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Developmental Changes in Aural Acoustic Admittance Measurements

Albert R. De Chicchis*
N. Wendell Todd†
Robert J. Nozza*

Abstract

Tympanometry is a clinical measurement routinely included in the assessment of middle ear function. Despite its widespread use, however, fundamental questions remain regarding the need for age-dependent normative data. This study examines normal developmental changes associated with four tympanometric measurements: (1) ear canal volume, (2) peak compensated acoustic admittance, (3) tympanometric width, and (4) tympanometric peak pressure. Of 221 infants and children, aged 6 months to 5 years, enrolled in this study, 99 met the criteria for normal middle ear function as determined via pneumatic tympanoscopy by an experienced pediatric otolaryngologist, and data analysis was confined to those 99 volunteers. Analysis of variance revealed statistically significant main effects showing increases in ear canal volume and peak compensated acoustic admittance and decreases in tympanometric width as age increased. Statistically significant differences were not achieved for tympanometric peak pressure. Although statistically significant differences were found, the differences were small and of questionable clinical significance.

Key Words: Ear canal volume, peak compensated acoustic admittance, tympanometric peak pressure, tympanometric width

Abbreviations: HSD = Honestly Significant Difference test, TPP = tympanometric peak pressure, TW = tympanometric width, V_{eq} = equivalent volume, Y_{tm} = peak compensated acoustic admittance

The measurement of aural acoustic immittance (henceforth acoustic admittance) plays a pivotal role in assessing the status of the middle ear. This noninvasive procedure yields several indices by which judgments regarding the normalcy of middle ear function are made, and the usefulness of tympanometry in the identification of middle ear disease is well documented (Jerger, 1970; Jerger et al, 1974; Paradise et al, 1976; Orchik et al, 1978; Fiellau-Nikolajsen, 1983; Nozza et al, 1992, 1994). Yet, acoustic admittance meters manufactured for use in clinical settings today differ from those used in similar environments in the 1970s and early 1980s. The newer instruments, operating in accordance with the standards developed by the American National Standards Institute (ANSI, 1987), specify the measured peak admittance value in physical units rather than arbitrary units and render a measured response that is reported in quantitative versus qualitative terms. Thus, judgments of whether a middle ear is functioning normally or abnormally, based on criteria developed with instruments that did not comply with the ANSI (1987) standards, are no longer valid.

In an effort to establish normative values, using instrumentation that complied with the ANSI (1987) standard, several investigations have provided some preliminary data as regards those various acoustic admittance parameters in the assessment of middle ear function (Koebsell and Margolis, 1986; de Jonge, 1986; Margolis and Heller, 1987). There is evidence from each of those studies and others (Shanks and Wilson, 1986; Holte, 1991; Roush et al, 1995) that these variables are age dependent. More recently, interim normative data were published by the American Speech-Language-Hearing Associa-

*Department of Communication Sciences and Disorders, The University of Georgia, Athens, Georgia; †Department of Otolaryngology, Emory University, Atlanta, Georgia

Reprint requests: Albert R. De Chicchis, Department of Communication Sciences and Disorders, The University of Georgia, Athens, GA

tion (ASHA, 1990) that were based on the work of Margolis and Heller (1987). To our knowledge, only one study (Roush et al, 1995) included children in an age range of 6 to 30 months. Moreover, no study has included an experienced pediatric otolaryngologist to determine middle ear status. Consequently, tympanometric data on children under 3 years of age are sparse, and developmental effects on these measurement variables for children in this age range still need to be examined. So lacking are the data on this age population that the ASHA ad hoc committee on screening for hearing impairment and middle ear disorders has called for developmental normative data on this age group (ASHA, 1995).

