

# Normative Multifrequency Tympanometry in Infants and Toddlers

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## Abstract

Multifrequency tympanometry data were measured multiple times between the ages of four weeks and two years from 33 infants/toddlers. Tympanograms were also measured from 33 adult participants. Tympanograms recorded with five probe-tone frequencies (226, 400, 630, 800, and 1000 Hz) were classified using the Vanhuyse et al model classification system (Vanhuyse et al, 1975). Admittance at +200 daPa ( $Y_{200}$ ) and middle ear admittance ( $Y_{ME}$ ) were calculated. The proportion of Vanhuyse et al patterns in infants and toddlers was different than in adults, especially for younger ages.  $Y_{ME}$  and  $Y_{200}$  both increased with age.  $Y_{ME}$  and  $Y_{200}$  data for all infant/toddler groups were significantly lower than adult values at all of the tested probe-tone frequencies. These data can be used as a guide in the clinic to assess normal tympanometric values for infants and toddlers.

**Key Words:** Admittance of air in ear canal, conductance, infant, middle ear admittance, multifrequency tympanometry, susceptance, toddler, Vanhuyse et al model

**Abbreviations:** B = susceptance; CNL = could not label; ECV = ear canal volume; G = conductance; JCIH = Joint Committee on Infant Hearing;  $Y_{ME}$  = middle ear admittance;  $Y_{200}$  = admittance at +200 daPa

## Sumario

Se colectó información en 33 infantes/lactantes de timpanometrías de multifrecuencia realizadas en múltiples ocasiones entre las edades de cuatro semanas a dos años. También se midieron los timpanogramas de 33 adultos participantes. Los timpanogramas, registrados con sondas de prueba de cinco frecuencias diferentes (226, 400, 630, 800 y 1000 Hz), se clasificaron usando el sistema de clasificación del modelo de Vanhuyse y col. (Vanhuyse y col., 1975). Se calculó la admitancia a + 200 daPa ( $Y_{200}$ ) y la admitancia del oído medio ( $Y_{ME}$ ). La proporción de los patrones de Vanhuyse y col. en infantes y lactantes fue diferente que en adultos, especialmente en las edades más jóvenes. Tanto la  $Y_{ME}$  como la  $Y_{200}$  se incrementaron con la edad. La información sobre la  $Y_{ME}$  y la  $Y_{200}$  en los grupos de infantes/lactantes fue significativamente más baja que los valores en los adultos en todas las frecuencias del tono de prueba. Estos datos pueden ser utilizados como guía en la clínica para evaluar los valores timpanométricos normales en niños pequeños y lactantes.

**Palabras Clave:** Admitancia del aire en el conducto auditivo, conductancia, infante, admitancia del oído medio, timpanometría de multifrecuencia, susceptancia, lactante, modelo de Vanhuyse y col.

**Abreviaturas:** B = susceptancia; CNL = sin poderse etiquetar; ECV = volumen del canal auditivo; G = conductancia; JCIH = Comité Conjunto sobre Audición Infantil;  $Y_{ME}$  = admitancia del oído medio;  $Y_{200}$  = admitancia a + 200 daPa

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**E**xternal and middle ear structures change with development, becoming adultlike at approximately nine years of age. The most rapid changes occur during the first several months of life; for example, the angle of the tympanic membrane increases relative to the ear canal, and the middle ear cavity continues to grow (review in Northern and Downs, 2001). Developmental changes in middle ear admittance and reflectance have also been reported (Holte et al, 1991; Keefe et al, 1993; Prieve et al, 2005) and are not yet complete by two years of age (Keefe et al, 1993; Prieve et al, 2005). These data suggest that age-specific norms for middle ear measurements may be necessary for infants and toddlers. Moreover, clinic norms specifically for infants are necessary in light of the recommendation of the Joint Committee on Infant Hearing (JCIH). JCIH advocates that diagnosis of hearing loss be made before three months of age for those children who do not pass their universal newborn hearing screening (JCIH, 2000). For proper diagnosis of hearing loss and subsequent intervention, JCIH proposes that middle ear admittance measures, including tympanometry, be included in the test battery.

Normative data are available for neonates (Keith, 1973; Kei et al, 2003; Margolis et al, 2003) and for infants broadly grouped into age categories starting at six months. (Roush et al, 1995; De Chicchis et al, 2000). Currently, normative data is not available for infants between four weeks and six months of age, although audiological diagnosis and intervention are most likely to occur during this period (JCIH, 2000). Roush et al (1995) provided data for infants between 6 and 30 months of age grouped into four age brackets, each spanning a six-month period. De Chicchis et al (2000) grouped data into five age groups, with the youngest age group covering infants 6 to 11 months of age. Four older age groups each covered an 11-month period. Holte et al (1991) reported data from infants less than six months, but the intent of the paper was to show developmental changes in tympanograms. Consequently, normative data for clinical use are not easily obtained from Holte et al (1991).

