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High frequency (1000 Hz) tympanometry in six-month-old infants

Sreedevi Aithal [a,b,c,*], Joseph Kei [b], Venkatesh Aithal [a,b]

[a] Department of Audiology, Townsville University Hospital, Queensland, Australia
[b] Hearing Research Unit for Children, School of Health & Rehabilitation Sciences, University of Queensland, Australia
[c] Department of Speech Pathology, School of Rehabilitation Sciences, James Cook University, Australia

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ABSTRACT

Objectives: High frequency tympanometry (HFT) using a 1000 Hz probe tone is recommended for infants from birth to six months of age. However, there is limited normative HFT data outside the newborn period. The objective of this study was to describe HFT data in healthy six-month-old infants.

Methods: HFT and distortion product otoacoustic emission (DPOAE) tests were performed on 168 six-month-old full-term healthy infants. Ears that passed DPOAEs and had a single-peaked tympanogram were included for analysis. The tympanometric measures included in the normative HFT data were tympanometric peak pressure (TPP), peak compensated static admittance (Y_{tm}) and tympanometric width (TW).

Results: A total of 118 ears from 118 infants who passed DPOAE and had single-peaked tympanograms were included in the analysis. Normative data were presented for TPP, Y_{tm} and TW. A comparison of the present study with studies on neonates and younger infants revealed significantly higher mean Y_{tm} and lower mean TPP for six-month-old-infants.

Conclusion: Significant differences in HFT findings between neonates and six-month-old infants suggest a developmental trend and confirm the need for separate age-appropriate norms for the tympanometric measures. Normative HFT data described in the present study may provide useful information for optimizing the diagnosis of conductive conditions in six-month-old infants.

1. Introduction

Tympanometry is an objective measure of middle ear function. It is an essential component of a paediatric test battery to assess and monitor auditory function in children. Although 226-Hz tympanometry is used successfully with children, it is reported to have poor sensitivity for detecting middle ear dysfunction in infants up to six months of age [1–5]. This has been attributed to the characteristic anatomy and physiology of their outer and middle ears that influence how acoustic energy is transmitted from the outer to the middle ear [6,7]. For instance, the non-rigid ear canal wall and eardrum of newborn infants produce various resonance conditions of the outer and middle ear system. Sweep frequency impedance studies have found two resonance conditions in newborns with mean resonance frequency of 0.279 kHz for the outer ear and 1.224 kHz for the middle ear [8]. Furthermore, the newborn infant's middle ear is a mass-dominated system which responds differently to tympanometry that employs low frequency probe tones.

Infant ears undergo significant outer and middle ear changes in the first six months of life. The developmental changes include growth in the outer and middle ears, stiffening of the compliant ear-canal wall, ossification of the inner 2/3 of the ear canal, changes in the orientation and fibre structure of the tympanic membrane, fusion of the tympanic ring, tightening of the ossicular joints, increase in bone density of ossicles and loss of mesenchyme and fluid in the middle ear [2,9,10]. These developmental changes in early infancy influence the acoustic properties of the ear and are reflected in the tympanometric results obtained from young infants.

There is convincing evidence that high frequency tympanometry (HFT) with a probe tone of 1000 Hz can detect conductive conditions with high accuracy in neonates and young infants up to six months of age [11,12]. Despite the popularity of HFT as a test of outer and middle ear function for young infants, there are limited normative HFT data outside the newborn period. Several studies have described normative data for infants from birth up to four months of age [6,7,13–16]. However, there is limited normative data for six-month-old infants. Although Alaerts et al. [13] have reported HFT measures in infants between three and nine months of age, the investigators pooled the data

* Corresponding author. Department of Audiology, Level 1, IMB 126, Townsville University Hospital 100 Angus Smith Drive Douglas, Queensland, 4814, Australia.
E-mail address: sreedevi.aithal@health.qld.gov.au (S. Aithal).

