Chapter 4

RESULTS AND DISCUSSION

This chapter aims to present the results of the empirical research and elucidates the meaning and significance thereof within the current body of knowledge

4.1 INTRODUCTION

The dawn of an era of early identification of hearing loss in newborns and infants poses new challenges and offers new opportunities to audiologists. With the advent of universal newborn hearing screening, it is common for an audiologist to see infants less than two to three months of age who, during the newborn period, have been identified as being at risk for hearing loss. It is therefore essential to find evidence in order to establish a protocol that would yield the most information with regard to residual hearing abilities in this population. Research, as initiated in this study, is essential to the implementation of appropriate diagnostic protocols in this specific population.

The methodological approach, specified in chapter 3 has provided the operational framework for extracting the necessary data for addressing the main aim of this study. The main aim of this study, to establish the clinical value of the ASSR for early diagnosis and amplification of infants

with hearing loss, was addressed through the realization of two sub-aims. These aims are schematically summarized in Figure 4.1.

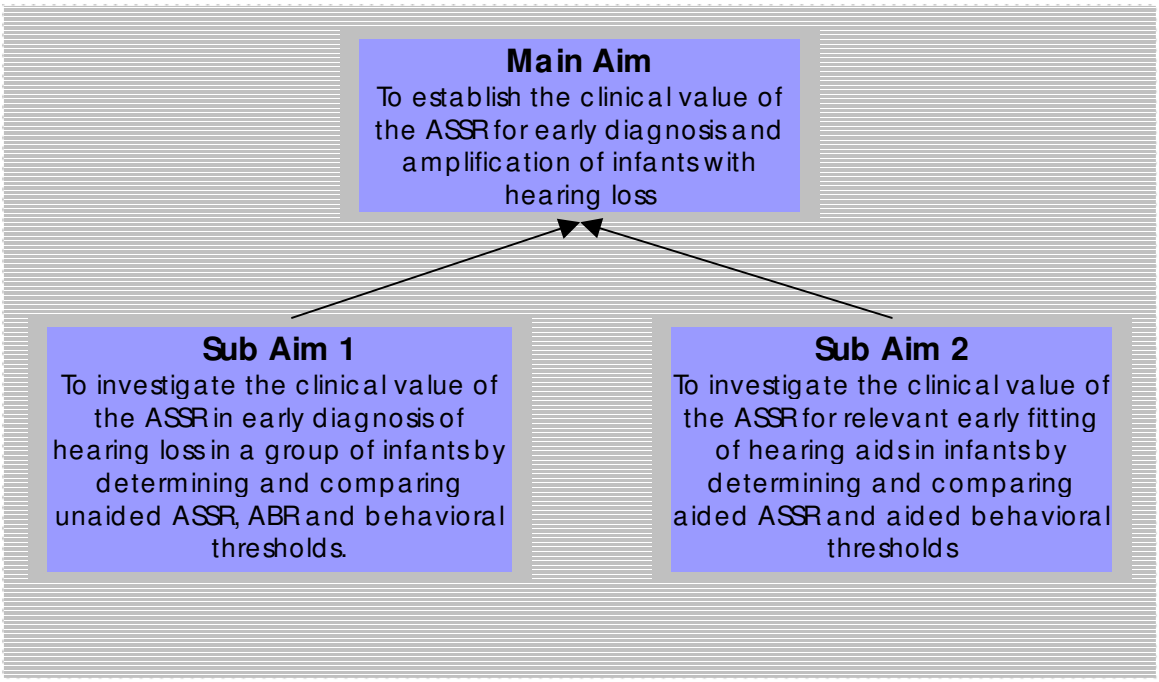

Figure 4.1 Main-aim and sub-aims of study

Analyzed results for the current study are grouped, reported, interpreted and subsequently discussed in relation to relevant and comparable literature. The first sub-aim was achieved by determining and comparing the unaided ASSR and ABR thresholds at the time of diagnosis at a young age (3-6 months of age). These ASSR and ABR thresholds were then compared with unaided behavioral thresholds obtained at a later developmental age, when subjects were able to provide reliable behavioral responses (8 – 14 months of age).

