9 (7.8)	85 (75 to 95)
60–69	391	87.2 (8.1)	85 (80 to 100)	405	86.5 (7.9)	85 (75 to 95)
70–79	343	87.8 (9.0)	85 (75 to 100)	323	87.0 (8.2)	85 (75 to 100)
≥80	85	87.9 (9.1)	85 (75 to 100)	85	86.7 (10.0)	85 (75 to 100)
Male	482	87.8 (8.1)	85 (80 to 100)	475	87.0 (8.0)	85 (75 to 95)
≤59	117	86.9 (7.8)	85 (79 to 100)	120	86.7 (7.7)	85 (75 to 95)
60–69	166	88.5 (7.8)	90 (80 to 100)	171	87.7 (7.9)	85 (80 to 95)
70–79	161	87.9 (8.7)	85 (75 to 100)	145	86.6 (7.9)	85 (75 to 100)
≥80	38	87.2 (7.9)	85 (75 to 100)	39	86.5 (10.1)	85 (75 to 105)
Female	621	86.6 (8.5)	85 (75 to 100)	627	86.1 (8.2)	85 (75 to 100)
≤59	167	85.4 (7.3)	85 (75 to 95)	169	85.3 (7.9)	85 (75 to 95)
60–69	225	86.2 (8.2)	85 (75 to 95)	234	85.7 (7.7)	85 (75 to 95)
70–79	182	87.7 (9.3)	90 (75 to 100)	178	87.4 (8.3)	85 (75 to 100)
≥80	47	88.5 (10.0)	90 (75 to 105)	46	86.9 (10.0)	85 (75 to 100)

with hearing level (at the relevant frequency for the ear under stimulation), there were increasing ASR thresholds with age for 500 Hz ($p = 0.001$) and 1000 Hz ($p = 0.002$) in the right ear but not in the left for 500 Hz ($p = 0.51$) or 1000 Hz ($p = 0.79$). Similarly (with age and hearing level as covariates), there was a significant difference in ASR thresholds for men and women at 500 Hz (right ear: $p = 0.001$, left ear: $p = 0.02$) and at 1000 Hz (right ear: $p = 0.001$) where men had a slightly higher ASR threshold than women. There was, however, no significant difference in left ear ASR thresholds for men and women at 1000 Hz ($p = 0.38$). Interactions between age and gender were statistically significant at 500 Hz ($p = 0.003$) and 1000 Hz ($p = 0.004$) in the right but not in the left ear at 500 Hz ($p = 0.34$) or 1000 Hz ($p = 0.11$). When the right ear ipsilateral ASR thresholds were compared with the left using a repeated measures ANOVA (and age group, gender, and hearing loss at the relevant frequency were entered to the model as covariates), a significant difference between the ears for both 500 and 1000 Hz (p values 0.04 and 0.001, respectively) was found where the left ASR threshold was slightly lower than that of the right ear.

Absent ASRs

Table 8 shows the proportion of participants with all ASRs absent as a function of gender and age. These variables were entered to logistic regression models together with the better ear or poorer ear four-frequency PTA. This statistical technique was used to assess the effects of gender, age, and hearing sensitivity on the absence of ASRs. There were no gender ($p = 0.66$ and $p = 0.55$) or age effects ($p = 0.56$ and $p = 0.47$), but hearing sensitivity in the better ear and poorer ear was significant ($p < 0.001$ for both ears) in predicting the absence of reflexes.

Table 9 shows the proportion of participants with all ASRs absent on one probe side only, by gender and age. The data for all ASRs absent by ear under stimulation is not tabulated by gender and age due to the small numbers involved. Only four subjects demonstrated an absence of reflexes only when the right ear was stimulated, and five subjects had absent reflexes only with left ear stimulation.

DISCUSSION

Tympanometry

Middle ear pressure, which at 226 Hz is highly correlated with tympanometric peak pressure, is reliant on adequate eustachian tube function (Zemlin, 1988). Chermak and Moore (1981) investigated the effects of aging on eustachian tube function and found no evidence to suggest that changes occur with age. More recently, Stenklev et al (2004) suggested that if there were any age-related changes in middle ear or eustachian tube structures, they were unlikely to affect the actual ventilation of the middle ear. In the present study, no significant change in tympanometric peak pressure with age was found, nor was there any difference in tympanometric peak pressure between older men and women, or between right and left ears. These findings are consistent with several previous reports (Chermak and Moore, 1981; Wiley et al, 1996; Uchida et al, 2000; Stenklev et al, 2004).