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across a large age range and hence, the results are not specific to six-month-old infants. Cai [17] investigated middle ear function in infants from birth to six months of age and provided age-specific HFT data on a limited sample. In light of the large developmental changes in the ear canal and middle ear during infancy, which are reflected in the marked changes in normative data with age and the large intersubject variability, the age groups on which recommendations are based should be clearly defined. Furthermore, normative data as well as data on protocol performance within each specific age group are needed [18].

Currently, there are no normative HFT data specially for six-month-old infants. These infants are at high risk of having otitis media with associated hearing losses [19]. To facilitate accurate diagnosis of middle ear dysfunction, it is necessary to have age-appropriate tympanometric norms to derive pass/fail criteria for these infants. The objective of the present study was, therefore, to describe data for HFT measures including TPP, Y_{tm} and TW for healthy six-month-old infants.

2. Materials and methods

2.1. Subjects

All infants were born at full term and had previously passed the automated auditory brainstem response (AABR) in both ears at birth. They were assessed again at six months of chronological age. One hundred and sixty-eight infants (75 males and 93 females) were recruited for the study. Infants with high risk factors for hearing loss such as syndromes and craniofacial anomalies were excluded. A total of 118 infants (53 males and 65 females) with mean age of 194.1 days (SD = 11.9 days; range = 167–221 days) passed both HFT and distortion product otoacoustic emissions (DPOAEs) in at least one ear. Of the 118 infants, 75 infants passed HFT and DPOAEs in both ears while 43 infants passed both tests in one ear. For infants who passed the tests in both ears, one ear was selected randomly for analyses. Finally, 118 ears from the 118 infants were included in the study.

This study was approved by the Human Research Ethics Committees of the Townsville University Hospital and University of Queensland. Written parental consent was obtained at the universal newborn hearing screening program in Queensland.

2.2. Procedure

Otoscopy, DPOAE and HFT tests were performed by experienced clinical audiologists in a sound-treated room in a community health clinic. The infants were seated on their carer's lap and the ear most accessible to the clinician was tested first. Testing began with otoscopy followed by DPOAE and HFT tests.

A handheld Welch Allyn otoscope was used to perform otoscopy in each ear to assess the status of ear canal and tympanic membrane. Both HFT and DPOAE tests were performed using an Interacoustics Titan device (IMP 440; version 3.2), coupled to a laptop computer. This equipment allowed the measurement of both HFT (IMP 440) and DPOAE (DPOAE 440) with the same probe.

For HFT measurements, a 1000-Hz probe tone was delivered to the ear at 75 dB SPL. Ear canal pressure was swept from +200 to −400 daPa at a pump speed of approximately 300 daPa/s at the tails, slowing down to 100 daPa/s around the peak of the tympanogram. An admittance tympanogram compensated at the positive tail (200 daPa) was obtained from the test ear. A repeat trace was also obtained to confirm the reliability of the tympanogram. When an invalid trace was identified by the tester (e.g., artifacts produced with infant's head or jaw movement), the test was repeated after reinserting the probe. Tympanogram traces were classified using a method similar to that adopted by Baldwin [11]. A baseline was drawn between the positive (+200 daPa) and negative (−400 daPa) extremes of the trace. A trace was classified as positively peaked if an identifiable peak was present above the baseline. For the purpose of the present study, the pass criterion for HFT was a single positively peaked tympanogram [11,19]. Based on the tympanograms, the tympanometric measures such as TPP, Y_{tm} (peak compensated static admittance with baseline compensation at +200 daPa) and TW (the pressure difference between the two points on the curve at which the admittance is half the peak admittance) were recorded for analyses.