The second sub-aim was addressed by determining aided ASSR thresholds within a month after diagnosis of hearing loss and after each subject was fitted with hearing aids. The aided ASSR thresholds were then compared

with aided behavioral thresholds when the subjects reached a developmental age allowing reliable behavioral responses to be elicited. The results are presented and described according to each of the sub-aims. The results from each individual subject are initially considered, followed by a collective analysis of the results for the six subjects. In the second part of this chapter, a discussion of results alongside current literature will follow. In the final section of this chapter, general conclusions from the study are drawn and the main research question is answered.

In order to determine the **clinical value of the ASSR method in early diagnosis of a hearing loss in infants**, each subject's individual performance will be described on each evaluation procedure. The results obtained during the unaided ASSR evaluation will be compared with the unaided ABR results at the time of diagnosis and subsequently both these procedures will be compared with the unaided behavioral assessment results obtained. Following presentations of each individual case, the results for the six subjects collectively will be considered. In the collective analysis of the data, the focus will be on a comparison of the threshold data for all 12 ears (of the six subjects) as it was recorded through the use of three different measuring techniques. The descriptive and inferential statistics from the group will be reported.

In order to determine the **clinical value of the ASSR in the validation of hearing aid fitting,** the second part of the results will present each subject's individual performance on the aided ASSR – comparing unaided ASSR values with the aided ASSR values and subsequently with results obtained during aided behavioral assessment. Thereafter the results of all six subjects will be analyzed collectively, as it was recorded through the

use of these two measuring techniques. The descriptive and inferential statistics from this group of six subjects will be presented.

4.2. RESULTS FOR SUB-AIM 1: TO INVESTIGATE THE POTENTIAL CLINICAL VALUE OF THE ASSR IN EARLY DIAGNOSIS OF HEARING LOSS IN A GROUP OF INFANTS BY DETERMINING AND COMPARING UNAIDED ASSR, ABR AND BEHAVIORAL THRESHOLDS.

Bilaterally click-evoked ABR responses were recorded first. Thereafter the tone burst ABR assessment was carried out, followed by the ASSR assessment. Behavioral thresholds were obtained from each subject at the developmental age when they could render reliable behavioral responses. The results for each individual subject are described in the following section.

4.2.1 Individual subject results for sub-aim 1

In order to aid the interpretation of the individual results, a short summary of each subject's background information is added to the unaided ABR, ASSR and behavioral assessment results summarized in table format (see Tables 4.1 – 4.6).

4.2.1.1 Subject 1: Results for sub-aim 1

The background information and test results for subject 1 are presented in Table 4.1 and Figure 4.2.

Table 4.1 Background information and test results for subject 1

Sex	**Male**			
Risk factors	Born at 34 weeks gestation age. Diagnosed with cytomegalovirus			
Age at time of hearing loss identification	3 months			
Degree of hearing loss	Moderately severe sensory neural hearing loss in the right ear. No response could be measured at maximum intensities of equipment in the left ear.			
Age at time of hearing aid fitting	4 months			
Type of hearing aid	Digital hearing aid on right ear			
Age at time of behavioral assessment	10 months			
ABR results	**Tone burst** R = 50 dBnHL L = NR		**Click** R = 65 dBnHL L = NR	
ASSR predicted results	**500 Hz** R = 55 dB L = NR	**1000 Hz** R = 55 dB L = NR	**2000 Hz** R = 65 dB L = NR	**4000 Hz** R = 70 dB L = NR
Behavioral assessment results	**500 Hz** R = 50 dB L = NR	**1000 Hz** R = 55 dB L = NR	**2000 Hz** R = 65 dB L = NR	**4000 Hz** R = 75 dB L = NR

