4. RESULTS AND DISCUSSION

Chapter 4 presents the results obtained from analysis of data acquired during the study. Results are discussed according to the main aim and sub-aims formulated at the onset of the study. Significant findings are discussed and recommendations made based on the current research.

4.1 INTRODUCTION

The main aim of the study was to determine and describe the characteristics and normative values of high frequency (1000 Hz) acoustic immittance measurement results in a sample of infants (N = 510) attending maternal health care clinics. Methodological and data collection procedures, as described in Chapter 3, served as the basic structure for accrual and analyses of information to answer the research questions posed at the onset of this study. The large sample of infant ears on which OAE, high frequency tympanometry and acoustic reflexes were performed, allowed for the compilation of comprehensive normative data for 1000 Hz probe tone acoustic immittance measures.

Results from the test procedures were initially analysed for left and right ears separately but as no statistically significant difference was observed, ears were viewed as independent variables. P-values of Paired T-test analysis (Leedy & Ormrod, 2001:278; Durrheim, 1999:119) to test for differences between left and right ears are shown in Table 4.1.

TABLE 4.1 P-values for differences between left and right ears

Variable analysed for statistically significant difference between Left and Right ears	P-value	Statistically significant difference?
• **Peak admittance (mmho) of Y_a tympanograms**	P = 0.7451	No
• **Peak pressure (daPa) of Y_a tympanograms**	P = 0.1301	No
• **Peak admittance (mmho) of B_a tympanograms**	P = 0.5980	No
• **Peak pressure (daPa) of B_a tympanograms**	P = 0.6885	No
• **Peak admittance (mmho) of G_a tympanograms**	P = 0.6071	No
• **Peak pressure of G_a tympanograms**	P = 0.0743	No
• **Acoustic reflex threshold value**	P = 0.7917	No

As is evident from Table 4.1, paired *t*-tests revealed no statistically significant differences in the immittance data for the left and right ears individually as all p-values were > 0.05. Consequently the data of immittance measures were combined and results for left and right ears will be discussed as *independent variables*. Onwards the n-value will refer to the number of ears upon which the specific test procedures were performed as opposed to the number of infants (N).

Results will be presented according to the sub-aims formulated at the onset of the study and an interpretation and discussion follows each presentation of the results.

4.2 DESCRIPTION OF ADMITTANCE (Y_a) TYMPANOGRAM SHAPES AND CHARACTERISTICS WITHIN SUBGROUPS A AND B

As discussed in Chapter 3 (Figure 3.5) results rendered from OAE testing were utilized to divide the data in subgroups A and B. 869 ears (93%) that passed the initial OAE-screening, were considered to have normal middle ear functioning and were assigned to Group A. 67 ears (7%) failing OAE screening were assigned to Group B. Though sensory hearing loss could not be excluded at this time, research has shown that a high incidence of false-positive test results can occur in hearing screening programs due to transient middle ear effusion (Kei *et al.,* 2003:21, Roush, 2001:26). Furthermore, as the incidence of confirmed sensory-neural hearing loss is relatively low, (one to two out of every 1000 in the USA), one in 67 subjects will have a negligible effect on the result. Thus 93% of the total sample of ears were therefore assumed to have *normal middle ear* functioning (OAE pass result), in addition to 7% of ears with possible middle ear effusion.

1000 Hz probe tone admittance tympanograms were analysed in terms of shape and characteristics, and compared to OAE results. Conclusions were drawn from associations between OAE pass or fail and corresponding tympanometric results to indicate normal or abnormal middle ear functioning.

Pass-fail results obtained for the recorded 1000 Hz probe tone admittance tympanograms are presented in Figure 4.1.

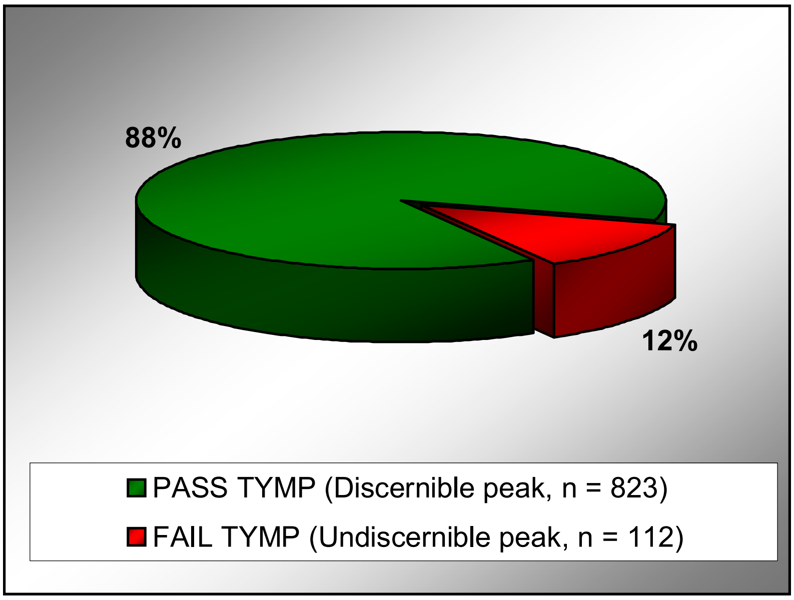


Figure 4.1 Results of admittance (Y_a) tympanometry (n = 936)

Figure 4.1 shows the relationship between ears in which normal, peaked tympanograms (pass) were recorded and ears displaying tympanograms suggestive of middle ear effusion (flat, with no discernable peak). 88% (n = 823) of the ears of the total case sample displayed normal, peaked tympanograms, while flat tympanograms, were recorded in 12% (n = 112) of the test ears.

Similar results for classification of tympanograms by shape were described by Sutton *et al*. (1996:11), although the authors further sub-classified tympanograms in terms of measurements from maximum peak compliance, raw data revealed 91% (153/168) peaked tympanograms and 9% (15/168) flat tympanograms (Sutton *et al.,*1996:11). In describing characteristics of 1000 Hz tympanograms, Kei *et al.,* recorded single peaked tympanograms in 92% (225/244) of their test sample. Pass-fail results for 1000 Hz tympanometry described by Margolis *et al.* (2003:388) varied for infants of different age groups. Test subjects of at least two weeks chronological age, revealed higher pass rates for tympanometry compared to subjects tested in the neonatal period. Margolis *et al.,* (2003:389) found that although pass results for newborns may be lower than for older infants, the pass rates are sufficiently high that 1000 Hz tympanometry may be useful for identifying potential middle ear problems.

4.2.1 Associations between results of OAE-testing and tympanogram shape

As there is no “gold standard” for the identification of middle ear effusion in infants, tympanometry as identification method of pathology could be validated by comparing results of tympanometry with other tests of auditory function. The effect of middle ear effusion on recording of OAEs has been described in earlier chapters and hence a correlation between test results obtained for tympanometric measurements and OAE-test results was performed. A significant concurrence between OAE and tympanometry results (pass associated with pass and conversely) would suggest the effect middle ear effusion can have on OAEs in addition to the sensitivity of 1000 Hz tympanometry to identify middle ear effusion. Similar analysis was described by Sutton *et al.,* (1996:10) in a study investigating the relationship between OAEs and tympanometry. A comparison between reported and current results will be given.

Associations between results obtained from OAE-testing and tympanogram shape are presented in Figure 4.2 and Figure 4.3.

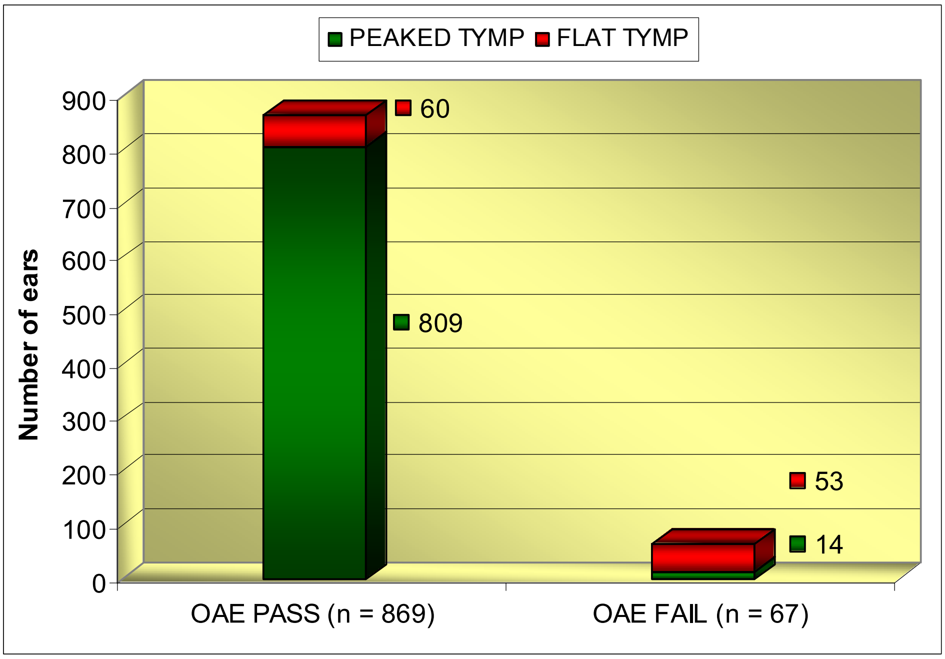


Figure 4.2 Relationships between OAE and Tympanometry results (n = 936)

As can be derived from Figure 4.2, OAE pass results were recorded in 869 ears and OAE fail results were recorded in 67 ears. Of the ears that passed OAE testing (n = 869), *93%* (809) of ears also produced a *peaked tympanogram;* whilst OAE pass results were obtained in 7% (60) of ears that displayed *flat tympanograms*. Of the ears in which an *OAE fail* result (n = 67) was recorded, *79%* (53) displayed *flat tympanograms,* while 21% (14) of ears with an OAE fail result displayed peaked tympanograms. Mann-Whitney (Leedy & Ormrod, 2001:278) and *t*-test analysis (Durrheim, 1999:119) verified statistically significant differences between the group with OAE pass and peaked tympanogram results, and the group with OAE fail combined with flat tympanogram results ($p < 0.05$).

Figure 4.3 more prominently illustrates the associations between OAE pass and peaked tympanogram results, and between OAE fail and flat tympanogram results.

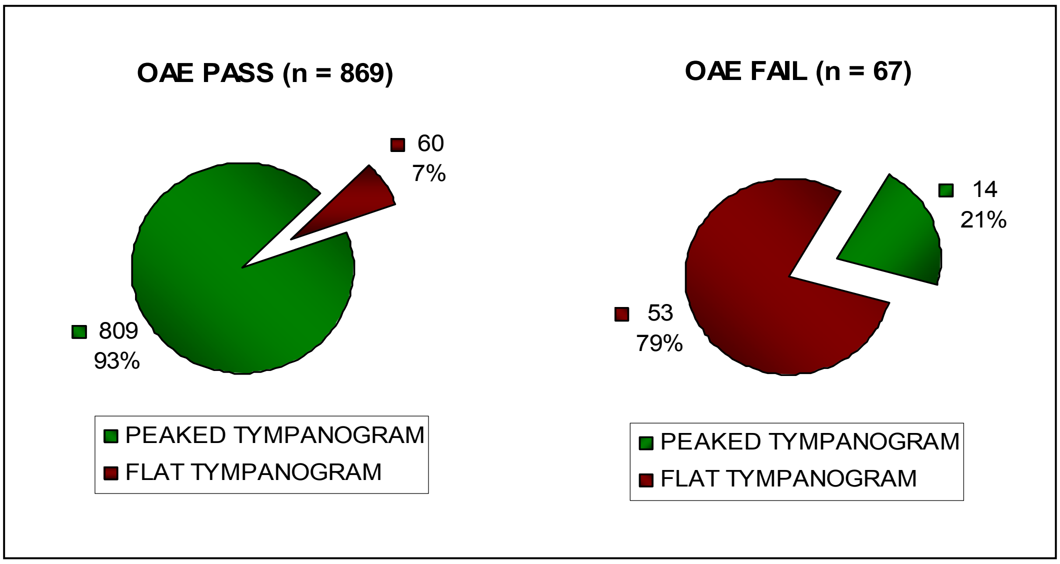


Figure 4.3 Independent relationships between OAE results and peak or flat tympanograms (n = 936)

It is clear within the separate subgroups that an OAE pass result was highly associated with a peaked tympanogram result, and conversely an OAE fail result was highly associated with a flat tympanogram response curve. This indicates that high frequency (1000 Hz) tympanometry shows good sensitivity and specificity to the assessment and identification of normal and abnormal middle ear functioning.