Perhaps one reason why normative tympanometric data for infants aged younger than six months are not available is that most tympanometry is performed using a 226 Hz probe tone. Tympanometry using this probe-

tone frequency is insensitive to middle ear effusion in infants less than six to seven months of age (Paradise et al, 1976; Shurin et al, 1976; Hunter and Margolis, 1992; Keefe et al, 1993; Rhodes et al, 1999; Purdy and Williams, 2000). The use of higher-frequency probe tones has been recommended when testing young infants, because higher-frequency tones appear to be more sensitive to middle ear effusion (Williams et al, 1995; Purdy and Williams, 2000; Kei et al, 2003; Margolis et al, 2003). However, using higher-frequency probe tones results in multi-peaked tympanometric shapes, making clinical interpretation more difficult. Normative data for tympanograms measured using higher-frequency probe tones (on newer instruments operating in accordance with the American National Standards Institute [ANSI] standards [ANSI, 1987]) exists only for 1000 Hz probe tones in newborns (Kei et al, 2003; Margolis et al, 2003).

The Vanhuyse et al model has been used in the interpretation of tympanograms recorded with higher-frequency probe tones (Vanhuyse et al, 1975). The Vanhuyse et al model defines four patterns of admittance tympanograms based on the number of combined minima and maxima (or extrema) in both susceptance (B) and conductance (G) tympanograms. This model was developed to better understand multi-peaked tympanograms, either due to differences in probe-tone frequencies or middle ear disease in adults, but has been extended to study middle ear transfer function characteristics in infants (Margolis et al, 2003; Holte et al, 1991; Prieve et al, 2005).

McKinley et al (1997) and Sprague et al (1985) used the Vanhuyse et al model to classify tympanograms recorded in neonates. McKinley et al (1997) concluded that the Vanhuyse et al model was not adequate for classifying and interpreting the majority of their high-frequency neonatal tympanograms. Sprague et al (1985) reported neonates' tympanograms to be less complex than those observed in adults. Holte et al (1991) also found the percentage of tympanometric types was different among infants of different ages (birth to 4.5 months) and adults, but felt that the model could be used to classify a large percentage of the tympanograms. No data exist describing tympanometric types for older infants and toddlers.

The purpose of the current study was twofold. First, we sought to describe

tympanogram patterns using the Vanhuysse et al model for infants and toddlers aged four weeks to two years of age. Second, we wanted to provide normative tympanometric data for infants and toddlers measured with 226, 630, and 1000 Hz probe tones.

## METHOD

### Subjects

The 33 infants/toddlers (12 female, 21 male) that were enrolled in the current study were a part of a larger longitudinal study designed to explore the relationship between changes in middle ear admittance and corresponding changes in otoacoustic emissions. None of the participants had any risk factors for hearing loss (JCIH, 2000) and were cared for in the well-baby nursery of the hospital.

Data were collected over a 24-month observation period. An attempt to collect data at specific ages (1, 2, 3, 4, 6, 8, 10, 12, 16, 20, and 24 months) was made. However, the maintenance of this schedule was difficult due to reasons such as negative middle ear pressure, noncooperation, missed appointments, relocation of families, and equipment failure. Data were collected on individual participants an average of 7.7 test ages/child (standard deviation = 3 test ages). Each participant had data collected on one randomly selected ear (18 left ears, 15 right ears). Participants' data were separated by age into five groups: 4 to 10 weeks (mean = 6.9 weeks,  $n = 39$ ), 11 to 19 weeks (mean = 15.6 weeks,  $n = 41$ ), 20 to 26 weeks (mean = 23.2 weeks,  $n = 15$ ), 6 to 12 months (mean = 38.1 weeks,  $n = 50$ ), and 2 years (mean = 102.8 weeks, range: 99–113 weeks,  $n = 26$ ). TEOAEs or DPOAEs were present and robust or behavioral thresholds were  $\leq 15$  dB HL for at least two of four frequencies (500, 1000, 2000, and 4000 Hz) on the days tympanograms were recorded.

Data were also collected on one ear from 33 adult subjects (18 female, 15 male; 24 right ears, 9 left ears) that were used as a control in examination of tympanogram type (mean age = 30.3 years, standard deviation = 7.9 years). One tympanogram for each frequency per adult subject were used in the analyses for this study. None of the adults had a history of ear pathologies and all had

normal hearing ( $< 15$  dB HL) bilaterally at octave frequencies between 250 and 8000 Hz. Adult subjects and the parents of infant subjects signed an informed consent form and were paid for their participation.

### Instrumentation and Procedures

The Virtual Model 310 acoustic admittance instrument was used to collect all data. The Virtual 310 is a two-component admittance meter, with the ability to analyze conductance (G) and susceptance (B) separately. The Virtual 310 was controlled by a Macintosh Powerbook 165 with software provided by Virtual Corporation. Prior to all data collection, calibration measurements were made for every probe-tone frequency in hard-walled calibration cavities (0.5, 2.0, and 5.0 cc) supplied by the manufacturer.