Typically, four measurements comprise the acoustic admittance battery and include (1) ear canal volume (V_{eq}), (2) peak compensated acoustic admittance (Y_{tm}), (3) tympanometric peak pressure (TPP), and (4) tympanometric width (TW). The purpose of this study, therefore, was to examine the correlates of age with those four tympanometric measurements in a group of infants and children, 6 months to 5 years of age, having normal middle ears, that is, ears that upon physical examination, via pneumatic tympanoscopy, by an experienced pediatric otolaryngologist, showed no evidence of any abnormality with respect to tympanic membrane position, appearance, mobility, and vascularity. For the purposes of this study, following pneumatic tympanoscopy, an ear was classified as being normal, clinically normal, or abnormal. Clinically normal implied that there was something wrong with the appearance or position of the tympanic membrane that may have been due to a developing or resolving ear pathology, or simply may have been due to residual effects of previous ear disease, but in either case was not serious enough to warrant medical attention. Abnormal meant that an ear pathology was evident and referral for medical treatment was warranted. Ears classified as normal indicated that there was no physical evidence that there was anything wrong with the tympanic membrane appearance or position.

METHOD

Subjects

A total of 221 infants and children aged birth to 4 years and 11 months were enrolled in this study. Of those, 99 children met the criteria of normal middle ear function, as defined above, and data analysis was performed only for this group. Data were collected at the Rainbow Children's Medical Group, a large pediatric practice that is associated with Egleston Children's Hospital in Atlanta, Georgia, and the Friendship Presbyterian Preschool Program in Athens, Georgia. The participants in this study who were recruited through Rainbow Children's Medical Group were done so at the time that they were being seen by their pediatrician for any number of medical conditions or were just being evaluated as part of a routine check-up. The children from the Friendship Preschool Program were being seen only as volunteers for this study. The rationale for selecting participants in this manner was to ensure, as much as possible, that those selected represented the general population.

Instrumentation and Procedures

Acoustic admittance measurements were obtained using a Grason-Stadler model 1733 (GSI 33) middle ear analyzer that was calibrated in accordance with ANSI specifications (ANSI, 1987). All measurements were made by a clinically certified and licensed audiologist. Pneumatic otoscopy was performed by the same experienced pediatric otolaryngologist (WT) at both sites.

All of the acoustic admittance measurements and the otoscopic examination were performed while the participant was either sitting in a chair or being held by a parent or guardian. The otoscopic examination was always conducted first in an effort to eliminate biasing the physician's judgment as to the condition of the ear. His clinical judgment regarding the status of the middle ear (i.e., normal, clinically normal, or in need of a medical referral) was made without knowing the tympanometric results. Admittance tympanograms were obtained using a 226-Hz probe tone for pressures swept from +200 to –400 daPa. Pressure changes were always directed from positive to negative employing a pump speed of 600/200 daPa/sec. That is, the pressure changes were swept initially at a rate of 600 daPa/sec, slowed to 200 daPa/sec near the peak of the tympanogram, and increased back to 600 daPa/sec in the final stages of measurement. Efforts were made to ensure that insertion of the probe tip was similar in all cases.

Four acoustic admittance measurements were made on each child including (1) V_{eq}, (2) Y_{tm}, (3) TW, and (4) TPP. V_{eq} was estimated by measuring the ear canal admittance when a pressure of +200 daPa was introduced to the ear. Although it has been reported that this is not the most accurate method for determining ear canal volume (Shanks and Lilly, 1981), we chose this method because it represents a common clinical practice in many audiologic settings. Y_{tm} was determined by adjusting the GSI 33 to its "baseline" setting, thereby subtracting the ear canal admittance at +200 daPa from the admittance measured when air pressure in the ear canal produced a peak in the tympanogram. TW was determined by the procedure described by de Jonge (1986), which defines that measurement as the pressure interval between two points on either side of the tympanometric peak reflecting a 50 percent reduction in its amplitude. Although several methods have been reported in the literature to describe the tympanometric shape (Brooks, 1968; Paradise et al, 1976; de Jonge, 1983), we chose this method because it has been found to correlate poorly with Y_{tm} (de Jonge, 1986; Koebsell and Margolis, 1986), suggesting that it can provide additional information regarding the characteristics of the middle ear. Only one ear from each child was included in the data analysis, and ears were selected in a quasi-random manner.

RESULTS

Normal Ears

Participants were categorized into five age groups: (1) 6–11 months, (2) 1 year–1 year, 11 months, (3) 2 years–2 years 11 months, (4) 3 years–3 years, 11 months, and (5) 4 years–4 years, 11 months. Means and standard deviations for the four acoustic immittance variables are shown in Table 1. It can be seen that Y_{tm} values increased in a rather orderly manner from the very youngest group, those less than 1 year of age, to the oldest group, those children whose age ranged from 4 years to 4 years, 11 months. Analysis of variance showed a significant main effect for age (df = 4, 94, F = 4.12, p = .004). Post hoc analysis using the Tukey Honestly Significant Difference (HSD) showed significantly lower Y_{tm} for the two youngest groups as compared to the oldest group.