These results are in agreement to results by Sutton *et al.,* (1996:12), who concluded that a 1000 Hz probe tone showed greater sensitivity for identification of middle ear pathology, as opposed to a 678 Hz probe tone. Sutton *et al.,* (1996:12) found that when comparing 678 Hz probe tone tympanometry to OAE results, about half (16/33) of the OAE fails had abnormal tympanograms. In contrast, however, this study indicated a significantly higher association of 79% (53/67) between OAE-fail, and abnormal tympanogram results. This supports the finding that 1000 Hz tympanometry shows greater to the identification of middle ear pathology. Similar results were also published by Kei *et al.,* (2003:26), who reported 92.3% of ears passing OAE testing displayed single peaked 1000 Hz tympanograms. A disparity was noted between current results and that of

Thornton *et al*., (1993:320) who did not find tympanogram shape to have a significant effect on the outcome of OAE measurement. Though significant associations between OAE pass results and peaked tympanograms, and between OAE fail results and flat tympanograms were obtained, there was evidence from results of the current research to confirm the notion that passing OAEs cannot serve as a gold standard for normal middle ear function (Kei *et al.,* 2003:26) as 7% (60) of ears with OAE pass results, displayed flat 1000 Hz tympanogram response curves.

In agreement to Sutton *et al.,* (1996:15), results obtained during this study are consistent with the conclusion that OAEs are sensitive to middle ear effusion and are usually abolished by it. Significant associations were found between *OAE pass* and *peaked* tympanograms results, and also between *OAE fail* and *flat* tympanograms results. It can therefore be concluded that the outcome of OAE testing is highly associated with tympanogram shape when a 1000 Hz probe tone is employed.

To assess the effect of peak pressure and admittance values in admittance tympanograms on OAE outcome, a discussion of these values, as related to OAE results will follow in the next section.

4.2.2 Maximum admittance and tympanometric peak pressure values for Y_a tympanograms within subgroups A and B

Maximum (peak) uncompensated acoustic admittance and corresponding tympanometric peak pressure were analysed for admittance (Y_a) tympanograms within subgroups A and B. Statistically significant differences ($p < 0.05$) (Durrheim 1999:119) were observed between results obtained from measurements for Group A, classified to have normal middle ear functioning and Group B, classified to have middle ear effusion. Mann-Whitney analysis (Leedy & Ormrod, 2001:278) of results from Group A and Group B revealed highly significant differences for peak admittance ($p = 0.000$) and for tympanometric peak pressure ($p = 0.000$).

OAE results were considered the criterion for the initial classification of ears into Group A (normal middle ear functioning) or Group B (abnormal middle ear functioning). As discussed in section 4.2.1, 93% of ears with an OAE pass result, also displayed a peaked tympanograms, whilst 7% of ears with an OAE pass result displayed no discernable tympanogram peak. Of the total number of ears in which peaked tympanograms were recorded (n = 823 ears), 809 presented with a corresponding OAE pass result, whilst only 14 ears corresponded to an OAE fail result.

Values obtained and analysed from admittance (Y_a) tympanograms are presented in the following section. In ears with discernable tympanograms peaks values were measured at the point of maximum displacement on the peak, whilst for the 7% of tympanograms where no discernable peaks were present, the highest point on the tympanogram was marked to obtain a maximum admittance value (mmho) with a corresponding pressure value (daPa). In the case of double peaked tympanograms, measures were taken from the highest peak.

The distribution of admittance and tympanometric peak pressure (TPP) values for the recorded tympanograms in Groups A and B are presented in Figures 4.4 and 4.5.

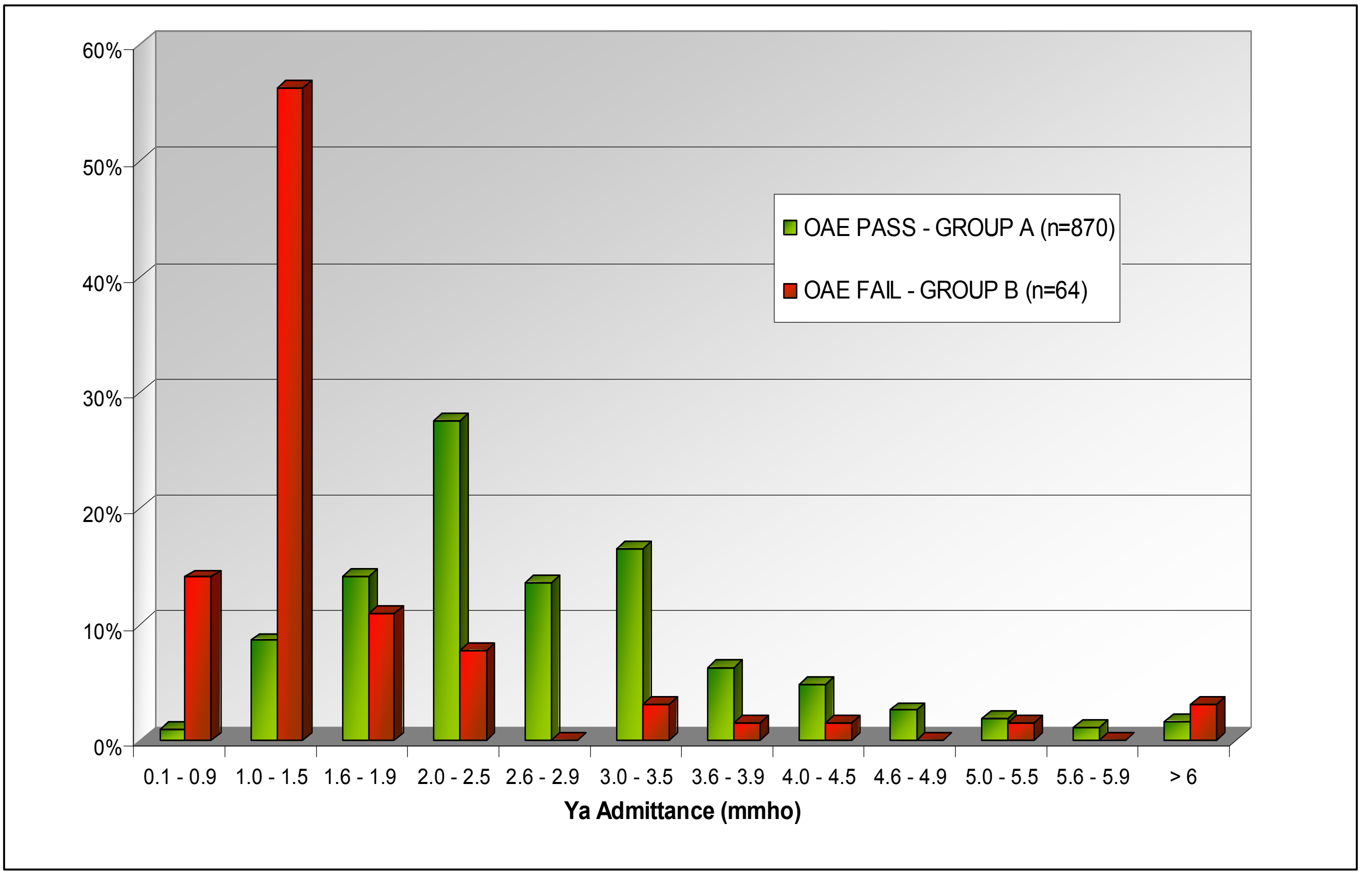


Figure 4.4 Distribution of maximum Y_a-*admittance values* for ears with OAE pass and refer results (n = 934)

The mean value for uncompensated acoustic admittance for peaked Y_a tympanograms was recorded at 2.85 mmho, with a standard deviation of 1.13 mmho. Maximum peak admittance corresponding to an OAE *pass* result was recorded at 9.64 mmho and minimum peak admittance relating to OAE *pass* result was 0.86 mmho. For the OAE pass group, the majority (77%) of the admittance values were 2 mmho and greater, compared to the majority (81%) of admittance values for the OAE refer group being less than 2 mmho. Although an overlap of results is visible, it is evident from Figure 4.8 that there is a clear trend toward lower Y_a-admittance values for the OAE refer group. Though the range for acoustic admittance relating to an OAE pass result was quite big, it is evident from Figure 4.8, that 75% of ears (n = 606) displayed admittance values between 1.6 and 3.5 mmho.

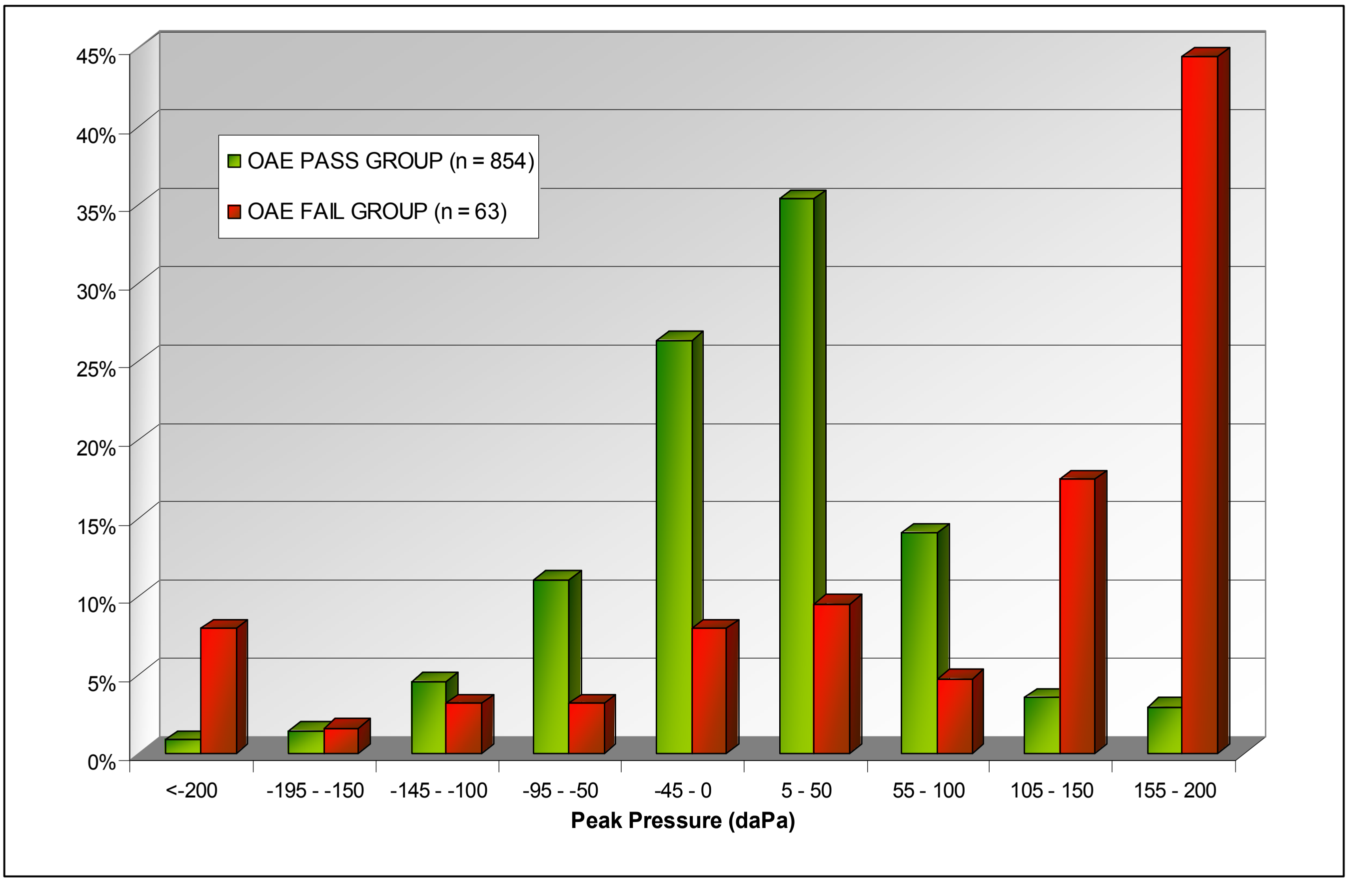


Figure 4.5 Distribution of tympanic peak pressure values for ears with OAE pass and refer results (n = 917)

Figure 4.5 shows the distribution of middle ear pressure results for ears with OAE pass and refer results. The mean pressure value for ears *passing* OAE testing was 0.13 daPa with a standard deviation of 60.93 daPa. The highest extreme pressure value related to an OAE pass resulted was 185 daPa, and the lowest extreme was measured at -275 daPa. For the OAE refer group the majority (62%) of tympanic peak pressure values were greater than 105 daPa, compared to the majority (62%) of tympanic peak pressure values for the OAE pass group being between -45 and 50 daPa. It is evident from Figure 4.5 that compared to the OAE pass group, there is clear trend indicating more positive pressure values for the OAE refer group. Additionally 8% of the OAE refer group indicated peak pressure values less than -200 daPa, compared to a 1% incidence in the OAE pass group. This indicates that positive peak pressure values exceeding 105 daPa, as well as negative pressure values of ≤ -200 daPa are more prone to OAE refer results, compared to pressure values for the OAE pass group. Similar results were reported by Thornton *et al.*, (1993:321) who found that high positive middle ear pressures (>150 daPa) correspond with OAE failures.