Measurement of five sweep-pressure tympanograms were attempted using a positive to negative air pressure sweep at a rate of 125 daPa/sec and probe level of 85 dB SPL. The five probe-tone frequencies were 226, 400, 630, 800, and 1000 Hz. Of these frequencies, detailed analyses were completed on tympanograms measured with probe-tone frequencies of 226, 630, and 1000 Hz, because these are typical frequencies used in the clinic. The order of the probe-tone frequencies used was quasirandomized, that is, as many tympanograms as possible were collected while the participant remained cooperative. Pediatric participants either were held asleep and/or awake by their parent or, for some toddlers, sat on their own while testing occurred. If the participant was awake, experimenters attempted to distract the child from the testing procedure with toys.

### Analyses

Tympanograms with tympanometric peak pressure more negative than -150 daPa were not included in analyses to avoid including any ears with middle ear dysfunction. There were ten infants who had negative middle ear pressure during at least one visit. Data were not collected from these ears on those days. B and G values from the tympanograms were measured at +200 daPa and at the air pressure with the greatest admittance. The admittance at +200 daPa

( $Y_{200}$ ) and middle ear admittance ( $Y_{ME}$ ) were calculated.

Middle ear admittance was calculated with the following equation:

$$Y_{ME} = \sqrt{(B_{tip} - B_{tail})^2 + (G_{tip} - G_{tail})^2}$$

The tip is the extrema (either peak or dip, depending on tympanometric shape) at the applied air pressure, and the tail is the admittance at +200 daPa.

Admittance at +200 was calculated using the following equation:

$$Y_{200} = \sqrt{B_{tail}^2 + G_{tail}^2}$$

$Y_{200}$  was reported rather than ear canal volume (ECV) because most clinical equipment calculates ECV only at 226 Hz. In a purely compliant system, the relationship between ECV and  $Y_{200}$  is as follows (Margolis and Shanks, 1990):

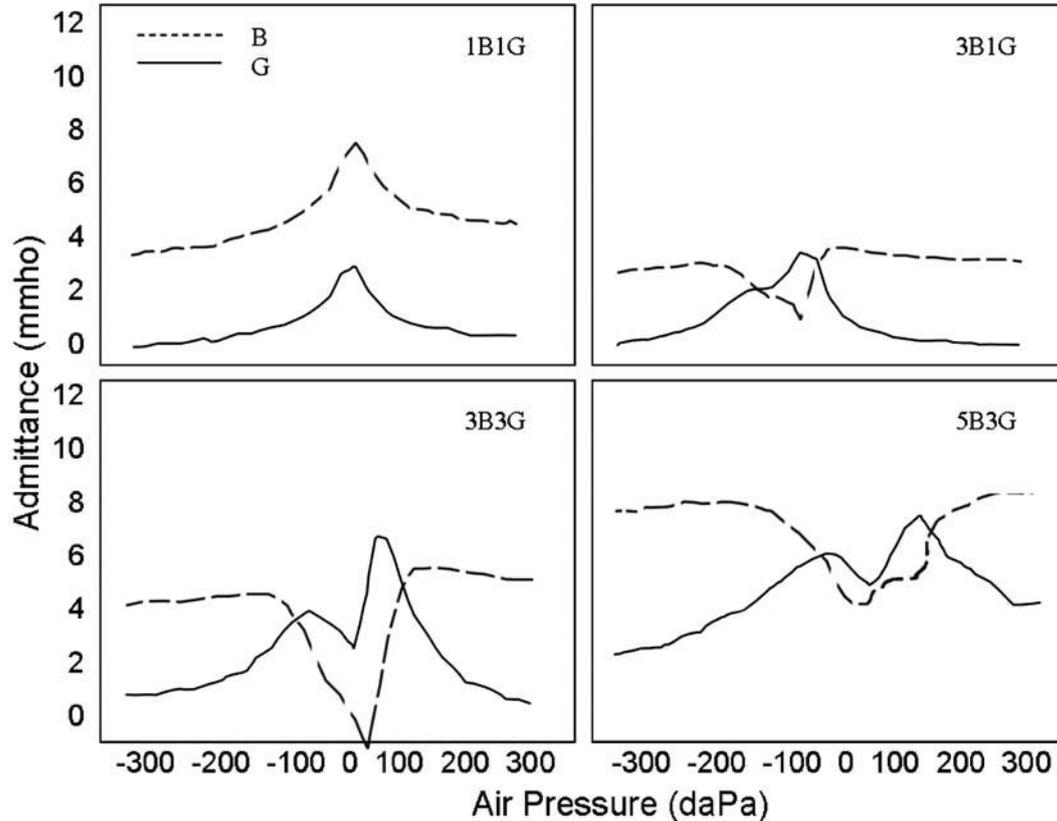
$$ECV = \left( \frac{226}{f_p} \right) * Y_{200}$$

Nonparametric, one-way ANOVAs were performed for  $Y_{ME}$  and  $Y_{200}$  data at a

significance level of  $\alpha = 0.05$ . Nonparametric statistics were used for these data, because more than one tympanogram from the same subject was usually included in a given age range (due to the longitudinal nature of the study). Consequently, the assumption of independence across the data was violated. To account for violations of independence, this type of ANOVA ranks the data prior to statistical testing. Post hoc testing was performed using Wilcoxon two-sample t-tests (Wilcoxon, 1945) to compare the relationship among all five groups ( $\alpha_{FW} = 0.05$ ).