DPOAEs were measured in response to pairs of primary tones (f1 and f2), with f2 set at 2, 3, 4 and 6 kHz. The f2/f1 ratio was 1.2 for each primary pair. The stimulus levels of f1 and f2 were 65 dB and 55 dB SPL, respectively. The test began when a good probe fit was indicated on the Titan device. Pass criteria for DPOAE amplitudes, signal-to-noise ratio (SNR) and noise levels were based on normative data provided for 5- to 15-month-old infants by Hunter et al. [20]. Values between 5th and 95th percentiles (90% normative range) were considered a pass. Pass criteria for DPOAE were (1) amplitudes greater than (5th percentile) −4.62, −3.44, −3.98 and −7.44 dB at 2, 3, 4 and 6 kHz, respectively, and (2) SNR greater than (5th percentile) 0 dB at 2 and 3 kHz and greater than 2.13 and 3.25 dB at 4 and 6 kHz, respectively, and (3) noise levels below (95th percentile) −11.77, −15.46, −15.41 and −19.68 dB SPL at 2, 3, 4 and 6 kHz, respectively.

3. Results

Of the 336 ears from 168 infants initially enrolled in the study, 193 ears (57.4%) from 118 infants passed both HFT and DPOAE tests, 102 ears (30.4%) presented with no discernible tympanometric peaks or irregular tympanogram shapes that were uninterpretable, 30 ears (8.97%) had incomplete data (i.e., either HFT or DPOAE was not completed), and 11 ears (3.3%) had a double-peaked configuration. Ears with a double-peaked pattern, no discernible tympanometric peaks and irregular tympanogram shapes were excluded from further analyses because of the uncertain middle ear status.

Of the 118 infants that passed DPOAEs, 75 infants had intact tympanic membranes and single-peaked tympanograms in both ears. One ear from each of these 75 infants was randomly selected for analyses. Another 43 ears from 43 infants who had intact tympanic membranes and single-peaked tympanograms in one ear were selected for analysis. Hence, a total of 118 ears were included for the HFT data analyses.

An analysis of variance (ANOVA) was applied to the HFT data with TPP as the dependant variable, and ear (right/left) and sex (male/female) as independent variables. The significance of any term was assessed at $p < 0.05$. This statistical procedure was repeated for Y_{tm} and TW.

The results revealed no significant effect of sex for TPP [$F(1, 116) = 1.88$, $p > 0.05$], Y_{tm} [$(1, 116) = 0.05$, $p > 0.05$] and TW [$F(1, 116) = 0.07$, $p > 0.05$]. Similarly, there were no significant ear effect for TPP [$F(1, 116) = 0.71$, $p > 0.05$], Y_{tm} [$(1, 116) = 0.56$, $p > 0.05$] and TW [$F(1, 116) = 3.15$, $p > 0.05$]. Since there were no significant ear or sex differences, the results were pooled between sexes and ears. Table 1 shows the tympanometric data for six-month-old infants who passed the DPOAE test and obtained single-peaked tympanograms. The normative data show a 90% range of values for TPP, Y_{tm} and TW. The 90% range was from −199 to 75 daPa for TPP, 0.7 to 3.7 mmho for Y_{tm}, and 55 to 195 daPa for TW.

3.1. Comparison with different studies investigating HFT in newborns and young infants

To validate and observe the developmental trend of HFT findings, the results of the present study were compared with that obtained from neonates and young infants from other studies [6,7,13,14]. Unpaired t-tests were applied to compare the HFT findings between the present study and neonatal studies.

3.1.1. Tympanometric peak pressure (TPP)

Table 2 illustrates a comparison of number of ears, mean, standard deviation, median, 5th percentile and 95th percentiles and significance

Table 1
Normative data from 118 infants aged six months who passed distortion product otoacoustic emission testing and obtained single peaked high frequency tympanograms.

	Tympanometric peak pressure (TPP in daPa)	Peak compensated static admittance (Y_{tm} in mmho)	Tympanometric width (TW in daPa)
Mean	−30	1.46	118
Std Dev	80	0.81	46
5th percentile	−199	0.70	55
10th percentile	−162	0.80	72
25th percentile	−63	0.90	90
Median	−8	1.28	112
75th percentile	23	1.67	140
90th percentile	59	2.37	165
95th percentile	75	3.70	195

Table 2
Comparison of tympanometric peak pressure (TPP) across high frequency tympanometry (HFT) studies in young infants (Age of infants is in parentheses).