OAE pass results were highly associated with tympanic peak pressures values *greater than -100 daPa and smaller than 100 daPa*, with 87% of ears in the OAE pass group falling within this region. These results are in agreement with Trine, Hirsch & Margolis (1993:406) who reported that negative middle ear pressure ≤ -100 daPa reduced the overall amplitude and reproducibility of TEOAEs. They concluded that middle ear pressure affects the amplitude, reproducibility, and spectral characteristics of TEOAEs (Trine *et al.,* 1993:406). Thornton *et al.,* (1993:321) found vast overlapping in middle ear pressures for groups that failed and passed OAE testing and concluded that though the effect of middle ear pressure was statistically significant, it seems unlikely that it could account for more that a small percentage of cases that fail OAE testing. Results from the current study and that of previous reports are however consistent with the finding that there is an apparent relationship between middle ear pressure, measured using a 1000 Hz probe tone, and OAE pass or fail results in neonatal and infant ears (Thornton *et al.,* 1993:322).

Among the group of ears with peaked tympanograms, a number of double peaked tympanograms were recorded. A description of results from double peaked tympanograms is presented in the next section.

4.2.3 Double peaked tympanograms

The number of double peaked tympanograms recorded in this study revealed that 5% of ears (n = 41) in which a peaked tympanograms (n = 823) were recorded, displayed double peaked admittance response curves. This is notably higher than the number of double peaked tympanograms recorded by Kei *et al.,* (2003:24) who reported recording of double peaked 1000 Hz tympanograms for only 3 out of 224 ears (1%). The discrepancy in results between the present study and that of Kei *et al.* (2003:24) may be attributed to differences in sample size (122 neonates in study by Kei *et al.* in comparison to 512 neonates in present study) and possibly even more so to age differences between samples (mean age of 3.26 days in study by Kei *et al.* compared to a mean age of 15.74 weeks in the present study). Holte *et al.,* (1991:13) found that as probe frequency increased more tympanometric types and shapes were recorded for all age groups, but that by the age of 4 months, the majority of infants had single peaked tympanograms. The oldest subject in whom a double peaked tympanogram was recorded in the present study was aged 44 weeks.

The relationship between male to female infants with double peaked tympanograms is illustrated in Figure 4.6.

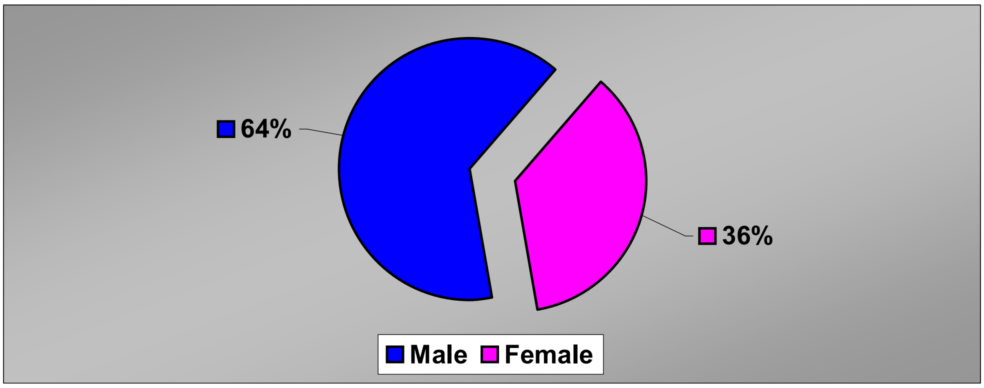


Figure 4.6 Gender relation of ears displaying double peaked tympanograms (n = 41)

As is evident in Figure 4.6, double peaked tympanograms were recorded in 64% (n=27) male infants compared to 36 (n=15) female infants. This *gender difference* is an interesting finding which may validate further research as the number of male to female ears with double peaked tympanograms, displayed a ratio of almost two to one. As double peaked tympanograms are generally less common, no large scale study has been performed to assess gender relations in double peaked tympanograms.

According to Thornton *et al.,* (1993:320), when using a high frequency probe tone with an infant's small ear canals, double peaked tympanograms are quite normal. Consequently tympanograms which displayed a double peak were judged as normal and included in the group of 'peaked' tympanograms, classified as normal. Double peaked tympanograms were also included in the case sample used for compiling normative values for 1000Hz tympanometry by Margolis *et al.,* (2003:387).

Further validation for judging double peaked tympanograms as normal, was performed by exploration of OAE results in the group displaying double peaked tympanograms. Results are illustrated in Figure 4.7.

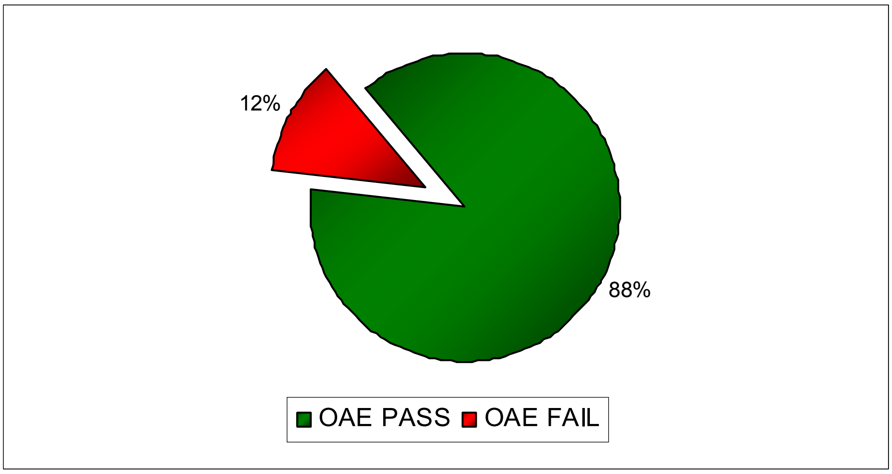


Figure 4.7 OAE test results of ears that displayed double peaked tympanograms (n = 42)

Congruent to reports by Thornton *et al,* (1993:320) double peaked tympanograms can be judged as normal, and current results revealed that, compared to OAE testing, 88% (n = 37 out of 42) of ears with double peaked tympanograms showed OAE pass results. 12% (n = 5 out of 42) of ears displaying double peaked tympanograms failed OAE testing. Further comparisons between OAE test results and the presence of double peaked tympanograms, revealed that within the total case sample of OAE pass results (n=869), 37 d*ouble peaked* tympanograms were recorded, while 5 out of the 67 ears with an OAE fail result displayed a double peaked tympanogram.

Due to the greater contribution of elements of mass in the newborn middle ear system, as opposed to elements of stiffness in the adult middle ear, tympanometric patterns observed in newborn infants do often not conform to the classic patterns found in older infants, children, and adults. Low frequency probe tone tympanograms are more likely to show notching or complex patterns in infants (Purdy *et al.,* 2000:10), while more informative tympanometric recordings in neonates are derived using higher probe tone frequencies (Shahnaz, 2003:3). Shahnaz (2002 in Shahnaz 2003:3) found that at 1000Hz admittance tympanograms had a single peak for 74% of infant ears. The author concluded that in the infant ear, admittance tympanograms become simpler in shape as probe frequency increases, the reverse of what is found in adult ears, where admittance tympanograms become more complex as probe frequency increases. Holte *et al.,* (1991:13), found that when using the Vanhuyse model of tympanometric shapes to classify tympanograms according to the number of extrema in the susceptance and conductance tympanograms, *more tympanometric types* were recorded for all age groups, and the types were *more complex*, as probe frequency increased. Examples of double peaked tympanograms recorded during this study are presented in Figure 4.8.

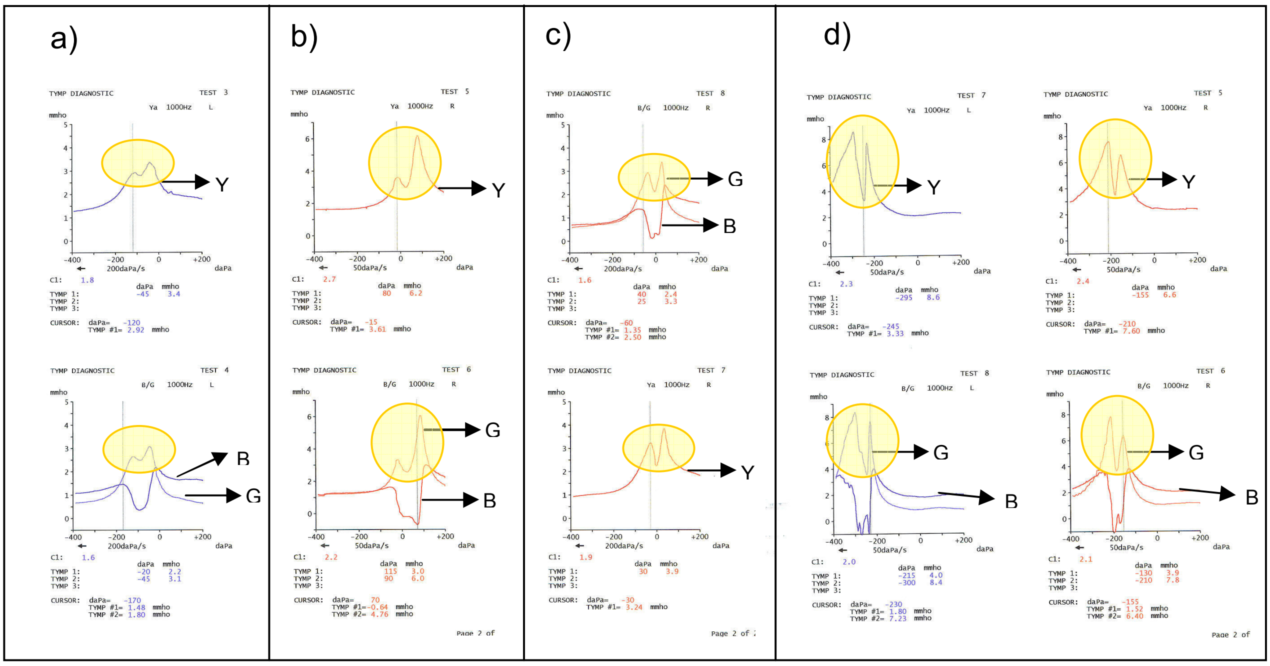


Figure 4.8 Examples of double peaked tympanograms

a) Double peaked tympanogram recorded from the left ear of an infant aged 36 weeks. A single peaked tympanogram was recorded from the right ear. OAE pass result was recorded from left (and right) ear and acoustic reflex was present bilaterally. b) Double peaked tympanogram recorded from the right ear of an infant aged 40 weeks. A single peaked tympanogram was recorded from the left ear. OAE pass result was recorded from right (and left) ear and acoustic reflex was present bilaterally. c) Double peaked tympanogram recorded from the right ear of an infant aged 9 days. A single peaked tympanogram was recorded from the left ear. OAE pass result was recorded from right (and left) ear. Acoustic reflex not recorded. d) Double peaked tympanograms recorded from right and left ears of the same infant aged 36 weeks. OAE refer results were recorded bilaterally and acoustic reflexes were absent. A pass result was obtained on AABR screening for the right and left ear.