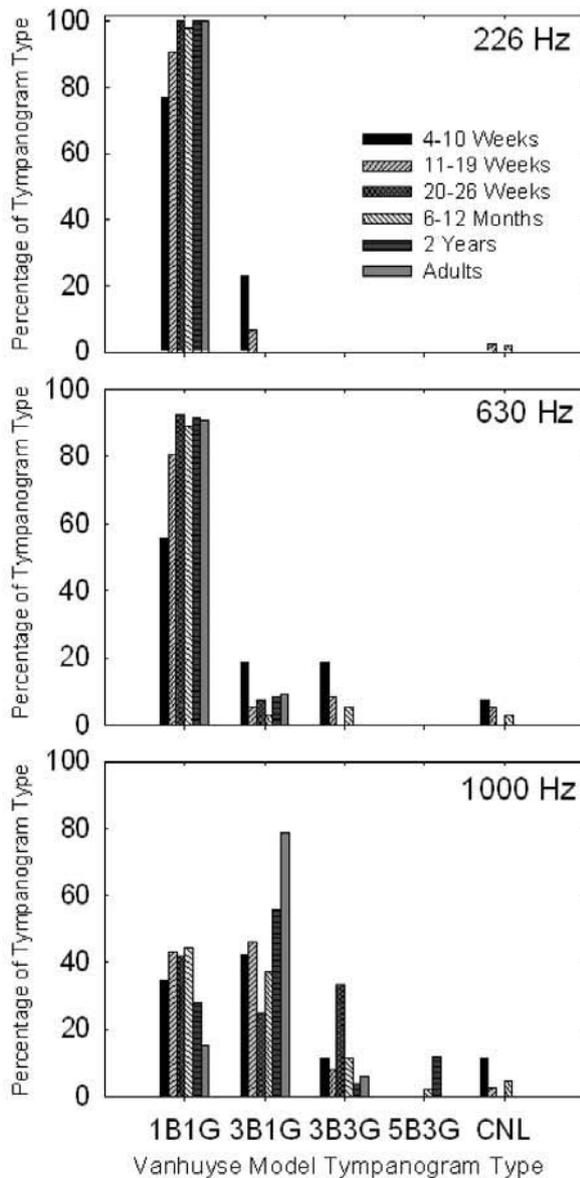
### RESULTS

A total of 204 tympanograms were successfully recorded at 226, 630, and 1000 Hz. All tympanograms were classified as one of the four Vanhuyse et al patterns or deemed "could not be labeled" (CNL). Figure 1 shows an example of the four Vanhuyse et al tympanogram types recorded from the current study's data. The top left panel of Figure 1 shows an example of a 1B1G tympanogram,



**Figure 1.** The four classic Vanhuyse et al patterns. These examples are actual data from the current study. The top left plot is a 1B1G type pattern; the bottom left plot is 93B1G plot; the top right plot is a 3B3G plot; and the bottom right plot is a 5B3G plot. All tympanograms were characterized as one of these four Vanhuyse et al types or were deemed "could not be labeled" (CNL).

where both the B and G tympanograms have a single peak. The top right panel illustrates a 3B1G tympanogram. For this classification the G tympanogram continues to have a single peak; however, the B tympanogram now has two maxima and one minimum, or three extrema. In the example of the 3B3G tympanogram, shown in the bottom left panel of Figure 1, both the B and G tympanograms have three extrema. In the bottom right panel, the 5B3G tympanogram, the G tympanogram has three extrema while the B tympanogram has five extrema.



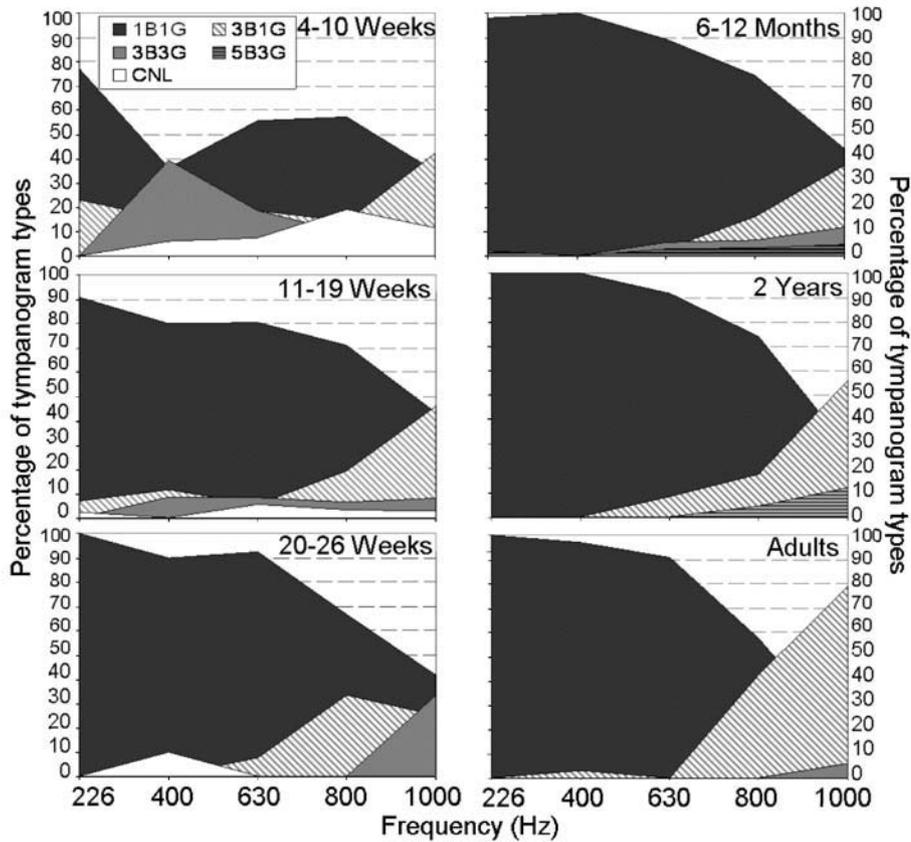
**Figure 2.** Percentage of tympanogram types as a function of Vanhuyse et al model tympanogram types are shown for six age groups. The tympanograms shown on the top panel were recorded using a 226 Hz probe tone, the middle panel with a 630 Hz probe tone, and the bottom panel with a 1000 Hz probe tone.