Tympanometric peak pressure (TPP in daPa)	N	Mean	SD	Median	5th percentile	95th percentile	Significance
Present study (6 months)	118	−30	80	−8	−199	75	
Kei et al., 2003 (1–6 days)	106	18	42	NA	−58	87	S
Margolis et al., 2003 (2–4 weeks)	46	−10	68	NA	−133	113	NS
Swanepoel et al., 2007 (0–4 weeks)	250	−1	49	NA	−75	80	S
Mazlan et al., 2009 (1–8 days)	273	9	53	NA	NA	NA	S
Mazlan et al., 2010 (6–7 weeks)	118	−7	64	NA	NA	NA	S
Alaerts et al., 2007 (3–9 months)	30	NA	NA	−52	−126	13	NA

NA= Not available; N = number of infants; SD = standard deviation; S = significant ($p < 0.05$).
NS = not significant, ($p > 0.05$).

of difference for TPP between the present study and other studies. As seen in this table, mean TPP of the present study was the lowest compared to that of the other neonatal studies. Mean TPP in the present study was 20–48 daPa lower than that of other neonatal studies. Comparison of median TPP values from Tables 1 and 2 indicated that the median values from the Alaerts et al. [13] study was 44 daPa lower than that reported in the present study. The 5th percentile for TPP in the present study was 66–141 daPa lower than those reported in other studies.

Results of unpaired t-tests showed the mean TPP of the present study was significantly lower than the mean TPP reported by Kei et al. [6] [t (222) = 5.53, p = 0.0001], Swanepoel et al. [7] [t(366) = 4.28, p = 0.0001], Mazlan et al. [21] [t(389) = 5.68, p = 0.0001] and Mazlan et al. [22] [t(234) = 2.44, p = 0.02]. Mean TPP of the present study was not significantly different to the mean TPP reported by Margolis et al. [14] [t(162) = 1.50, p > 0.05].

3.1.2. *Peak compensated static admittance (Y_{tm})*

Table 3 compares the mean, standard deviation, median, 5th percentile and 95th percentiles and significance of difference for Y_{tm} of the present study with that of other infant studies. Mean value of Y_{tm} from the present study was 0.16–0.91 mmho higher than that reported by most neonatal studies [6,14,22,23]. In comparison, median Y_{tm} value for three-to nine-month-old infants from Alaerts et al. [13] study was 0.6 mmho higher than the median Y_{tm} value from the present study. Further, the 5th percentile of Y_{tm} from the present study was 0.5–0.6 mmho higher than that obtained by other neonatal studies, but 0.08 mmho lower than that reported by Alaerts et al. [13].

Results of unpaired t-tests showed the mean Y_{tm} of the present study was significantly different to the mean Y_{tm} reported by Kei et al. [6] [t (222) = 11.03, p = 0.0001], Mazlan et al. [21] [t(273) = 11.14, p = 0.001], Shahnaz et al. [23] [t(148) = 4.73, p = 0.001] and Mazlan et al. [22] [t(234) = 7.23, p = 0.0001]. In contrast, mean Y_{tm} of the present study was not significantly different to that reported by Margolis et al. [14] [t(162) = 1.06, p > 0.05].

3.1.3. *Tympanometric width (TW)*

A comparison of the number of ears, mean, standard deviation, median, 5th percentile and 95th percentile values and significance of difference for TW between the present study and other studies is provided in Table 4. As shown in Table 4, mean TW of the present study was 15 daPa higher than that reported by Kei et al. [6,23] and 18 daPa lower than that reported by Shahnaz et al. [23] in neonates. Median TW reported in the present study was 20 daPa lower than that the median TW reported by Alaerts et al. [13]. The 5th percentile values of TW from the present study was similar to that reported by Kei et al. [6], but 27 daPa lower than that reported by Shahnaz et al. [23] and 47 daPa lower than that reported by Alaerts et al. [13].

Results of unpaired t-tests showed a significant difference in mean TW between the present study and Shahnaz et al.'s study [23] [t(148) =

Table 3
Comparison of peak compensated static admittance (Y_{tm}) across normative high frequency tympanometry (HFT) studies in young infants (Age of infants is in parentheses).