Figure 4.8 depicts examples of double peaked tympanograms obtained during this study. Though it was beyond the scope of this study to investigate the significance and occurrence thereof, it was of interest to note that in all these examples (and the majority of all double peaked tympanograms obtained) notching occurred in the G_a (conductance) tympanograms at approximately the same pressure point as in the Y_a (admittance) tympanograms. When classified according to the Vanhuyse classification system the double peaked tympanograms showed a frequent 5B3G type tympanogram. Figure 4.8 a), b), and c) were all associated with an OAE pass result, while d) was associated with an OAE fail result. OAE failure in Figure 4.8 d) can be related to the considerable negative pressure at peak admittance, measured as –210 daPa at point of maximum displacement in the admittance tympanogram. This association is in agreement with Sutton *et al.,* (1996:13) who concluded that negative pressure, as measured with high frequency tympanometry, had a marked effect on OAEs.

4.3 SUSCEPTANCE (B_a) AND CONDUCTANCE (G_a) TYMPANOGRAM ANALYSIS AND DESCRIPTION

As discussed in Chapter 2, *component* tympanometry refers to measurement of the susceptance (B_a) and conductance (G_a) components of a tympanogram, which provides an adequate view of the magnitude and direction of the admittance. Because of the variety of tympanometric shapes that can occur in normal as well as abnormal ears at higher probe frequencies, evaluation of these two components is important for the interpretation of tympanograms measured with high frequency probe tones than for tympanograms measured with a 226 Hz probe tone (Wiley & Fowler, 1997:56).

The immttance measurement instrument utilized in this study allowed for simultaneous measurement of susceptance (B_a) and conductance (G_a) components. B_a and G_a tympanograms were successfully recorded from 889 ears (96%). Though it was beyond the scope of this study to statistically analyse and classify the shape of susceptance and conductance tympanograms, a number of examples of recorded tympanograms are presented in Figure 4.9. Specifically note the difference in notching patterns in the B/G tympanograms that are evident across all age groups depicted. Notching was mainly evident in the susceptance (B_a) tympanograms and this pattern was in agreement with Holte *et al.,* (1991:9) who found that reactance shifts towards mass with high probe frequencies and towards asymmetrical resistance, with the interactions resulting in notched susceptance (B_a) tympanograms. Similar results were seen for all tympanograms recorded throughout this study with a general trend for single peaked conductance (G_a) tympanograms and notching occurring in the susceptance (B_a) tympanograms only. As also illustrated in Figure 4.9, a second frequent shape across the age range of subjects was a single peaked conductance tympanogram, in conjunction with a single peaked susceptance tympanogram. With reference to the Vanhuyse *et al.* (1975 in Fowler & Shanks, 2002:191) classification system (see Chapter 2, Figure 2.5), these shapes can be classified according to the number of extrema in the susceptance and conductance tympanograms, and hence the most frequent shapes observed can be classified as *3B1G and 1B1G*. It is evident from the presented examples that a great range of variation of tympanogram shape occurs across all age groups with the most frequent shape being the 3B1G and 1B1G Vanhuyse type. Initially resistance is greater than reactance and the B_a tympanogram is expected to show a double peak gradually changing to a single peak as the resistance-reactance relationship changes (Vanhuyse *et al.,* 1974 in Meyer *et al.,* 1997:192). When the height of the susceptance (B_a) tympanogram is greater than the height of the conductance (G_a) tympanogram and both are single peaked (1B1G), the acoustic admittance vector is between 90° and 45° (see Figure 2.4) and relates to a stiffness-controlled middle ear (Fowler and Shanks, 2002:191). This shape can be seen in Figure 4.9 - ii) d; iii) d; iv) c; v) c; vi) b; vii) d; viii) a and b; ix) b. More complex configuration and notching patterns were observed in susceptance and conductance tympanograms, while 95% of ears displayed single peaked admittance (Y_a) tympanograms. Highly significant associations between OAE pass results and peaked tympanograms and between OAE fail results and flat admittance tympanograms, suggest that admittance tympanograms have good sensitivity and specificity for middle ear status.

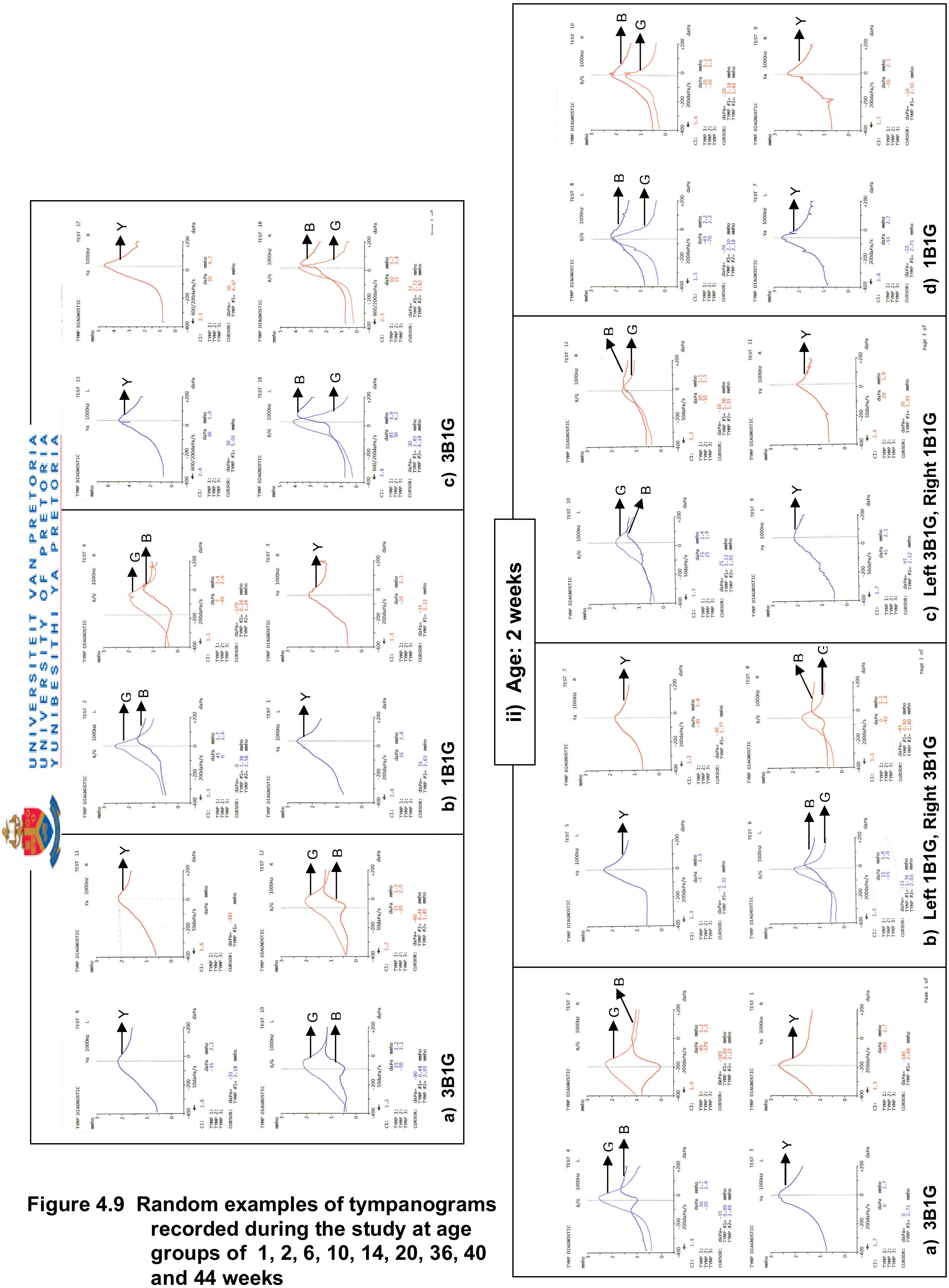
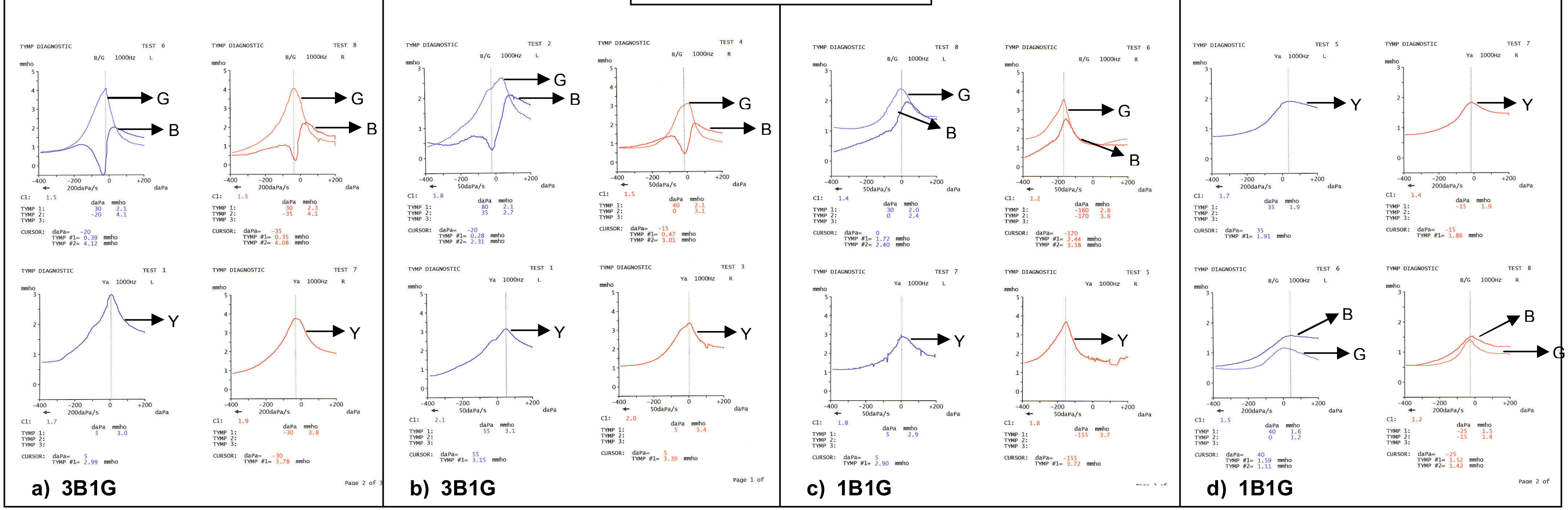
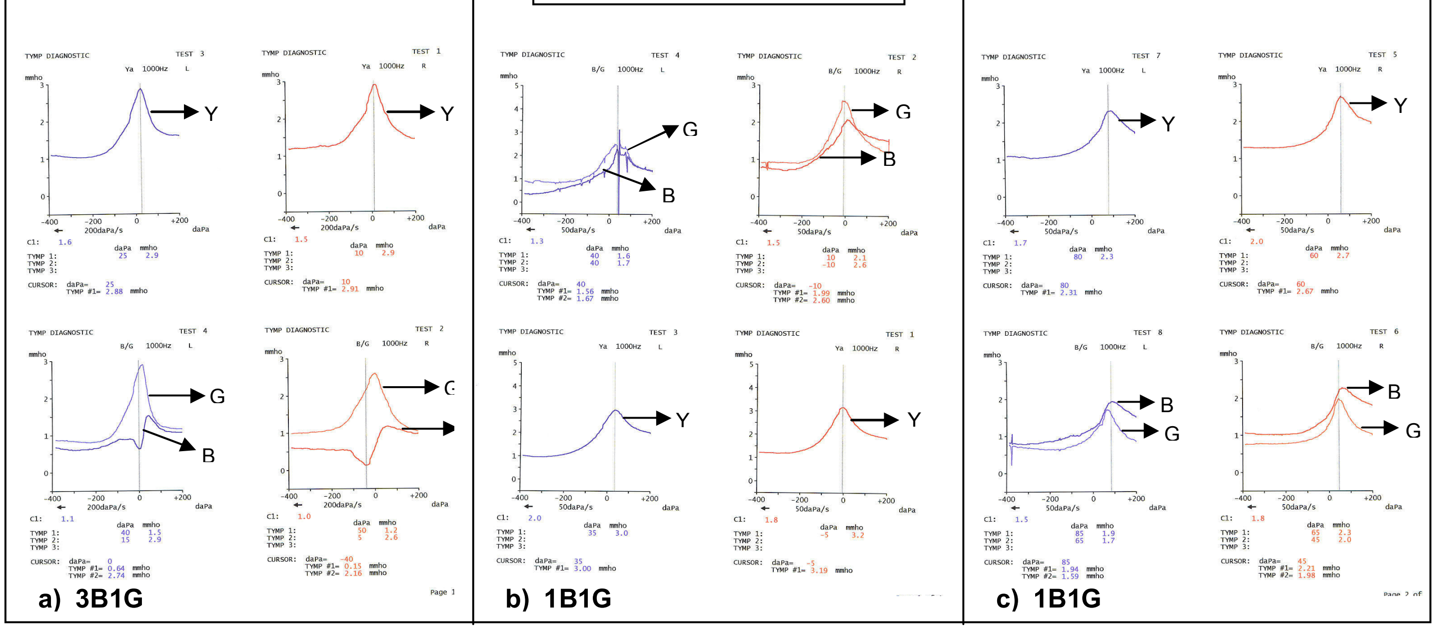