Figure 2 illustrates the percentage of tympanogram types for the six different age groups assessed in this study. As expected, the shapes of the tympanograms become more complex as probe frequency increases. The results shown in the top panel of Figure 2 were collected using a 226 Hz probe tone. The majority of 226 Hz tympanograms for all age groups had a 1B1G Vanhuyse et al-type pattern. However, the two youngest groups (4–10 weeks and 11–19 weeks) also had a small proportion of 3B1G tympanograms (23.1% and 6.8%, respectively).

When a 630 Hz probe tone was used (the middle panel of Figure 2), all age groups continued to have predominantly 1B1G tympanograms. This type comprised more than 90% of tympanograms for the three oldest infant/toddler and adult age groups. However, the youngest group had a larger proportion of 3B1G and 3B3G tympanograms. Data for the 1000 Hz probe tone are shown in the bottom panel of Figure 2. Adults had predominantly 3B1G patterns, whereas infants and toddlers had a wider variety of tympanogram types at this frequency.

The distribution of tympanogram types as a function of frequency for all age groups is examined in Figure 3. The percentage of tympanogram type for five probe-tone frequencies (226, 400, 630, 800, and 1000 Hz) are shown. The top panel displays data from the 4–10-week-old group. The percentages of tympanogram types for the 4–10-week-old group are markedly different from the percentages for all other age groups. The two most notable differences are a lower percentage of 1B1G tympanograms for all probe-tone frequencies and a greater percentage of 3B3G tympanograms, especially at 400 and 600 Hz. With respect to the three youngest age groups (the left column of plots), the overall proportion of 3B3G and CNL tympanograms decreased with age from 8.8% to 2% and 15.8% to 6.6%, respectively, when data were averaged across probe-tone frequencies, while the average percentage of 1B1G tympanograms increased with age from 52.2% to 78.1%. However, the percentages of tympanogram types continued to change between six months and adulthood (the right column of plots). The most noticeable of these changes is the increase in 3B1G tympanograms at 1000 Hz.

Descriptive statistics, including medians



**Figure 3.** Distribution of tympanogram types as a function of frequency for all age groups. Each of the six panels illustrate data from one of the six age groups reported in this study. For example, the bottom plot in the right column illustrates the percentage of tympanogram types as a function of frequency for children 20–26 weeks of age. The filled black area represents 1B1G type tympanograms. At 226 Hz all of the tympanograms for the 20–26 week age group were 1B1G (filled black area reaches 100% at 226 Hz). The other tympanogram types are represented by different color patterns indicated in the key.

and 5th and 95th percentiles, for  $Y_{ME}$  and  $Y_{200}$  for 226, 630, and 1000 Hz probe tones are shown in Tables 1 and 2, respectively. The nonparametric statistics reflect comparisons across age groups, not across probe-tone frequencies; therefore, statistical comparisons can be made only within frequencies (displayed in columns). Group data within a column that were not significantly different from one another are enclosed in brackets. Thus, those groups not within the same bracket were significantly different from one another.

For a 226 Hz probe tone, there were few significant differences in middle ear admittance among infant age groups. The dashed portion of the leftmost bracket indicates that  $Y_{ME}$  was significantly higher for the youngest group than for the 11–19-week-old group, but not significantly different from the other infant/toddler age groups. There were more significant differences between

age groups for the two higher probe frequencies. For a probe tone of 630 Hz, the youngest age group was significantly different from all other age groups. Infants aged 11–19 weeks had significantly lower middle ear admittance than infants aged six months to two years, and infants aged 20–26 weeks had significantly lower middle ear admittance than those aged two years. Using a 1000 Hz probe tone, infants aged 4–19 weeks had significantly lower middle ear admittance than those aged six months to two years.