NR = No Response

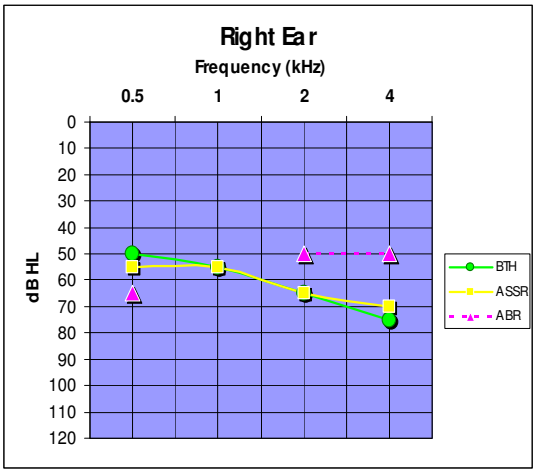

Figure 4.2 Schematic representations of the ABR, ASSR predictions and BT results for subject 1

For this individual case the tone burst ABR was 5 dB lower than the 500Hz ASSR predicted threshold. The click ABR yielded the same threshold as the 2000 Hz ASSR predicted threshold and there was only a 5 dB difference compared to the 4000 Hz ASSR predicted threshold, with the ABR having the lower value. In comparison with the behavioral thresholds measured at a later stage, the ASSR prediction thresholds closely followed the configuration of the behavioral thresholds – a difference of only 5 dB at 500 Hz and 4000 Hz was noted. Thresholds corresponded at 1000 Hz and 2000 Hz on these two procedures. When comparing the results from the ABR with the behavioral thresholds, identical thresholds were measured with the tone burst ABR and at 500 Hz. The click ABR and 2000 Hz behavioral response yielded the same thresholds and at 4000 Hz the behavioral response was 10 dB lower than the click ABR.

No response could be measured on any of the three measuring techniques in the left ear at maximum intensity of the equipment.

4.2.1.2 Subject 2: Results for sub-aim 1

The background information and test results for subject 2 are presented in Table 4.2 and Figure 4.3.

Table 4.2 Background information and test results for subject 2

Sex	**Female**
Risk factors	Born at 36 weeks gestational age through

	emergency caesarian; Low birth weight; Admitted to NICU.			
Age at time of hearing loss identification	Five months			
Degree of hearing loss	Moderately severe sensory neural loss in right ear; Moderate sensory neural hearing loss in left ear			
Age at time of hearing aid fitting	Five months			
Type of hearing aid	Digital hearing aids binaurally			
Age at time of behavioral assessment	14 months			
ABR results	**Tone burst** R = 60 dBnHL L = 70 dBnHL		**Click** R = 75 dBnHL L = 60 dBnHL	
ASSR predicted results	**500 Hz** R = 60 dB L = 40 dB	**1000 Hz** R = 50 dB L = 50 dB	**2000 Hz** R = 65 dB L = 55 dB	**4000 Hz** R = NR L = 50 dB
Behavioral assessment results	**500 Hz** R = 70 dB L = 50 dB	**1000 Hz** R = 65 dB L = 60 dB	**2000 Hz** R = 80 dB L = 75 dB	**4000 Hz** R = 95 dB L = 95 dB