Figure 4.9 Random examples of tympanograms recorded during the study at age groups of 1, 2, 6, 10, 14, 20, 36, 40 and 44 weeks

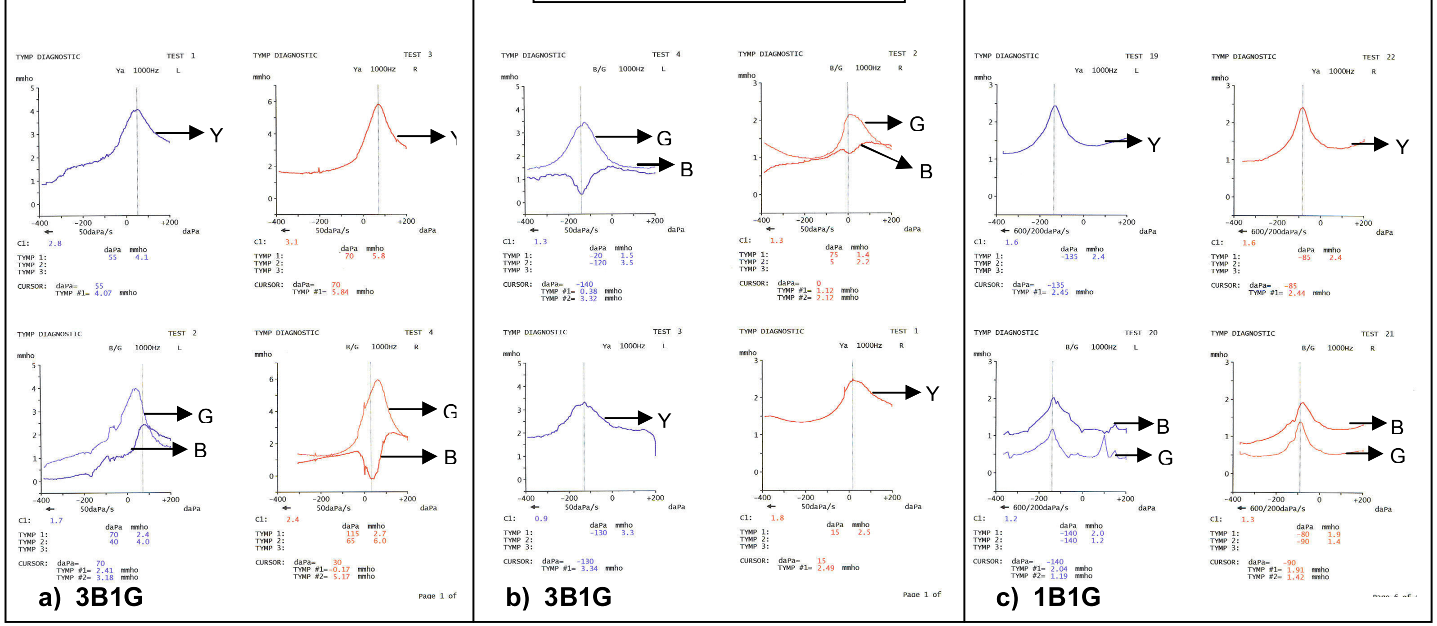
iii) Age: 6 weeks



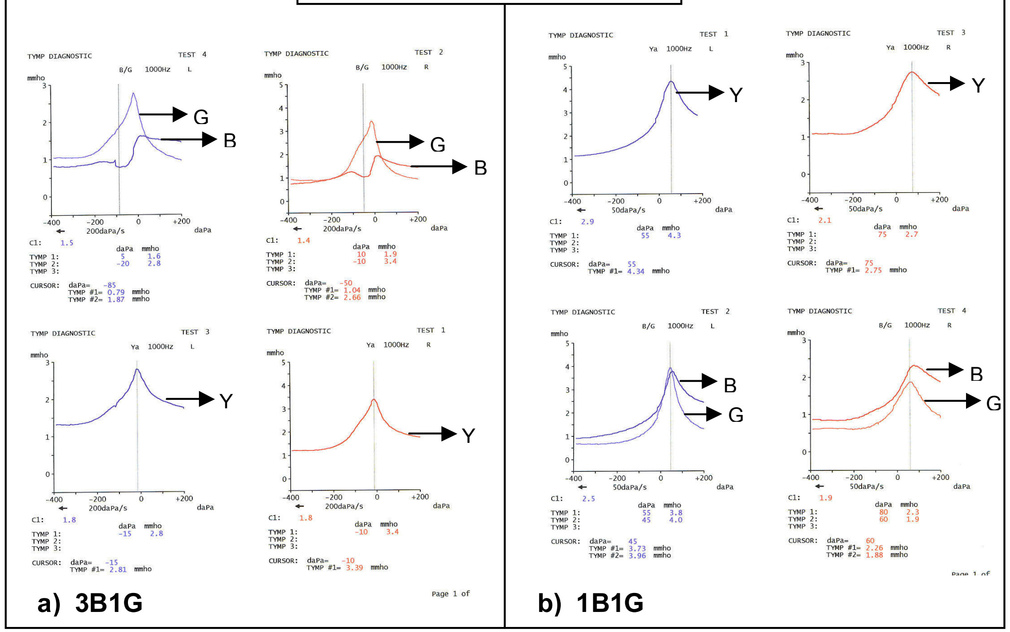
iv) Age: 10 weeks

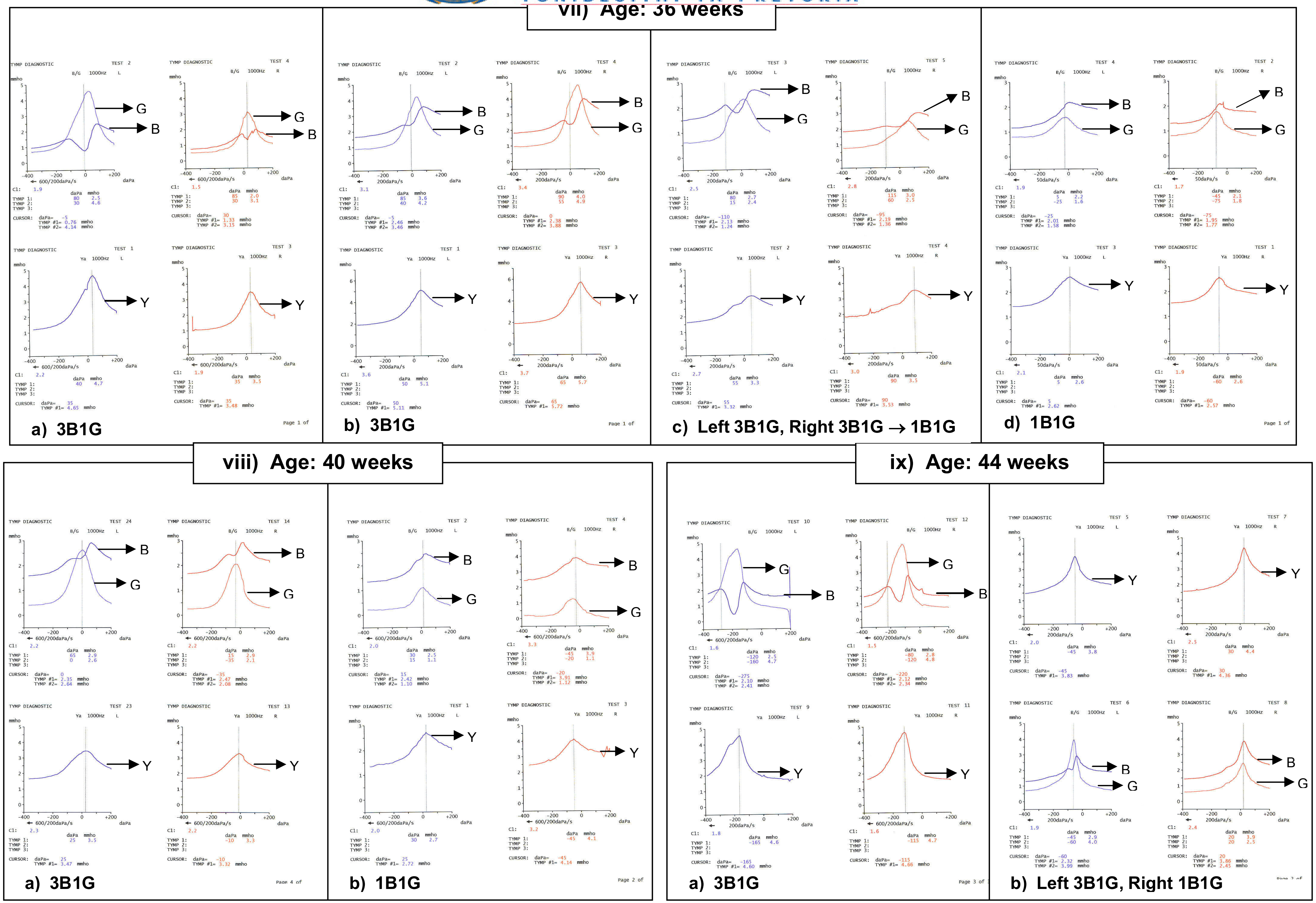


v) Age: 14 weeks



vi) Age: 20 weeks




vii) Age: 36 weeks
a) 3B1G
b) 3B1G
c) Left 3B1G, Right 3B1G → 1B1G
d) 1B1G
viii) Age: 40 weeks
a) 3B1G
b) 1B1G
ix) Age: 44 weeks
a) 3B1G
b) Left 3B1G, Right 1B1G

4.4 ACOUSTIC REFLEXES USING A HIGH FREQUENCY PROBE TONE

The acoustic reflex can be a very useful part of the audiologic evaluation of infants. A present acoustic reflex is added support for normal middle-ear function, and as the reflex arc involves the seventh and eighth nerve and the low brainstem, a normal or present reflex can be useful in ruling out abnormalities such as Auditory Neuropathy (Sininger *et al.,* 2003:380).

Acoustic reflexes using a 1000 Hz probe tone were evaluated at 1000 Hz in 840 ears of infants who tolerated the entire test battery. Results of reflex measurement from the present study are illustrated in Figure 4.10.