Peak compensated static admittance (Y_{tm} in mmho)	N	Mean	SD	Median	5th percentile	95th percentile	Significance
Present study (6 months)	118	1.46	0.81	1.28	0.70	3.70	
Kei et al., 2003 (1–6 days)	106	0.55	0.27	NA	0.2	1.1	S
Mazlan et al., 2009 (1–8 days)	157	0.66	0.34	NA	0.2	1.4	S
Shahnaz et al., 2008 - (3 weeks)	32	0.74	0.56	NA	0.1	1.9	S
Margolis et al., 2003 (2–4 weeks)	46	1.3	1	NA	0.1	3.5	NS
Mazlan et al., 2010 (6–7 weeks)	118	0.83	0.49	NA	NA	NA	S
Alaerts et al., 2007 (3–9 months)	30	NA	NA	1.88	0.78	3.55	NA

NA= Not available; N = number of infants; SD = standard deviation; S = significant ($p < 0.05$).
NS = not significant, ($p > 0.05$).

Table 4
Comparison of tympanometric width (TW) across normative high frequency tympanometry (HFT) studies in young infants (Age of infants is in parentheses).

Tympanometric width (TW in daPa)	N	Mean	SD	Median	5th percentile	95th percentile	Significance
Present study (6 months)	118	118	46	112	55	195	
Kei et al., 2003 (1–6 days)	62	103	29	NA	51.4	149.1	S
Shahnaz et al., 2008 (3 weeks)	32	136	41	NA	82	203	S
Alaerts et al., 2007 (3–9 months)	30	NA	NA	132	102	174	NA

NA= Not available; N = number of infants; SD = standard deviation; S = significant ($p < 0.05$).
NS = not significant, ($p > 0.05$).

2.01, p = 0.048]. Significant differences in mean TW between the present study and Kei et al.'s study [6] were also observed [t(178) = 2.33, p = 0.02].

4. Discussion

Tympanometry using a probe tone of 1000 Hz is recommended for evaluating middle ear function in infants from birth to six months of age [6,11–14,19,24]. While the HFT norms for neonates are established [6,7,16,23], there is limited normative HFT data for six-month-old infants [13,17]. Although Alaerts et al. [13] have reported HFT measures in infants between three and nine months of age, the authors have pooled the data across a large age range and hence, these results are not specific to six-month-old infants. Cai [17] has reported HFT data for limited sample of infants from birth to six-months of age. Age appropriate HFT data are necessary as significant developmental changes in the outer and middle ears in the first six months of life have been shown to alter HFT results [17]. The present study developed normative HFT data for use with six-month-old infants with single-peaked tympanograms.

To describe HFT measures in healthy six-month-old infants, two criteria were set for including ears for analysis: (1) a pass in DPOAE screening, and (2) a single-peaked tympanogram. Of the 336 ears from 168 infants recruited into the study, 193 ears (57.4%) met both criteria. The present study found that the proportion of infants who passed DPOAEs and had single-peaked tympanograms is significantly lower than that of HFT studies on neonates. For instance, Mazlan et al. [22] studied 297 neonates aged one to eight days and reported that 91.9% of neonates passed a transient evoked otoacoustic emission (TEOAE) test and exhibited a single-peaked tympanogram. Kei et al. [6] reported that 92.2% of 122 neonates passed both tests. Swanepoel et al. [7] reported a pass rate of 89.9% in 278 neonates. Low pass rates for six-month-old infants in the present study may partly be related to the physiologic noise and movement artifacts which affect DPOAE and tympanometry results. Another contributing factor to the low pass rates could be due to the increased risk of a conductive pathology in this age group compared to the neonates [25,26] because conductive hearing loss could not be completely ruled out with our testing paradigm.