NR = No Response

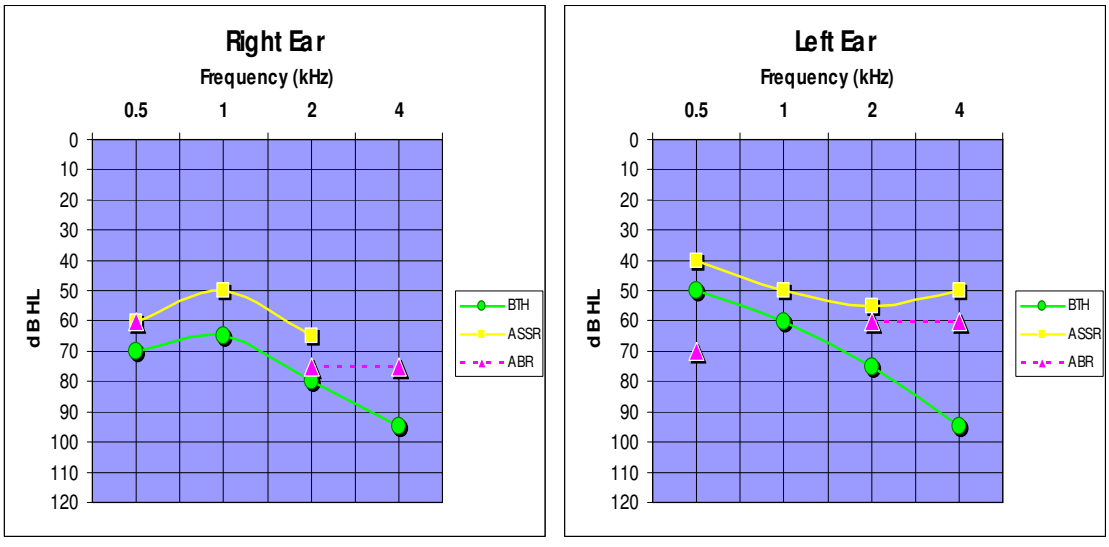

Figure 4.3 Schematic representations of the ABR, ASSR predictions and BT results for subject 2

The ABR and ASSR indicated comparable results in the right ear. On both the tone burst ABR and 500 Hz ASSR prediction, a threshold estimation of 60 dB was measured. A difference of only 10 dB with the click ABR threshold and 2000 Hz ASSR predicted threshold was noted. This subject woke up before completing the 4000 Hz ASSR in the right ear and therefore no result is available on that specific measurement. Behavioral responses were measured at 14 months of age. These thresholds were elevated by 10 to 15 dB at the respective frequencies for both the ASSR and ABR measurements.

In the left ear the tone burst ABR threshold was 30 dB higher than the 500 Hz ASSR predicted threshold. A difference of 5 to 10 dB was present between the ASSR predicted thresholds for 2000 and 4000 Hz in comparison with the click evoked ABR threshold. The ASSR had the lower value. The behavioral thresholds yielded responses with a difference of 10 dB at 500 Hz and 1000 Hz in comparison with the ASSR predicted thresholds at the same frequencies (the ASSR again had the lower values). The high frequencies (2000 and 4000 Hz) showed big discrepancies between the ASSR predicted thresholds and behavioral thresholds (± 20 to 45 dB) with the ASSR having the lower values. The tone burst ABR thresholds were 20 dB higher than the 500 Hz behavioral threshold, but the high frequencies of 2000 Hz and 4000 Hz behavioral thresholds were 15 to 35 dB higher than the click ABR thresholds.

4.2.1.3 Subject 3: Results for sub-aim 1

The background information and test results for subject 3 are presented in Table 4.3 and Figure 4.4.

Table 4.3 Background information and test results for subject 3

Sex	**Female**			
Risk factors	One of a twin, born at 32 weeks gestational age with a family history of congenital deafness.			
Age at time of hearing loss identification	Six months			
Degree of hearing loss	Severe sensory neural hearing loss in right ear; Profound sensory neural hearing loss in left ear.			
Age at time of hearing aid fitting	Six months			
Type of hearing aid	Digitally programmable analogue hearing aids binaurally			
Age at time of behavioral assessment	12 months			
ABR results	**Tone burst** R = 90 dBnHL L = 90 dBnHL		**Click** R = 70 dBnHL L = 95 dBnHL	
ASSR predicted results	**500 Hz** R = 90 dB L = 95 dB	**1000 Hz** R=105 dB L = 95 dB	**2000 Hz** R = 95 dB L = 85 dB	**4000 Hz** R = 80 dB L = 80 dB
Behavioral assessment results	**500 Hz** R = 80 dB L = 80 dB	**1000 Hz** R = 70 dB L = 75 dB	**2000 Hz** R = 70 dB L = 90 dB	**4000 Hz** R = 80 dB L = 80 dB