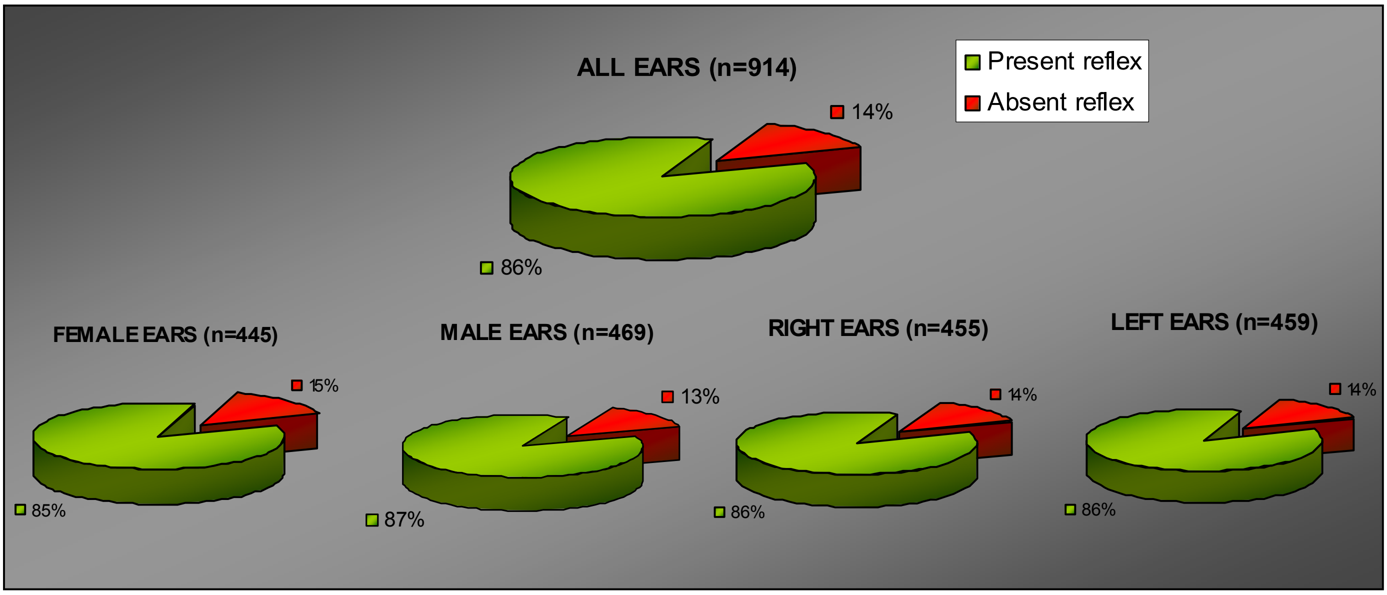


Figure 4.10 1000 Hz acoustic reflex results using a 1000 Hz probe tone (n = 914)

Figure 4.10 shows the results of acoustic reflexes recorded in the total case sample and results for male versus female, and left versus right ears. As is clearly evident from Figure 4.10, no significant differences were observed between left and right, and male and female ears ($p > 0.05$). Present acoustic reflexes were recorded in 86% (n=785) of the ears tested. In 14% (n=129) of the ears no reflexes were recorded. In view of the fact that present acoustic reflexes were recorded in a significantly high proportion (86%) of the test subjects, the above results are consistent with Weatherby and Bennett (1980:106), and support the validity of high frequency probe tones for measurement of acoustic reflexes in infants. Wetherby and Bennett (1980:107) demonstrated that neonatal acoustic reflexes were not measurable using 226 Hz probe tones, but when employing high frequency probe tones, acoustic reflexes were obtained at levels comparable to adults. *This suggests that the use of a high frequency probe tone for measurement of acoustic reflexes is more sensitive in infants and shows promise for inclusion in audiologic assessment protocols in infants*. To arbitrate this application, a discussion of the degree of association between acoustic reflexes and OAE's, and between acoustic reflexes and tympanometry will follow.

4.4.1 Comparison of acoustic reflex measurement results with OAE and tympanometry results

A comparison of reflex measurement- to OAE results is provided in Figure 4.11 to indicate the relationship between OAE and acoustic reflex testing results.

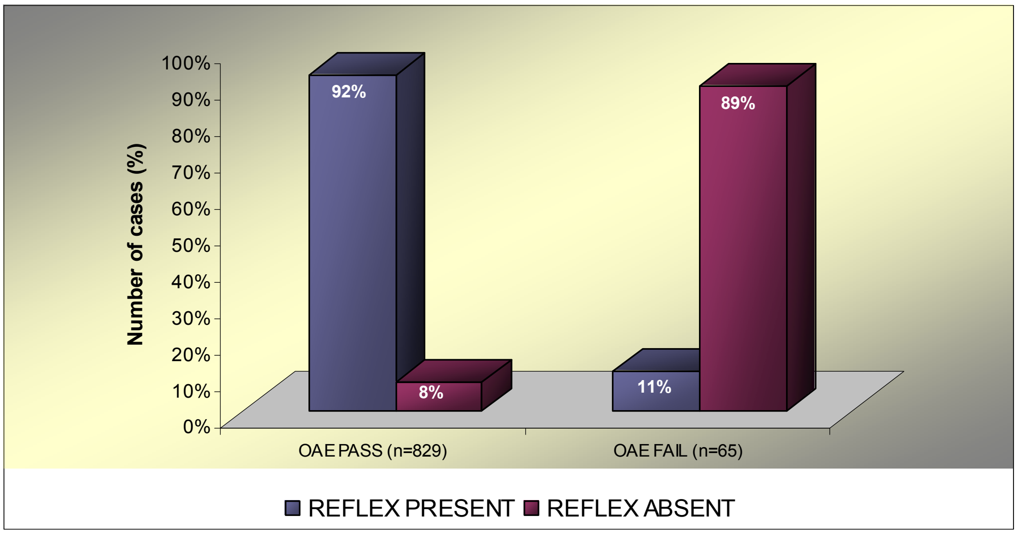


Figure 4.11 Distribution of acoustic reflex compared to OAE results

As presented in Figure 4.11 acoustic reflex arcs were recorded in 92% (n=763) of ears who passed OAE testing, while 8% (n=66) of ears obtaining and OAE pass result displayed absent acoustic reflexes. In the group of infants failing OAE testing, 89% (n=58) also had absent acoustic reflexes, though reflexes were present in 11% (n=7) of this group. As OAE and acoustic reflex measurement require normal middle ear transmission (Casselbrandt *et al.,* 2002:96; Gelfand, 2002:208), acoustic reflex results obtained in the current study were compared with results of 1000 Hz tympanometry. Results are presented in Figure 4.12.

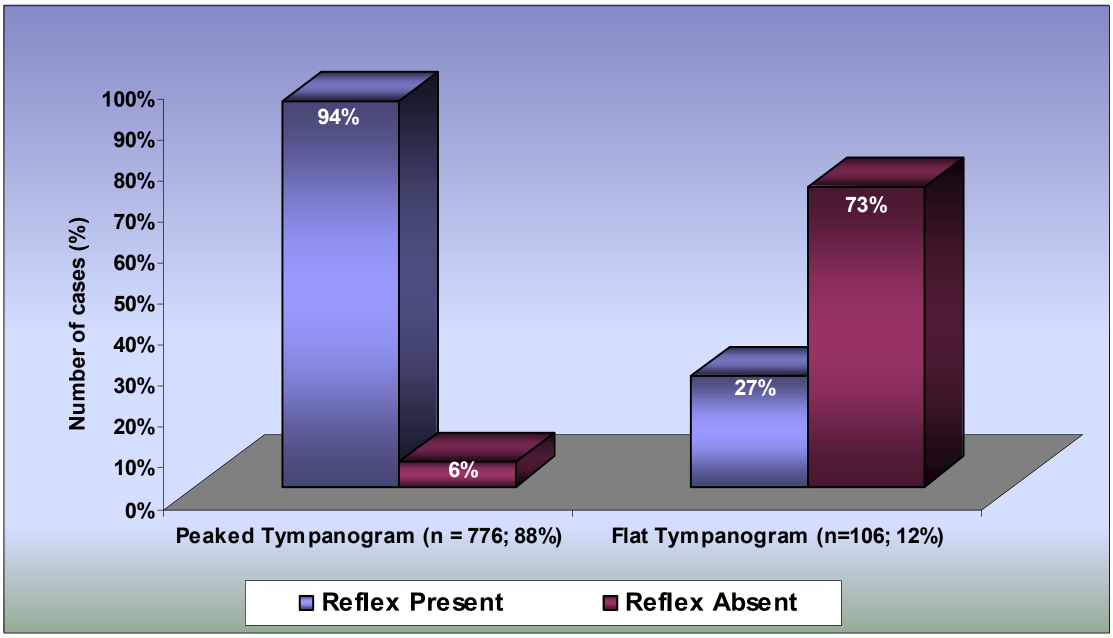


Figure 4.12 Relationship of tympanometry to acoustic reflex results (n = 882)

Results of acoustic reflex measurement with a 1000 Hz probe tone indicate a high percentage of present acoustic reflexes (86%). McMillan *et al.,* (1985:146) reported similar findings and recorded present acoustic reflexes in 95% of infant ears when a 660 Hz probe tone was used. Contrary to current findings, Sutton *et al.,* (1996:12) reported acoustic reflexes, measured with a 678 Hz probe tone, to be absent in most of the ears with *normal* tympanograms and in most of the ears *passing* OAE testing. This difference in findings can be attributed to the risk status and young age of the neonates, as well as to the use of a 678 Hz probe tone as opposed to a 1000 Hz probe tone. Current findings are also in contrast to reports on poor reliability of recording present reflexes using a low frequency probe tones in infants (Gelfand, 2002:212). This can be attributed to the fact that: 1) a 1000 Hz probe tone was used, 2) an ipsilateral stimulus was used, and 3) a mid-frequency (1000 Hz) stimulus was used to activate the reflex.

Significant associations between OAE pass results, peaked tympanograms and present acoustic reflexes were evident. Normative values for present 1000 Hz probe tone acoustic reflex measures, corresponding to an OAE pass result and a peaked tympanogram, will be discussed in the final section of this chapter.

Preliminary normative data for 1000 Hz probe tone tympanometry compared to OAE results have recently been reported, although previous studies were limited in sample size and encompassed a limited age range (Kei *et al.,* 2003:23 – 25; Margolis *et al.,* 2003:385 – 388). The current study therefore presents data that can be used to establish normative data for 1000 Hz tympanometry and acoustic reflexes within a large sample of infants ranging in age from one day to one year. This normative data will be discussed in the following section.

4.5 HIGH FREQUENCY (1000 Hz) IMMITTANCE NORMS

Various authors have highlighted the need to perform further studies to establish guidelines for interpretation of high frequency immittance results, and for distinguishing normal from pathological ears in neonates and infants (Fowler & Shanks, 2002:202; Purdy & Williams, 2000:9; De Chicchis, 2000:98). This chapter concludes with a description of normative values derived from the cohort of neonates and infants included in the final analysis of the current study. The large sample of infant ears on which OAE and high frequency tympanometry and acoustic reflexes were performed allowed for compilation of comprehensive normative data for 1000 Hz probe tone immittance measures. The criteria for inclusion will be discussed, followed by a description of 1000 Hz tympanometry norms.

As normative studies of tympanometry in infants are often complicated by a lack of an independent method for assuring only normal ears are included in the study (Margolis *et al.,* 2003:384), two criteria were set out for classification of normal middle ear functioning. The first criterion was based on results from OAE-testing. As previously discussed, an initial division was made where cases, in which an OAE pass result was obtained, were considered to have normal middle ear functioning (Group A). The hypothesis as described in Chapter 3 was tested by comparing results obtained from OAE testing to results of 1000 Hz tympanometry and acoustic reflex measurement. Current results from 1000 Hz tympanometry indicated that the majority of (93%) of ears with an OAE pass result displayed a discernable tympanogram peak and therefore confirmed that the hypothesis was true. However, as reported by Sutton *et al.,* (1996:11) and Thornton *et al.,* (1993:322), emissions can occasionally be recorded from ears with middle ear disease and hence OAEs alone cannot be considered as the only decisive factor for normal middle ear functioning. In 7% of ears with an OAE pass result no discernable peak could be identified in the current study. Based on reports in literature that 1000 Hz probe tone tympanograms with a discernable peak can be accepted as representative of normal middle ear functioning, this was specified as a second criterion alongside an OAE pass result (Kei *et al.,* 2003:22; Purdy & Williams, 2000:18, Sutton *et al.,* 1996:13). Accordingly only ears displaying both a pass OAE result in addition to a peaked 1000 Hz probe tone admittance tympanogram in the same ear, were included in the compilation of normative values. Ears classified as ‘abnormal’ indicated a fail result in either OAE-testing or tympanometry, or both measures.

According to the two criteria, normative data were compiled for 809 ears. Normative values for 1000 Hz probe tone tympanometry are presented for maximum peak uncompensated admittance and tympanometric peak pressure (TPP) values, measured from admittance (Y_a), susceptance (B_a) and conductance (G_a) tympanograms. Norms for 1000 Hz probe tone acoustic reflexes are also presented.

Uncompensated admittance values for Y_a, B_a and G_a tympanograms were measured at point of maximum positive displacement, and corresponding middle ear pressure was measured at this point. When double peaks occurred, the peak admittance, as described here, was obtained from the higher peak.

Table 4.2 presents norms for 1000 Hz probe tone admittance (Y_a), susceptance (B_a) and conductance (G_a) tympanograms recorded for all ears included in the final analysis of this study.