Descriptive statistics for V_{eq} also show changes in volume measurements as a function of age. It is observed that a fairly systematic increase in V_{eq} is present across age categories, a finding that is not surprising. As expected, analysis of variance shows a statistically significant main effect for V_{eq} (df = 4, 94, F = 4.56, p = .002). Post hoc analysis (Tukey HSD) showed the V_{eq} for the two youngest groups to be significantly smaller than the oldest group.

Developmental changes also were observed for TW, but, in comparison to those found for Y_{tm}

Table 1 Means and SDs for Four Tympanometric Measurements across Five Age Groups

	Age				
Variable	*6–11 Mo*	*1 Yr–1 Yr, 11 Mo*	*2 Yr–2 Yr, 11 Mo*	*3 Yr–3 Yr, 11 Mo*	*4 Yr–4 Yr, 11 Mo*
Y_{tm} (mmho)					
Mean	.32	.34	.47	.34	.52
SD	.16	.008	.24	.14	.32
TW (daPa)					
Mean	168	143	130	138	128
SD	57	37	33	35	38
TPP (daPa)					
Mean	–46.3	–24.4	–42.1	–13.4	–28.1
SD	121.7	83.3	76.7	58.9	45.9
V_{eq} (cm^3)					
Mean	.49	.53	.56	.58	.71
SD	.14	.13	.12	.17	.26

Y_{tm} = peak compensated acoustic admittance, TW = tympanometric width, TPP = tympanometric peak pressure, V_{eq} = ear canal volume.