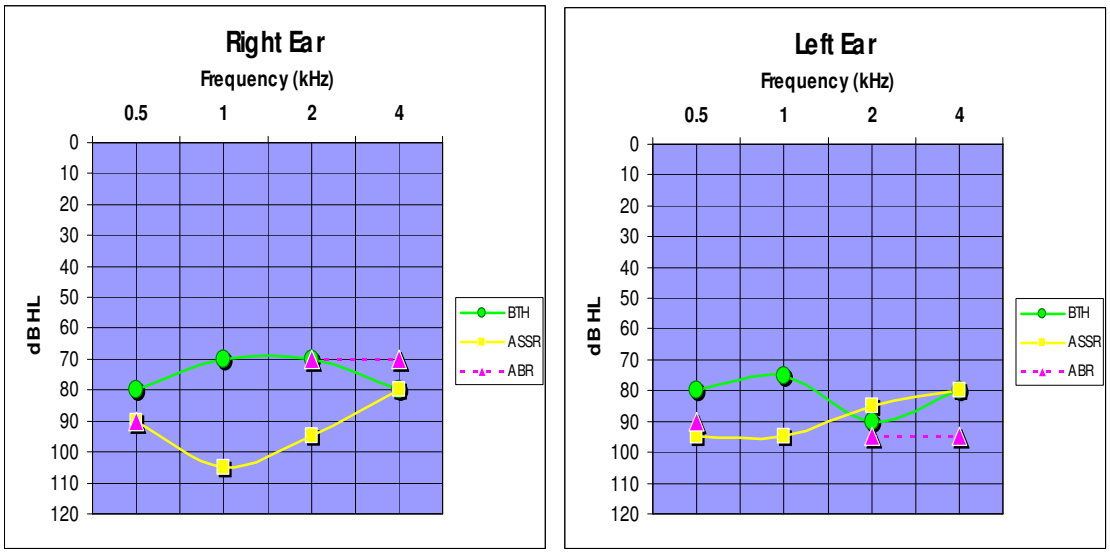

Figure 4.4 Schematic representations of the ABR, ASSR predictions and BT results for subject 3

The right ear's responses can be described as follows: responses in the right ear for the tone burst ABR and 500 Hz ASSR predicted thresholds yielded the same threshold. The click ABR threshold was 25 dB lower than the 2000 Hz ASSR predicted threshold. The difference between the click ABR threshold and 4000 Hz ASSR predicted threshold was 10 dB, with the click ABR having the lower value. When comparing the ASSR predicted thresholds and behavioral thresholds, a difference of 10 dB was noted at 500 Hz and a difference of 35 dB at 1000 Hz. The 2000 Hz comparison between these two measurements showed a 25 dB difference. In all of these instances the ASSR predicted thresholds had the higher value. At 4000 Hz the thresholds between these two measurements corresponded well. A 10 dB difference was noted between the tone burst ABR and 500 Hz behavioral thresholds, with the tone burst ABR having the higher value. The click ABR yielded the same threshold as the 2000 Hz behavioral threshold. A 10 dB difference was present between the click ABR and 4000 Hz behavioral threshold with the behavioral response being the lower value.

The thresholds from the left ear corresponded better between the different measurements. A difference of 5 dB was noted between the tone burst ABR and 500 Hz ASSR predicted thresholds with the ASSR having the higher value. A similar result was obtained in the high frequencies – with a difference of 10 dB between the click ABR and 2000 Hz ASSR predicted thresholds, and 15 dB difference between the click ABR and 4000 Hz ASSR predicted thresholds. In this instance the click ABR had the higher value. When comparing the ASSR predicted thresholds and behavioral thresholds in the low frequencies (500 Hz and 1000 Hz), behavioral thresholds were 15 to 20 dB lower than the ASSR thresholds. The

ASSR predicted thresholds yielded 5 to 10 dB lower thresholds in the high frequencies of 2000 Hz and 4000 Hz. When comparing the tone burst ABR threshold with the behavioral threshold, a 10 dB difference is noted between these two measurement techniques – the tone burst ABR being the higher value. The comparison between the click ABR threshold and behavioral threshold shows a 5 dB difference with the 2000 Hz comparison and a 15 dB difference with the 4000 Hz comparison – in both cases the ABR having the higher value.

4.2.1.4 Subject 4: Results for sub-aim 1

The background information and test results for subject 4 are presented in Table 4.4 and Figure 4.5.