Our findings do, however, suggest that peak Y_{tm} decreases with age, but in the left

Table 8. Logistic Regression Modeling Results for Participants with All ASRs Absent

Logistic Regression Results with Better Ear Four-Frequency PTA as a Variable

Variable	n/N	Odds ratio (95% Confidence interval)	P value
Gender Male	20/689 (0.03%)	1.2 (0.6 2.2)	0.66
Female	19/872 (0.02%)	1.0	
Age (yrs)			
≤59	5/360 (0.01%)	1.0	0.56
60–69	9/532 (0.03%)	1.0 (0.3 3.1)	
70–79	16/500 (0.03%)	1.5 (0.5 4.3)	
≥80	9/169 (0.05%)	1.9 (0.6 6.3)	
Better ear four-frequency PTA		1.0 (1.01 1.05)	<0.001

Logistic Regression Results with Poorer Ear Four-Frequency PTA as a Variable

Variable	n/N	Odds ratio (95% Confidence interval)	P value
Gender Male	20/689 (0.03%)	1.2 (0.6 2.3)	0.55
Female	19/872 (0.02%)	1.0	
Age (yrs)			
≤59	5/360 (0.01%)	1.0	0.47
60–69	9/532 (0.03%)	1.0 (0.3 3.1)	
70–79	16/500 (0.03%)	1.5 (0.5 4.4)	
≥80	9/169 (0.05%)	2.1 (0.6 6.8)	
Poorer ear four-frequency PTA			<0.001

Table 9. Proportion (%) of Participants with All ASRs Absent on One Probe Side Only by Gender and Age

Gender and age (yrs)	All reflexes absent probe right	All reflexes absent probe left
All	58/1561 (0.04)	65/1561 (0.04)
≤59	10/360 (0.03)	10/360 (0.03)
60–69	22/532 (0.04)	16/532 (0.03)
70–79	15/500 (0.03)	32/500 (0.06)
≥80	11/169 (0.07)	7/169 (0.04)
Male	28/689 (0.04)	30/689 (0.04)
≤59	5/159 (0.03)	7/159 (0.04)
60–69	9/231 (0.04)	7/231 (0.03)
70–79	7/230 (0.03)	15/230 (0.07)
≥80	7/69 (0.10)	1/69 (0.01)
Female	30/872 (0.03)	35/872 (0.04)
≤59	5/201 (0.02)	3/201 (0.01)
60–69	13/301 (0.04)	9/301 (0.03)
70–79	8/270 (0.03)	17/270 (0.06)
≥80	4/100 (0.04)	6/100 (0.06)

ear only. Previous studies with smaller-size samples have either concluded that no significant age-related changes occur (Nerbonne et al, 1978; Osterhammel and Osterhammel, 1979; Thompson et al, 1979; Wilson, 1981; Holte, 1996; Uchida et al, 2000; Stenklev et al, 2004) or that acoustic admittance does decline with age (Jerger et al, 1972; Blood and Greenberg, 1977; Hall, 1979). Gates et al (1990) reported findings from the population-based study known as the "Framingham cohort" and demonstrated a small but significant decrease in acoustic admittance with age. Similarly, Wiley et al (1996) found decreasing acoustic admittance with age in the population-based study of older adults, the Epidemiology of Hearing Loss Study (EHLS). This effect, however, disappeared when the outcome was adjusted for gender, and in a recent five-year follow-up study of this same population, acoustic admittance changes with age could not be demonstrated (Wiley et al, 2005).

In the Framingham and EHLS studies, results from the right and left ear were combined either as an average (Gates et al, 1990) or they were added together, which effectively doubled the sample size (Wiley et al, 1996). It is therefore difficult to compare our ear-specific results with these directly. The observed left/right asymmetry is, however, consistent with other left/right asymmetries within the auditory system such as reported differences in hearing thresholds for the right and left ears (Rudin et al, 1988). Pirila et al (1992) also reported that hearing thresholds for 3000 to 6000 Hz in the left ear were inferior to those of the right, but their result was consistent for men and women. Similarly, left/right differences in performance on dichotic listening tasks have also been found in older adults (Jerger et al, 1995; Jerger, 1997; Jerger et al, 2000). The possibility that the right and left auditory pathways age differently along their entire length cannot therefore be excluded.