TABLE 4.2 1000Hz Admittance (Y_a), Susceptance (B_a) and Conductance (G_a) tympanometry norms (Total sample)

	Y_a (n=809 ears)		B_a (n=791 ears)		G_a (n=791 ears)	
Variables	**Peak admittance**	**TPP (daPa)**	**Peak admittance**	**TPP (daPa)**	**Peak admittance**	**TPP (daPa)**
Mean	2.9	0.13	1.8	43.8	2.6	-8.7
Std Deviation	1.1	60.93	0.8	69.1	1.2	62.1
Max	9.6	185	6.1	195	9.9	180
Min	0.9	-275	0.4	-235	0.2	-285
5th Percentile	1.5	-110	0.9	-80	1.2	-120
50th Percentile Median	**2.60**	**5**	**1.7**	**45**	**2.3**	**-5**
95th Percentile	4.9	90	3.1	155	4.9	80

Though a number of studies have reported preliminary normative data for admittance 1000 Hz tympanometry, there are very limited data on results obtained from susceptance and conductance tympanograms. Most studies investigating high frequency tympanometry in infants have measured admittance or susceptance tympanograms (Kei *et al.,* 2003:20; Margolis *et al.,* 2003:383; Purdy & Williams, 2000:14). A distribution curve of the normative values (as shown in Table 4.2) for admittance tympanograms is provided in Figure 4.13.

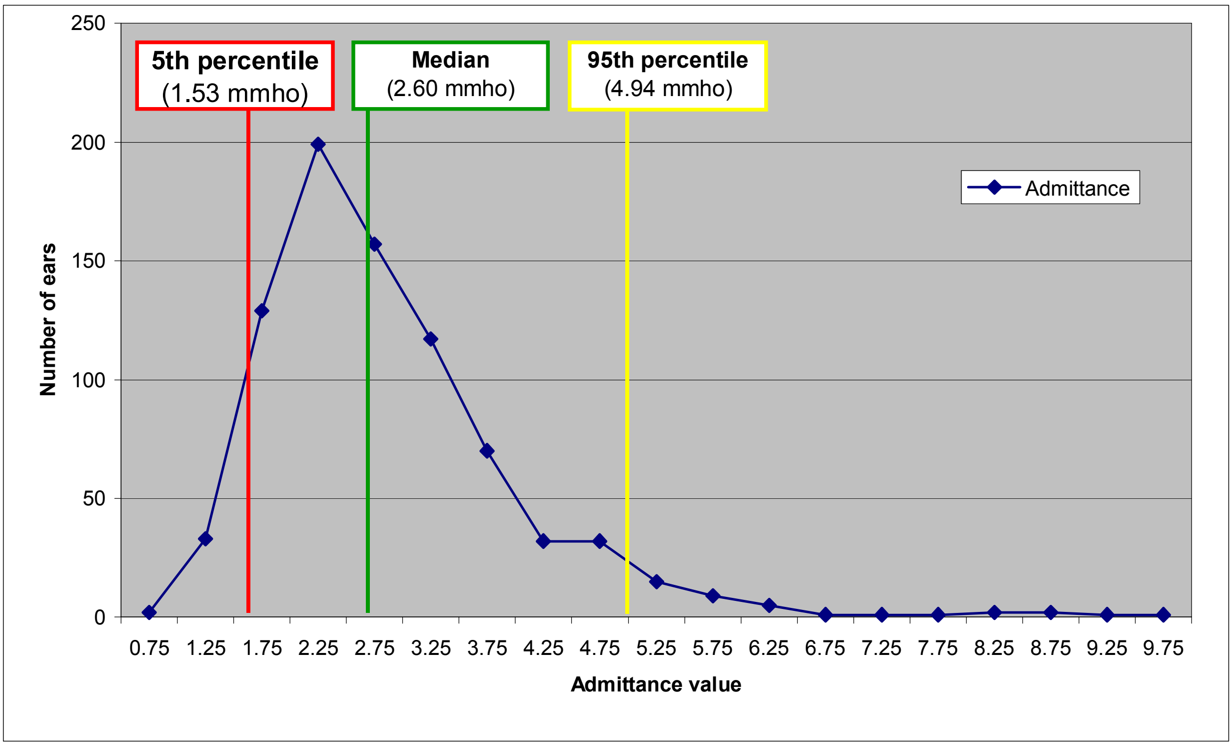


Figure 4.13 Distribution of admittance results for Y_a tympanograms (n= 809)

Figure 4.13 shows the distribution of *uncompensated* peak admittance values recorded for the total case sample (n = 809). The mean admittance value is 2.85 mmho. As indicated in Figure 4.13 the admittance values that account for normality between the 5^{th} and 95^{th} percentile, ranges from 1.53mmho to 4.95mmho, with a median of 2.60 mmho. These results correspond highly to normative values from 1000 Hz admittance tympanograms for full-term babies reported by Margolis *et al.,* (2003:386). A comparison between results from the present study and results reported by Margolis *et al.,* (2003:386) is presented in Table 4.3.

TABLE 4.3 Comparison between results obtained from the current study and results by Margolis *et al.,* (2003:386)

	This study	Results by Margolis et al., 2003:386
Mean	2.8	2.7
SD	1.2	1.3
5th Percentile	1.5	1.2
50th Percentile	2.6	2.5
95th Percentile	4.9	4.8

It is clear that results obtained in the current study showed similar results to that of Margolis *et al.,* (2003:389). Margolis *et al.,* (2003:389) also reported a single cutoff value of 0.6 mmho for static admittance (peak-to-negative tail difference), though this was not compared in the current study.

As peak admittance values, as presented for the total sample in Table 4.2, indicated statistically significant differences between male and female ears, gender specific norms are presented separately in Table 4.4 and Table 4.5. A comparison between Y_a admittance normative data male and female ears is provided in Table 4.6.

TABLE 4.4 1000Hz tympanometry norms (Female ears)

FEMALE	Y_a (n=385 ears)		B_a (n=376 ears)		G_a (n=376 ears)	
Variables	Peak admittance	TPP (daPa)	Peak admittance	TPP (daPa)	Peak admittance	TPP (daPa)
Mean	2.6	-4.9	1.7	35.9	2.3	-17.4
Std Deviation	0.8	60.5	0.7	69.4	0.9	61.2
Max	8.7	185	5.6	195	9.0	165
Min	0.9	-205	0.5	-235	0.2	-280
5^{th} Percentile	1.4	-115	0.75	-85	1.1	-135
50^{th} Percentile Median	**2.4**	**5**	**1.6**	**35**	**2.1**	**-15**
95^{th} Percentile	4.2	90	2.7	155	4.2	75

TABLE 4.5 1000 Hz tympanometry norms (Male ears)

MALE	Y_a (n=424 ears)		B_a (n=415 ears)		G_a (n=415 ears)	
Variables	Peak admittance	TPP (daPa)	Peak admittance	TPP (daPa)	Peak admittance	TPP (daPa)
Mean	3.1	4.7	1.9	50.8	2.9	-1.0
Std Deviation	1.3	60.9	0.8	68.1	1.3	61.9
Max	9.6	160	6.1	190	9.9	180
Min	1.1	-275	0.4	-210	0.9	-285
5^{th} Percentile	1.7	-100	0.9	-70	1.3	-110
50^{th} Percentile Median	**2.9**	**10**	**1.8**	**55**	**2.5**	**5**
95^{th} Percentile	5.4	95	3.3	150	5.4	85

TABLE 4.6 Comparison between peak admittance values in Y_a tympanograms in male and female ears

Variable	*Ya* Peak admittance (mmho)	
	MALE	**FEMALE**
Mean	3.1	2.6
Std deviation	1.3	0.8
Max	9.6	8.7
Min	1.1	0.9
5th Percentile	1.7	1.4
50th Percentile Median	**2.9**	**2.4**
95th Percentile	5.4	4.2

Peak admittance values presented in Tables 4.4, 4.5 and 4.6 indicated a statistically significant difference (p = 0.00) between male and female ears for maximum uncompensated acoustic admittance, with admittance being higher for male infants than female infants. No significant difference was observed for peak pressure values (p = 0.16) in Y_a tympanograms between genders.

In contrast to Kei *et al.,* (2003:20) who reported a significant ear effect with right ears showing significantly higher mean peak compensated static admittance and who found no significant gender effects or interaction with results, this present study revealed *no* statistical significant differences between right and left ears for peak uncompensated acoustic admittance (p = 0.75) or peak pressure values (p = 0.13) in Y_a tympanograms, whilst a significant difference between male and female ears for peak uncompensated acoustic admittance were found. Similar results have been reported by Palmu *et al.,* (2001:182) who investigated infant ears at 7 and 24 months of age with 226 Hz probe tone tympanometry. They found a statistically significant difference between acoustic admittance values for male and female ears, with the admittance values for males being significantly higher than for female ears. Differences in middle ear and tympanic membrane sizes were impeached for these results (Palmu *et al.,* 2001:183). In the adult population differences between male and female ears have been widely reported for 226 Hz probe tone tympanometry (Fowler & Shanks, 2002:178). This is of important consideration when assessing infant ears, as peak admittance values for 1000 Hz probe tone tympanometry are significantly lower in female in comparison to male ears.

Several investigations have provided some preliminary data with regards to various acoustic admittance parameters in the assessment of middle ear function in infants. There is evidence from those studies and others that these variables are age dependant (De Chicchis *et al.,* 2000:97, Holte *et al.,* 1991:20). When assessing the infant middle ear *age-related changes* in acoustic admittance values need careful consideration. These changes have shown to increase with age and therefore necessitate age specific normative data to avoid false-positive results due to inappropriate normative values (Meyer *et al,* 1997:192; Holte *et al.,* 1991:12). A study by De Chicchis *et al.,* (2000:97) investigating developmental changes in acoustic admittance measurements of children aged 6 months to 5 years, indicated statistically significant effects showing increases in acoustic admittance and ear canal volume as ages increased (De Chiccis *et al.,* 2000:99). In another study Palmu *et al.,* (1999:210, 211) investigated the diagnostic value of tympanometry using a 226 Hz probe tone in infants and found that middle ear compliance increases with age and is quite low in infants. They concluded that the compliance limit of >0.2 ml for normal ears is too high for the infant population, and that normal infant ears commonly have compliance values of less the 0.2 ml when a 226 Hz probe tone is used (Palmu *et al.,* 1999:211).

Normative data were therefore calculated for neonates and infants across four age groups: 1) 0 weeks of age, 2) 0 – 4 weeks of age, 3) 5 – 28 weeks of age and 4) 29 – 52 weeks of age. Means and standard deviations for the acoustic admittance variables across these four age groups are shown in Table 4.7. Statistically significant differences were obtained for peak admittance values between all age groups. In comparison to the older age groups, infants in the 0 – 4 week age group presented with much lower mean and standard deviations for peak admittance. The range of values form the 5th to the 95th percentile for the 0 – 4 weeks age group was 2.2 mmho, compared to 2.7 and 3.4 mmho for infants 5 – 28 weeks and 29 – 52 weeks of age, respectively. Y_a admittance values increased in a rather orderly manner from the youngest group, those zero weeks of age, to the oldest group, those infants who range in age from 29 to 52 weeks. Additionally an increasing range of variability accompanies increasing age, illustrated by the higher standard deviation values as infants become older. A graphic representation of the increase in mean admittance values and standard deviations as a function of age is provided in Figure 4.14A.

Figure 4.14 illustrates the mean values for peak admittance (Figure 4.14A) and tympanometric peak pressure (Figure 4.14B) across the four age groups. The error bars in Figure 4.14 represent the standard deviations observed within these groups.

Mean tympanometric peak pressure data are graphically represented in Figure 4.14B. No significant differences or age-related trends were observed for this measurement variable and the mean pressure values were very similar across all age groups approximating 0 daPa. Higher standard deviations for tympanometric peak pressure were however noted in the older age groups (5 – 28 weeks and 29 – 52 weeks), indicating increased variability in peak pressure with increase in age. These results are similar to pressure values for 1000 Hz probe tone tympanometry reported by Margolis *et al.,* (2003:386) with a 90% range for tympanometric peak pressure of -133 daPa (5th percentile) to 113 daPa (95th percentile). The lower standard deviation and 90% range for peak pressure observed in the 0 – 4 weeks age group (-75 daPa to 80 daPa / 5th – 95th percentile), compared to -120daPa to 90 daPa (5th – 95th percentile) and -130 daPa to 105 daPa (5th to 95th percentile) in the 5 – 28, and 29 – 52 week age groups respectively, indicate more stringent criteria for normality in the younger age groups.