Table 4.4 Background information and test results for subject 4

Sex	**Female**			
Risk factors	Twin of subject 3, born at 32 weeks gestational age with a family history of congenital deafness.			
Age at time of hearing loss identification	Six months			
Degree of hearing loss	Severe sensory neural hearing loss bilaterally			
Age at time of hearing aid fitting	Six months			
Type of hearing aid	Digitally programmable analogue hearing aids binaurally			
Age at time of behavioral assessment	12 months			
ABR results	**Tone burst** R = 75 dBnHL L = 75 dBnHL		**Click** R = 75 dBnHL L = 75 dBnHL	
ASSR predicted results	**500 Hz** R = 90 dB L = 80 dB	**1000 Hz** R = 85 dB L = 85 dB	**2000 Hz** R = 85 dB L = 85 dB	**4000 Hz** R = 80 dB L = 70 dB
Behavioral assessment results	**500 Hz** R = 80 dB L = 85 dB	**1000 Hz** R = 80 dB L = 75 dB	**2000 Hz** R = 75 dB L = 80 dB	**4000 Hz** R = 90 dB L = 80 dB

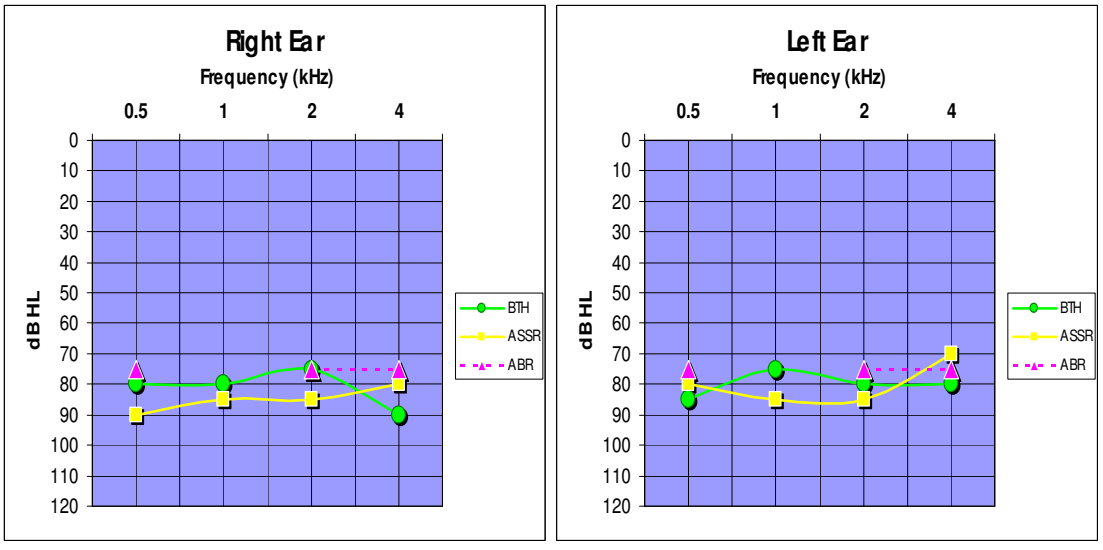

Figure 4.5 Schematic representations of the ABR, ASSR predictions and BT results for subject 4

The results from this subject showed a good comparison between the different procedures. The right ear showed a difference of 15 dB when comparing the tone burst ABR threshold with the 500 Hz ASSR predicted threshold. In this case the ABR had the lower threshold. The click ABR threshold was 10 dB lower than the threshold for the 2000 Hz ASSR predicted threshold and 5 dB lower than the threshold for 4000 Hz ASSR prediction. The comparison between the ASSR predicted thresholds and behavioral thresholds showed an average difference of 5 to 10 dB with the ASSR having the lower threshold at all frequencies except at 4000 Hz. The tone burst ABR threshold was 5 dB lower than the 500 Hz behavioral threshold. The click ABR threshold had the same value as the 2000 Hz behavioral threshold and was 5 dB lower than the 4000 Hz behavioral threshold.

Similar results were found in the left ear. The tone burst ABR threshold was 5 dB lower than threshold for the 500 Hz ASSR prediction. The threshold for the click ABR was 10 dB lower than the threshold at 2000 Hz on the ASSR prediction and 5 dB lower than the 4000 Hz threshold on the ASSR prediction. The ASSR predicted thresholds differed with 5 to 10 dB from those of the behavioral assessment across the frequency range. A 10 dB difference was present between thresholds of the tone burst ABR and the 500 Hz behavioral - with the tone burst ABR having the lower value. The click ABR threshold was 5 dB lower than the 2000 Hz and 4000 Hz behavioral thresholds.