While TPP is not a direct measure of the pressure in the middle ear space, it is the best estimate of middle ear pressure using tympanometry. The present study found a mean TPP of −30 daPa (90% range, −199 to 75 daPa) in six-month-old infants, which is significantly lower than that reported by other researchers for neonates and infants aged 6–7 weeks [16]. Studies have reported mean TPP of 0–8 day old infants to be between 9 and 18 daPa [6,21] and that of two to seven week old infants to be between −7 and −10 daPa [14,27]. Alaerts et al. reported median TPP of −52 daPa in infants between 3 and 9 months of age [13]. This suggests that TPP becomes more negative with age. This trend of decreasing TPP with age suggests that older infants up to the age of 9 months are at higher risk for Eustachian tube dysfunction than younger infants and neonates.

The present study found that 15% of six-month-old infants had TPP below −100 daPa which suggests these infants were at risk for Eustachian tube dysfunction [28–31]. However, TPP has not been found to be useful for the diagnosis of middle ear disorders and is not recommended as a screening tool for assessing middle ear disorders [32]. Fortunately, research has demonstrated that children with Eustachian tube dysfunction alone may have at most a mild hearing loss in the low frequencies [33,34].

The measurement of TPP using HFT is not always accurate as it is not possible to accurately measure ear canal volumes in infants. Without an accurate measure of ear canal volume, it is not possible to calculate pressure, since pressure equals density/volume [35,36]. Hence, TPP may not be an accurate predictor of middle ear status in infants [36–39]. Further, TPP appears to be a less useful criterion for tympanometric assessment in neonates due to large intersubject variability as evidenced by large standard deviation [7,16,18]. Nevertheless, further investigation is warranted to determine if a TPP of −100 daPa or less can impact on hearing sensitivity in six-month-old infants [40].

The HFT data revealed a mean peak compensated static admittance (Y_{tm}) of 1.46 mmho and a 90% range of 0.7–3.7 mmho for six-month-old infants. These results are significantly higher than that obtained from neonates and younger infants as reported by other researchers (see Table 3), and lower than the median values reported by Alaerts et al. [13] for three to nine-month-old infants. Cai [17] suggests that the increase in Y_{tm} in six-month-old infants may be indicative of rapid growth of the middle ear. In particular, the increase in volume of the middle ear cavity may result in an increase in admittance. The general trend of increasing static admittance during early infancy necessitates the consideration of age specific normative HFT data in infants.

The present study provided TW data for use with six-month-old infants with single-peaked tympanograms. When compared with that obtained from neonates, mean TW for six-month-old infants did not appear to change rapidly with age (see Table 4). Comparison of TW between the present study and other neonatal studies showed equivocal results. While there was a significant difference between the present study and Shahnaz et al. [23], there was no significant difference between the present study and Kei et al. [6]. Further, as TW shows low correlations with static admittance [41,42], TW would be an additional useful test parameter which provides supplementary clinical information to assist with the diagnosis of conductive conditions. For instance, Smith et al. [38] investigated various combinations of tympanometric peak height, peak pressure and width with otoscopic diagnosis of middle ear effusion in 6350 children under the age of 3 years. They reported that the lower the tympanometric height and the greater TW, the greater was the probability of associated middle ear effusion [43].

Overall, significant differences in mean TPP and Y_{tm} between the present study and neonatal studies suggest the need for age specific normative data in infants. Nonetheless, there were differences in methods between the present study and the neonatal studies. First, the age groups of subjects were different as shown in Tables 2–4 Second, the pass criteria were different across the studies. The present study used a single-peaked tympanogram and a pass in DPOAE. In comparison, neonatal studies required a pass in TEOAE [6,21,22] or AABR [23]. Studies have reported that both TEOAE and DPOAE tests are sensitive to middle ear conditions such as otitis media [44]. Third, some researchers have used the negative tail (−400 daPa) for peak compensation [14] while others have used the positive tail (200 daPa) [6,45]. Finally, some studies have included double-peaked or notched tympanograms [7,45] while others have included only single-peaked tympanograms [6]. Since double-peaked tympanograms are not uncommon and are accompanied with OAE pass results, researchers have suggested that notched/peaked tympanograms are suggestive of normal middle ear function for 1000 Hz probe tone measurements [7]. Lack of significant differences in TPP and Y_{tm} between the present study and Margolis et al. [14] may be accounted for by the small sample size used in the latter study.