There were striking differences in middle ear admittance between infants/toddlers and adults. All infant age groups had significantly lower middle ear admittance than did adults for all three frequencies. These results are similar to those seen in Keefe et al (1993) and Prieve et al (2005) and indicate that developmental changes in the middle ear are not yet complete even at 24 months of age.

**Table 1. Middle Ear Admittance ( $Y_{ME}$ ) for Tympanograms Using 226, 630, and 1000 Hz Probe Tones for Five Young Age Groups and Adults**

MIDDLE EAR ADMITTANCE ( $Y_{ME}$ )	226 Hz Median 5th–95th percentile	630 Hz Median 5th–95th percentile	1000 Hz Median 5th–95th percentile
4–10 Weeks n=39	0.400 0.140–0.733	0.325 0.075–1.278	1.067 0.201–2.258
11–19 Weeks n=39	0.249 0.126–0.567	0.552 0.255–1.247	1.453 0.701–2.272
20–26 Weeks n=15	0.276 0.145–0.544	0.763 0.440–1.158	1.409 0.616–2.177
6–12 Months n=50	0.310 0.158–0.597	0.930 0.401–1.919	1.933 0.948–4.197
2 Years n=26	0.310 0.209–1.029	1.114 0.686–4.543	2.466 1.118–4.073
Adults n=33	0.626 0.360–1.113	2.033 0.814–4.139	2.761 0.867–4.690

*Note:* Statistical significance of the data were classified by brackets, where group medians within the same bracket were not significantly different from one another. Statistical analyses were conducted across age groups, not across probe-tone frequencies; therefore, comparisons should be made within columns only. Note that the dashed line in the furthest bracket on the left indicates that the 11–19-week group was significantly different from the youngest group; however, the youngest group was not significantly different from all other pediatric groups.

Age differences for admittance at +200 daPa were also frequency dependent. At 226 Hz, infants aged four weeks to 26 months had significantly lower admittance at +200 daPa than children aged two years. At 630 Hz, infants aged 4–19 weeks had significantly lower admittance at +200 daPa than did infants aged six months to two years. At 1000 Hz, infants aged 4–10 weeks had significantly lower admittance at +200 daPa than did those aged 20 weeks to two years of age, and those aged 11–19 weeks had lower values than those aged two years. All infants had

lower admittance at +200 daPa than did adults at all frequencies tested. Lower admittance at +200 daPa would result in smaller calculated ear canal volumes.

Figure 4 is an illustration of the most clinically relevant data from Tables 1 and 2. The dark line in each plot represents the median data for each age group, while the gray shaded area represents the 5th to 95th percentile. For all four measures, the lower limit (5th percentile) did not vary as considerably with age as did the upper limit (95th percentile).

**Table 2. Admittance at +200 daPa ( $Y_{200}$ ) for Tympanograms Using 226, 630, and 1000 Hz Probe Tones for Five Young Age Groups and Adults**

ADMITTANCE AT +200 daPa ( $Y_{200}$ )	226 Hz Median 5th–95th percentile	630 Hz Median 5th–95th percentile	1000 Hz Median 5th–95th percentile
4–10 Weeks n=39	0.358 0.228–0.551	1.006 0.731–1.692	1.263 0.997–1.714
11–19 Weeks n=41	0.363 0.249–0.602	1.064 0.839–1.429	1.432 1.087–1.857
20–26 Weeks n=15	0.288 0.193–0.506	0.870 0.755–1.365	1.525 1.310–1.974
6–12 Months n=50	0.400 0.129–0.687	0.971 0.727–1.576	1.768 1.432–2.513
2 Years n=26	0.435 0.184–0.577	1.207 0.789–1.599	2.040 1.469–3.375
Adults n=33	1.051 0.700–1.685	2.729 1.740–3.703	3.896 2.567–5.239