A gender difference in peak Y_{tm} outcomes was also demonstrated in our study, which is consistent with that reported by Wiley et al (1996) but not with that reported by Gates et al (1990) where no difference was found. This inconsistency between studies may reflect the fact that Framingham participants were not screened for preexisting middle ear conditions before testing, and therefore, outcomes should not be considered as normative data but, rather, a report of acoustic admittance measures for a general older adult population. Gender effects have also been observed for other measures of auditory function in older adults including hearing for high frequencies and performance on dichotic listening tasks. High-frequency peripheral hearing loss is reported to be more common in men than women, even allowing for work-related noise exposure (Mitchell, 2002), and hearing thresholds decline more than twice as fast in men as in women at most frequencies (Pearson et al, 1995). Similarly, older men do not perform as well as older women on dichotic listening tasks, which many reflect differences in degenerative changes to the central auditory pathways (Johnson et al, 1994; Janowsky et al, 1996).

While the gender and age effects for the left ear peak Y_{tm} measure are relatively small, they potentially impact on the relevance of young adult normative data to older adult populations. A comparison of our results with those obtained by Margolis and Heller (1987) for younger adults indicates a wider range of peak Y_{tm} values for older adults because of higher admittance values at the upper end of the 90th percentile range and a trend towards lower admittance with age. Wiley et al (1996) also reported a wider range for older adults compared with that of young adults, at the lower end of the 5th to 95th percentile range specifically. This broadening of the range in older adults should not be surprising given the potential for minor but cumulative changes to the middle ear associated with general physiological degeneration as one ages. Irrespective of the reason for differences between the apparently healthy ears of younger and older adults, these results suggest that the application of normative data based on young adult populations to older adult populations is likely to be inappropriate and misleading.

ASR Thresholds

An inconsistent age effect on ASR thresholds was found for both contralateral and ipsilateral reflexes after allowing for the potential influence of hearing loss on results. Other population-based data on age-related changes to ASR thresholds have been rarely reported, and if so, they were restricted to one frequency. Gates et al (1990) tested ASRs to 1000 Hz only (ipsilateral and contralateral presentation) in participants of the Framingham cohort, but the ipsilateral testing was only performed on a subset of participants who were free of evidence of middle ear disease while the contralateral measures were performed on the larger cohort. They found that although the mean ASR thresholds remained within normal limits across age groups (although this was not defined), the ASR thresholds to contralateral stimulation increased slightly with age whereas ASR thresholds to ipsilateral stimulation did not increase with age. Gates et al (1990) also reported a median ASR threshold of 85.5 dB HL with an interquartile range of 80 to 90 dB for contralateral stimulation and a median ASR threshold of 80.0 dB HL with an interquartile range of 75 to 85 dB for ipsilateral stimulation for all participants. A review of Tables 3 to 7 shows that our 10th to 90th percentile ranges encompass 20 to 25 dB HL depending on the frequency and ear under stimulation. All these figures seem relatively consistent with Jerger et al (1972), who reported that 95% of normal reflexes will fall in the range of 70 and 100 dB HL. Further comparisons between our outcomes and these two studies are difficult to make because of differences in the sampling of participants and the lack of adjustment for hearing thresholds in both of the earlier reports. It is, however, possible to conclude that any statistically significant age-related increases in the mean ASR thresholds to tonal stimuli are small and unlikely to be clinically significant.

An interaction between age and gender was found in our study for some but not all frequencies, and again, these effects were too small to be clinically significant. In general, then, no overall gender difference in contralateral or ipsilateral ASR thresholds was observed, which was consistent with previous findings (Jerger et al, 1972; Gates et al, 1990).

Finally, only 39 participants (2.1%) in our study demonstrated a complete absence of ASRs in both ears, and only a small number had absent ASRs on one side. This represents a much smaller proportion than might be predicted from earlier studies where 25.9% of normal participants over the age of 60 had absent reflexes (Gelfand and Piper, 1984). Logistic regression modeling for the cases with complete absence of ASRs showed that hearing loss and not age was the most salient factor in predicting this absence, but it is acknowledged that a limited number of predictive factors were used.

In summary, our results suggest that older adults demonstrate greater variability in their peak Y_{tm} values than younger adults, and this should be taken into account in clinical decision making for older adults. In contrast, when hearing loss is taken into account, our findings do not indicate a need for different ASR threshold normative data for older adults.

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