The results of the present study showed no significant difference between male and female ears for TPP, Y_{tm} and TW. In contrast, eSilva et al. [46] reported a significant sex effect in neonates with males demonstrating higher static admittance than females. However, the authors claimed that the difference was too small to be of clinical significance. The present study also found no significant differences between right and left ears for TPP, Y_{tm} and TW. eSilva et al. [46] and Kei et al. [6] reported no significant differences between right and left ears for TW and TPP in neonates. These results suggest that a single set of norms is sufficient for male and female infants and for right ear and left ears.

At present, there are no universally accepted guidelines for interpreting HFT findings in neonates and young infants. Further, there are no guidelines on which HFT parameters should be included for collecting normative data. For instance, Marchant et al. [47] and Baldwin [11,21] proposed a classification system based on identifying positive versus negative peaks above a baseline between +200 and −400 daPa. Kei et al. [6] classified three types of tympanograms based on the configuration: Type 1 (single-peaked); Type 2 (flat or sloping), Type 3 (double-peaked). Presently, most clinicians report the presence of a positively peaked tympanogram as suggestive of normal middle ear function in neonates and young infants [6,47–49]. However, normative studies have shown a propensity for peak compensated static admittance to be used as one of the main parameters in examining HFT data. Based on the normative HFT data obtained from 157 healthy neonates, Mazlan et al. [21] proposed the following pass criteria: (1) a single-peaked pattern, and (2) static admittance (compensated at +200 daPa) within a 90% range of 0.23–1.35 mmho. Margolis et al. [14] recommended that a single-peaked tympanogram with static admittance compensated at −400 daPa of at least 0.6 mmho should be awarded a pass. It is not clear how important TW and TPP are in the interpretation of HFT results. Nonetheless, the normative data showing mean and 90% range of these parameters may serve as a reference to assist in the interpretation of HFT results.

Based on the data provided from 118 healthy ears of six-month-old infants, the normative region can be described as between the 5th and 95th percentiles. A pass in HFT may be considered if a single-peaked tympanogram with the static admittance (compensated at +200 daPa), TPP and TW fall in the 90% range. Should any infant not display parameter values within this range, the clinician should be alerted to the possibility of middle ear dysfunction. However, the HFT findings should be interpreted together with other test findings from a battery of objective tests such as auditory brainstem response (air- and bone-conduction), otoacoustic emissions and wideband absorbance measures. Future research should investigate the predictive accuracy of HFT to detect middle ear dysfunction in six-month-old infants based on these HFT normative data.

4.1. Strengths and limitations

The present study has described HFT data and established pass criteria in healthy six-month-old infants with single-peaked tympanograms. It provides valuable clinical information for establishing criteria for differentiating normal middle ear function from conductive conditions. The current practice of diagnosing middle ear conditions based on tympanometric configurations alone should be complemented with quantitative measures such as static admittance compensated at the positive tail (200 daPa), TW and TPP.

One of the limitations of the present study was the use of DPOAE outcomes as a reference standard. Although DPOAE measures are sensitive to conductive conditions [9], it cannot completely rule out conductive hearing loss and cannot be considered as a 'gold standard' for normal auditory function [50,51]. The other limitation was that only infants with single-peaked tympanograms were included in the present study. The middle ear status of ears with a double-peaked pattern, no discernible tympanometric peaks and irregular tympanogram shapes was not investigated.

5. Conclusion

In conclusion, significant differences in TPP and Y_{tm} between the present study and other neonatal studies suggest a developmental trend, and hence, the need for age-specific normative data in infants. The present study described HFT data in healthy six-month-old infants with single-peaked tympanograms. From these data, a set of pass criteria can be derived to assist in diagnosing conductive conditions in these infants.

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Financial disclosures/Conflict of interest

There is no conflict of interest with any of the authors.

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