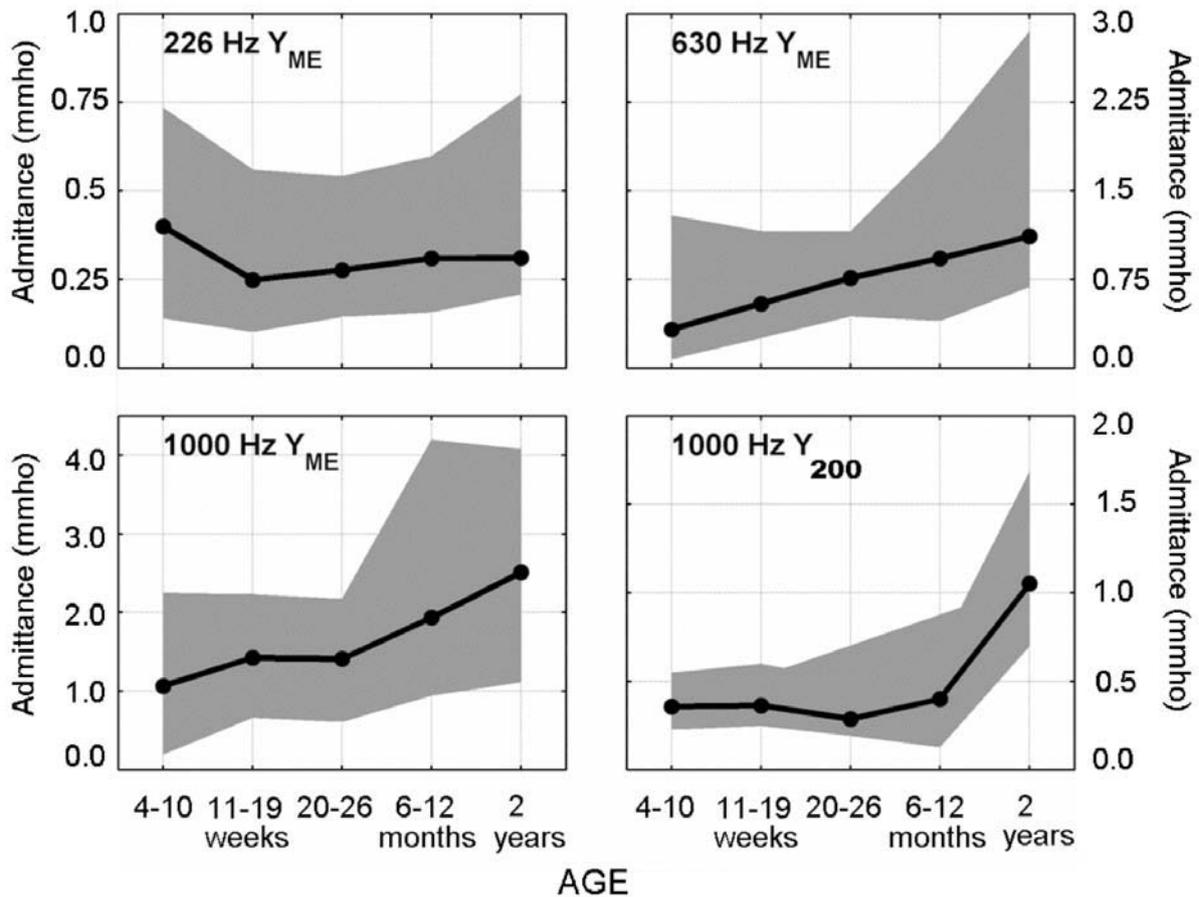
*Note:* Group medians within the same bracket were not significantly different from one another.

DISCUSSION

Data from this study indicate that the proportions of Vanhuysse et al-type tympanograms in infants and toddlers are different than those in adults, especially for younger infants. One of the most noticeable differences occurred for tympanograms recorded with a 1000 Hz probe tone. At this frequency, adults had predominantly 3B1G tympanograms (80%), whereas infants and toddlers tended to have a more equal distribution between 1B1G and 3B1G types. An equal distribution of 1B1G and 3B1G tympanograms was noted for adults at approximately 800 Hz. The percentages of the different Vanhuysse et al types as a function of frequency for adults are similar to data reported in Margolis and Goycoolea (1993).

Few researchers have attempted to use

the Vanhuysse et al model to classify tympanogram types in infants. Data in these studies were collected only from neonates (Shurin et al, 1976; Sprague et al, 1985) or using slightly different probe-tone frequencies than those used in the present study (Holte et al, 1991). A gross comparison can be made between the current results and those of Holte et al (1991). Holte et al (1991) reported Vanhuysse et al tympanometric types for 226 Hz probe tones in infants aged 26–47, 51–66, and 103–133 days old. If we combine the two younger groups from their study (26–47, 51–66 days old) and average the data, it can be compared to those from our youngest group (4–10 weeks old). Results from Holte et al (1991) for this age range indicated that 54.5% had 1B1G, 20% had 3B1G, 19.5% had 3B3G, and 5.5% had 5B3G tympanograms. In the current study, infants



**Figure 4.** Middle ear admittance ( $Y_{ME}$ ) for tympanograms using 226 (top left), 630 (top right), and 1000 (bottom left) Hz probe tones for five young age groups (data taken from Table 1). Admittance at +200 daPa ( $Y_{200}$ ) for tympanograms using a 1000 Hz probe tone (bottom right) for five young age groups (data taken from Table 2). Note that the y-axes of the four subplots are scaled differently for each condition.

in the youngest group have a similar percentage of 3B1G tympanograms (23.1%) but a higher percentage of 1B1G tympanograms (76.9%) and no tympanograms classified as 3B3G or 5B3G. The oldest group (103–133 days old) reported in Holte et al (1991) can be compared to our 11–19-week-old group. Results for this age range were similar between our study and the Holte et al (1991) study; 90.9% and 100% demonstrated 1B1G types, respectively. Holte et al (1991) measured tympanograms with slightly different probe-tone frequencies than those used in this study, with the exception of 226 Hz. For example, the results in Holte et al (1991) at 450, 710, and 900 Hz were similar to our results at 400, 800, and 1000 Hz, respectively. Because higher probe-tone frequencies were different between studies, direct comparisons cannot be made. However, percentages of tympanogram types for each of the higher probe frequencies, even when the probe frequencies differed by approximately 100 Hz, were similar between the two sets of data. Based on our results and those from others, the Vanhuyse et al model can be used to classify tympanograms in infants and toddlers aged four weeks to two years.