A summary of the normative tympanometric data for the different age groups is presented in Figure 4.15.

TABLE 4.7 Norms for 1000 Hz admittance tympanometry across four age groups

	AGE							
	0 WEEKS (n = 73 ears)		***0 – 4 WEEKS (n = 250 ears)***		***5 – 28 WEEKS (n = 457 ears)***		***29 – 52 WEEKS (n = 98 ears)***	
Variables	*Peak admittance*	*TPP (daPa)*	*Peak admittance*	*TPP (daPa)*	*Peak admittance*	*TPP (daPa)*	*Peak admittance*	*TPP (daPa)*
Mean	2.2	-2	2.4	-1	2.9	0.1	3.8	3
Std Deviation	0.9	48	0.8	49	1.0	65	1.5	72
Max	7.7	185	7.7	185	8.5	160	9.6	170
Min	1	-130	1	-185	0.86	-275	1	-205
5th Percentile	1.2	-70	1.4	-75	1.7	-120	2.1	-130
50th Percentile Median	2.0	-10	2.2	-5	2.7	10	3.4	15
95th Percentile	3.4	70	3.7	80	4.97	90	7	105

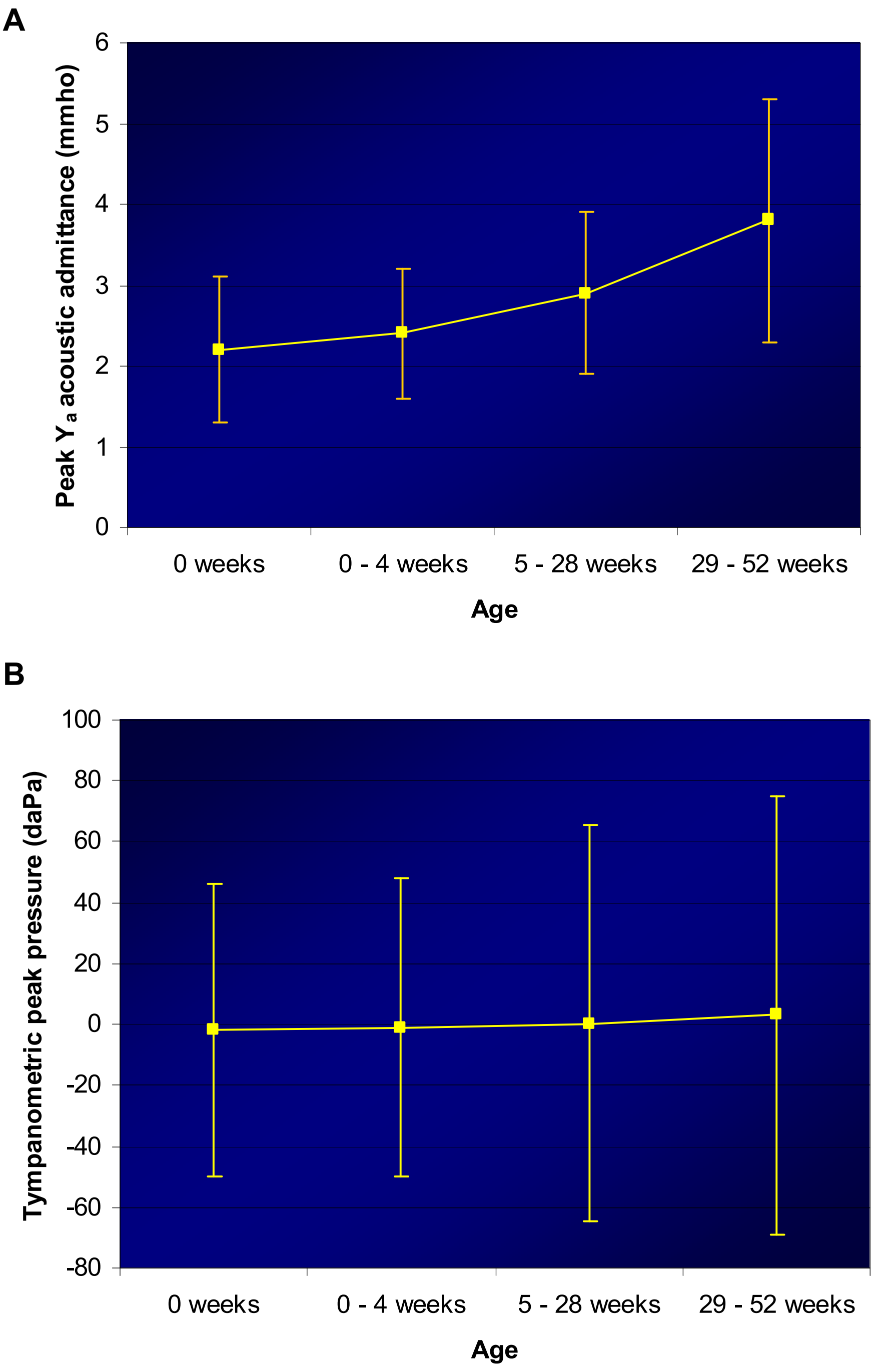


Figure 4.14 Mean values for Y_a tympanometric variables across age groups: (A) peak admittance in mmho, (B) tympanometric peak pressure in daPa. (Error bars represent plus and minus one standard deviation)

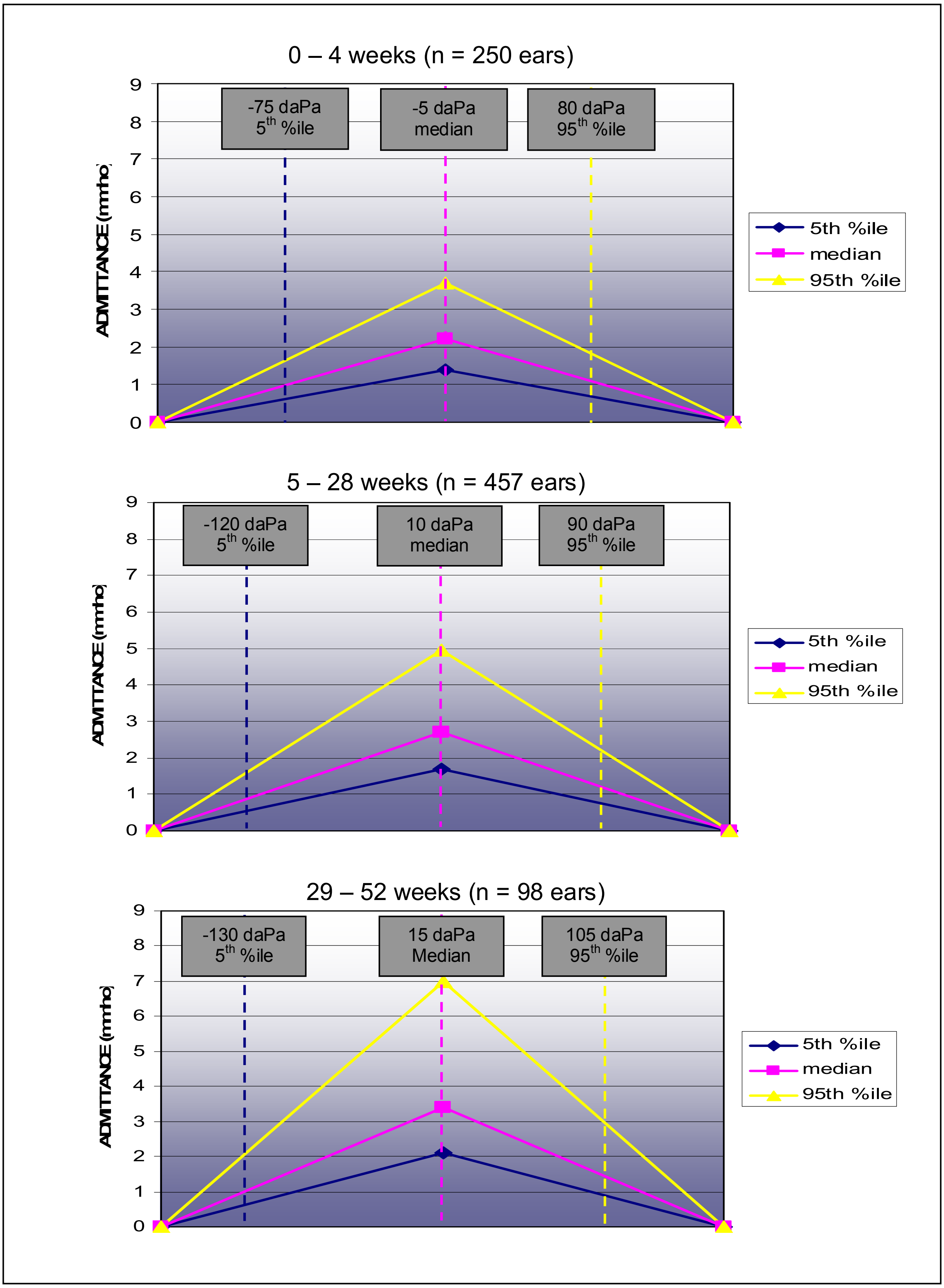


Figure 4.15 Peak admittance and pressure norms

Normative values for acoustic reflexes were investigated in the current study. As previously indicated in Figure 4.12, acoustic reflexes were recorded in 94% of ears displaying peak 1000 Hz tympanograms. Normative values for 1000 Hz probe tone acoustic reflexes were however compiled for 727 ears that displayed both a peaked tympanogram, in addition to an OAE pass result. These norms are presented in Table 4.8.

TABLE 4.8 1000 Hz probe tone acoustic reflex norms (n = 727)

	MALE & FEMALE (n=727 ears)	***MALE (n=379 ears)***	***FEMALE (n=438 ears)***
VARIABLES	**Reflex threshold (dB)**	**Reflex Threshold (dB)**	**Reflex Threshold (dB)**
Mean	93	92	94
Std Deviation	9	9	9
Max	110	110	110
Min	60	65	60
5th Percentile	80	75	80
50th Percentile (median)	**95**	**95**	**95**
95th Percentile	105	110	105

As is evident from Table 4.8, no significant difference was observed between reflex thresholds obtained for male and female ears. All ears considered together indicated a mean reflex threshold of 93dB, with a standard deviation of 9dB. The 90% range varied from 80dB to 105dB. Though the usefulness and diagnostic significance of these preliminary normative values may be limited until further research is conducted which include ears with pathology, the presence or absence of acoustic reflexes still remain a useful part in the audiological evaluation in infants. This can aid in the differential diagnosis of infants who failed newborn hearing screening and who display abnormal results on other tests of hearing function. However, the normative values for acoustic reflexes indicated a 95th percentile of 105dB (Table 4.8), which is very close to the maximum output of the equipment (110dB). Therefore the diagnostic significance is limited and the *absence* of acoustic reflexes alone cannot confirm the presence of abnormality in any age (McMillan *et al.,* 1985:148)

Ipsilateral acoustic reflex measurement, as utilized in this study, offers advantages over contralateral testing in infants, as results cannot be confounded by contralateral ear factors, and testing is easier as an earphone need not be positioned in the contralateral ear. Further studies are however needed to define the role of ipsilateral acoustic reflexes, with different stimuli in the infant population.

4.6 Summary

This chapter presented the results obtained from the clinical research investigation as described in Chapter 3. Systematic analysis of data was employed to derive meaning from raw data. Results and findings were presented and critically discussed according to the main and sub-aims formulated for this study within the context of previous research.

1000 Hz acoustic immittance results were described for infants failing and passing OAE testing. A high incidence of peaked tympanograms and present acoustic reflexes, suggestive of normal middle ear function, could be obtained in infants using a 1000 Hz probe tone. Double peaked tympanograms were recorded in 4.5% of the total sample, and 64% of these were recorded from male ears. For ears passing OAE testing and displaying a peak 1000 Hz tympanogram normative values were compiled. Age appropriate and gender specific normative data were also described and merit consideration when assessing the infant middle ear.

Peaked tympanograms and present acoustic reflexes were highly associated with OAE pass results and conversely flat tympanograms and absent reflexes were more associated with OAE fail results. High frequency (1000 Hz) immittance measures therefore prove to be a valid measure of middle ear function in infants. Current normative values and that of previous studies on 1000 Hz tympanometry provide criteria for identifying middle ear dysfunction in infants and can assist in distinguishing between screening fails caused by sensorineural hearing loss and those caused by transient middle ear conditions.