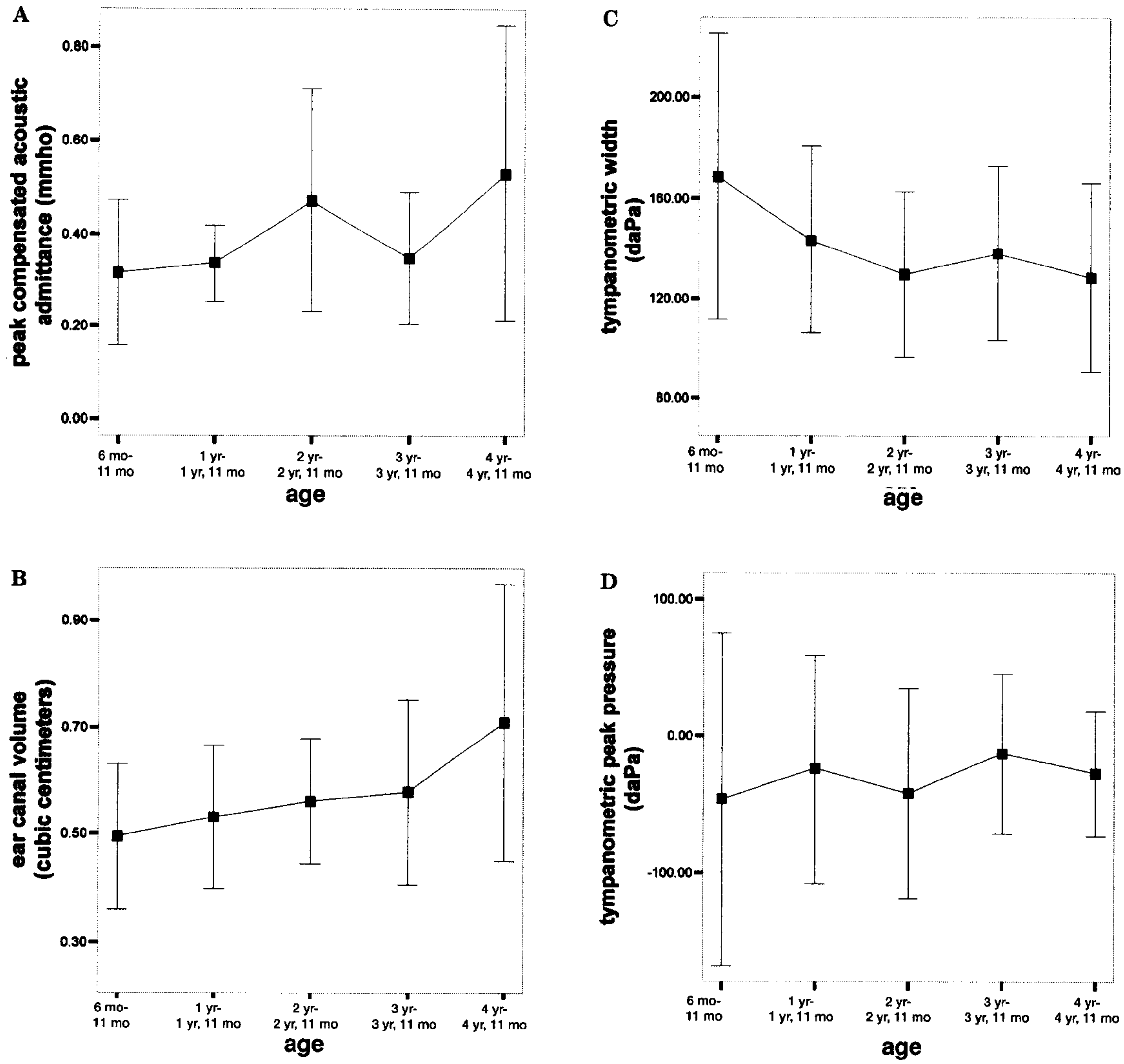

Figure 1 Mean values for four tympanometric variables across age groups: peak compensated acoustic admittance in acoustic mmho (*A*), ear canal volume in cm^3 (*B*), tympanometric width in daPa (*C*), and tympanometric peak pressure in daPa (*D*). Error bars represent plus and minus one standard deviation.

and V_{eq}, the change was in the opposite direction. That is, the widest tympanograms were observed for the youngest children (< 1 year). For the most part, tympanograms narrowed as the age of the children increased. An exception to this trend occurred for the children aged 3 years to 3 years, 11 months. As shown in Figure 1C, the TW for children in this age group widened slightly. Analysis of variance showed a statistically significant main effect for this measurement (df = 4, 94, F = 3.13, p = .018). The Tukey HSD indicated that those children less than 1 year had tympanograms that were significantly wider than those children aged 2 years to 2 years, 11 months and 4 years to 4 years, 11 months; no other significant differences were found for this variable.

Mean TPP data are graphically represented in Figure 2D. No significant differences or age-related trends were observed for this measurement condition.

DISCUSSION

This investigation was undertaken to examine developmental changes relative to four acoustic admittance variables in a group of children aged 6 months to 5 years. Although several studies have reported normative acoustic admittance data using instruments that conform to the

ANSI (1987) specifications, most of these investigations were concerned with adults or children over 3 years of age (Koebsell and Margolis, 1986; Margolis and Heller, 1987; Nozza et al, 1992). Only one study (Roush et al, 1995) has investigated acoustic admittance measurements for children between the ages of 6 and 30 months. Roush et al reported normative data for Y_{tm} and TW measurements obtained from a longitudinal study that they conducted over a 2-year period on 88 children ranging in age from 6 to 30 months. For this population, Roush et al found an overall mean Y_{tm} of 0.45 mmhos and a 90 percent range from 0.20 mmhos to 0.70 mmhos. Their TW measurements yielded an overall mean 148 daPa and a 90 percent range from 102 to 204 daPa.

In comparison to other studies that have included older children and adults, the findings of Roush et al (1995) showed lower Y_{tm} values and wider tympanograms. For example, Margolis and Heller (1987) found, for a group of children 2.8 years to 5.8 years, that the mean Y_{tm} was 0.50 mmhos and the 90 percent range 0.22 to 0.81 mmhos, whereas, for their adult population, the mean Y_{tm} was 0.72 mmhos and the 90 percent range was from 0.27 to 1.38 mmhos. Similarly, Nozza et al (1992) provided Y_{tm} data on a group of children who were free from middle ear effusion and deemed normal by otoscopic examination. These children ranged from 3 years to 16 years with a mean age of 9 years. This somewhat older group of children yielded a mean Y_{tm} of 0.78 mmhos and a 90 percent range of 0.4 to 1.4 mmhos, results that were more similar to the adult data reported by Margolis and Heller (1987). The mean TW for this group of children (reported in Nozza et al, 1994) was 104 daPa and the 90 percent range was 60 to 168 daPa, which was consistent with the findings observed by Margolis and Heller (1987) for the children in their study but narrower than those data reported by Roush et al (1995) for younger children.