Data in the present study are similar to  $Y_{ME}$  reported by others, although some differences in data collection and reporting exist. One difference is that various pump speeds have been used. Current clinical equipment uses a pump speed of 200 or 600/200 daPa/sec. The pump speed in the current study was 125 daPa/sec. A review of the literature, reported by Margolis and Shanks (1990), indicates that in infants aged two to four-and-a-half months,  $Y_{ME}$  were smaller using a pump sweep of 200 daPa/sec compared to 50 daPa/sec. In children aged three to five years, the opposite was true; that is,  $Y_{ME}$  increased with faster pump speeds. Because our data span the ages of four weeks through two years of age, we are uncertain how different pump speeds would affect our data. Previously published data were collected using various pump speeds and/or from different age groups than the data in the present study; therefore, comparisons among studies are broadly interpreted.

Data from the present study compare favorably with the interim normative adult tympanometric data published by ASHA

(1990), based on the results reported by Margolis and Heller (1987). The median  $Y_{ME}$  at 226 Hz from the current study (0.626 mmhos) is similar to their mean  $Y_{ME}$  (0.72 mmhos). The 90% range for our  $Y_{ME}$  data (0.360–1.113 mmhos) also fell within the 90% range reported by Margolis and Heller (1987) (0.27–1.38 mmhos).

Median  $Y_{ME}$  results for the 6–12-month-old age group using a 226 Hz probe tone (0.31 mmhos) are similar to those results reported in both De Chicchis et al (2000) and Roush et al (1995). These authors reported mean admittance values of 0.32 and 0.39 mmhos, respectively. The range reported in the Roush study for this age range is similar to our reported range, 0.20–0.50 and 0.16–0.60 mmhos, respectively. However, the upper limit for the range of our two-year-old group (0.20–1.029 mmhos) is larger than the results reported for the 18–24 month group reported in Roush et al (1995) (0.30–0.70 mmhos).

Data from our 11–19-week-old group is similar to  $Y_{ME}$  in infants (mean age = 14 weeks) reported by Margolis and Popelka (1975). Margolis and Popelka (1975) reported mean  $Y_{ME}$  of 0.312 and 0.679 mmhos for 220 and 630 Hz probe tones, respectively, whereas the median  $Y_{ME}$  for similar frequencies in the current study were 0.249 and 0.552 mmhos, respectively. Holte (1989) reported a mean  $Y_{ME}$  value of 0.32 mmhos for two- to four-and-a-half-month olds when using a 226 Hz probe tone. Median data for our two youngest groups (4 to 19 weeks) was similar ( $Y_{ME}$  of 0.316 mmhos). Results from the current study are similar to previously reported data if the differences between mean and median calculations are accounted for.

It is not possible to compare our 1000 Hz  $Y_{ME}$  and  $Y_{200}$  data with other recent studies that have measured 1000 Hz tympanograms (Kei et al, 2003; Margolis et al, 2003). The oldest infants tested by Kei et al (2003) were six days old, while the oldest tested by Margolis et al (2003) were four weeks old. Thus, our youngest age group was older than both studies' populations. In addition, both Kei et al (2003) and Margolis et al (2003) used the term "static admittance" to indicate the peak-to-tail difference in admittance magnitude. Subtracting the tail from the tip using admittance magnitude does not take into account any phase differences that could be present between the pressures at the tail and the tip, and does not accurately estimate

the admittance at the tympanic membrane.  $Y_{ME}$  data reported in the current study is admittance recorded at the tympanic membrane. Additionally, Margolis et al (2003) recommended that  $Y_{ME}$  be calculated for infants using the tip value minus the tail at -400 daPa applied pressure. Our data were based on calculations at +200 daPa applied pressure because data were collected using a positive-to-negative sweep, as recommended by Holte et al (1991). Tympanogram traces were generally less noisy at the beginning of the trace than at the end of the trace, so more accurate measurements could be made. In addition, the most negative pressure tested in the current study was -280 daPa, making direct comparisons between studies impossible.

Our results indicated that  $Y_{ME}$  and  $Y_{200}$  generally increased with age; however, significant differences among infant/toddler age groups varied across frequencies. Taken as a whole, age-specific, probe-tone-frequency-specific norms for  $Y_{ME}$  and  $Y_{200}$  are necessary for infants younger than six months of age. Comparing  $Y_{ME}$  and  $Y_{200}$  measurements to a normative range, such as the one presented in Figure 4, may prove to be useful in diagnostic evaluations.

Future research should focus on tympanometric types and admittance in infants and toddlers with confirmed middle ear disease. The distribution of data from ears with pathology should be compared to the distribution from a normal population to determine whether these data can be used to diagnose middle ear disorders. Future research should also seek to determine which admittance measures are the most beneficial, for instance, whether both subcomponents should be monitored separately or whether simply looking at admittance magnitude provides the most useful information.

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