The results of this study show a definite trend for an increase in Y_{tm} and V_{eq} and a decrease in TW with increasing age. With regard to TW, a statistically significant difference was found between the youngest age group (children < 1 year) and children aged 2 years to 2 years, 11 months, as well as 4 years to 4 years, 11 months. V_{eq} measurements yielded statistically significant differences for the two youngest age groups and the oldest age group. Statistically significant differences also were found for Y_{tm}. For this measurement variable, the two youngest age groups showed Y_{tm} values that were significantly lower than the oldest age group (4 years–4 years, 11 months).

The most plausible explanation for the developmental differences in Y_{tm} found in the present investigation and those of Roush et al (1995) in comparison to studies incorporating older children and adults is the anatomic and physiologic changes that occur in the developing ear. In a further attempt to explain the lower Y_{tm} and wider tympanograms found in their study, Roush et al (1995) raised the possibility that the recurrent episodes of otitis media experienced by the children during the course of their study may have resulted in residual effects on middle ear function. The results from the present investigation do not support that idea. The findings for the children identified as having normal otoscopic examinations in this study showed TW and Y_{tm} values that were very consistent with those reported by Roush et al. Although we cannot be sure that the children in this study did not experience previous bouts of otitis media, it should be noted that there were important differences between the two studies. In contrast to Roush et al, whereby the children were evaluated several times over the course of 24 months, the children in this study were examined only once. Following that one evaluation, the children were classified as being normal, clinically normal, or abnormal. Ears were identified as clinically normal if there was any evidence of a physical abnormality, but the abnormality was not deemed appropriate for medical referral. For example, the tympanic membrane may have been fibrotic, highly vascularized, slightly retracted, discolored, restricted in its movement to pneumatic otoscopy, or there was something else about its appearance or position that was not normal but did not warrant medical attention. Ears identified as normal were, in the judgment of the pediatric otolaryngologist, as nearly "textbook" normal as could be determined by physical examination. In this study, we only included those "textbook" normal ears in our analysis and excluded all other ears, which would indicate that the differences observed in the acoustic admittance measurements employed in this study were due to developmental changes.

Although there were slight differences in measurement procedures employed in this investigation as compared to other studies presenting normative data, it is unlikely that those methodological changes account for the differences in group mean data observed across studies. For example, Nozza et al (1992) measured Y_{tm} by subtracting the admittance at +300 daPa from the admittance observed at the peak, whereas this study determined Y_{tm} by subtracting the admittance measured at +200 daPa from that observed at the peak, similar to the method employed by Margolis and Heller (1987). Y_{tm}, however, was found to be lower in this investigation than in either of those other two studies. Likewise, Roush et al (1995) incorporated a pump speed of 150 daPa/sec as compared to 200 daPa/sec employed by Margolis and Heller, or 600/200 daPa/sec used in this investigation. Yet, the findings in this study compare favorably with those of Roush et al, and both investigations showed lower Y_{tm} and wider tympanograms than those reported by Margolis and Heller (1987).

In summary, this investigation found an age-related trend for four tympanometric measurements that indicated an increase in Y_{tm} and V_{eq} measurements and a decrease in the TW with increasing age. These data reflect a rather systematic change in the acoustic admittance characteristics of the developing ear from the age of 6 months through 4 years and 11 months. The biggest changes occur during the first 2 years and 11 months, after which acoustic admittance values become more stable. We should point out, however, that although mean differences reached statistical significance between some of these age groups, the differences were small and may not be clinically significant. In an effort to further explore the clinical feasibility of having multiple age-specific normative data for this pediatric population, we are currently in the process of investigating sensitivity and specificity values with respect to these tympanometric variables in similarly aged infants and children.

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