4.2.1.5 Subject 5: Results for sub-aim 1

The background information and test results for subject 5 are presented in Table 4.5 and Figure 4.6.

Table 4.5 Background information and test results for subject 5

Sex	**Female**	
Risk factors	Born at 26 weeks gestational age; Admitted to NICU for 2 months.	
Age at time of hearing loss identification	Four months	
Degree of hearing loss	Profound sensory neural hearing loss bilaterally	
Age at time of hearing aid fitting	Five months	
Type of hearing aid	High power digitally programmable analogue hearing aids binaurally	
Age at time of behavioral assessment	12 months	
ABR results	**Tone burst**	**Click**

	R = NR L = NR		R = NR L = NR	
ASSR predicted results	**500 Hz** R=105 dB L=105 dB	**1000 Hz** R=115 dB L=105 dB	**2000 Hz** R=105 dB L=105 dB	**4000 Hz** R=100 dB L=110 dB
Behavioral assessment results	**500 Hz** R = 95 dB L = 95 dB	**1000 Hz** R=105 dB L=105 dB	**2000 Hz** R=100 dB L=110 dB	**4000 Hz** R=100 dB L=110 dB

NR = No Response

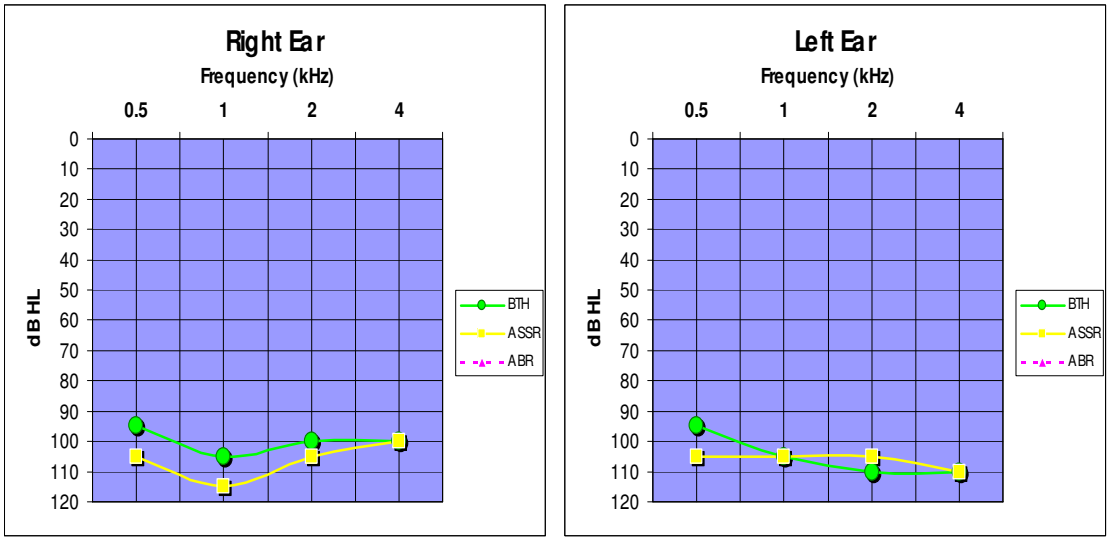

Figure 4.6 Schematic representations of the ABR, ASSR predictions and BT results for subject 5

No response could be measured on the ABR at maximum output (90 dBnHL) of the equipment on both the tone burst ABR and the click ABR. The ASSR showed responses across the frequency range of 500 Hz to 4000 Hz. Behavioral responses were also measured at all the frequencies.

When comparing the results of the right ear between the ASSR predicted thresholds and behavioral assessment, a 5 to 10 dB difference was noted

at 500, 1000 and 2000 Hz, with the behavioral thresholds being lower. The thresholds at 4000 Hz corresponded on these two procedures.

The left ear had similar results. A difference of 10 dB was noted at 500 Hz between the ASSR predicted thresholds and behavioral thresholds - with the behavioral threshold being lower. A difference of 5 dB was present at 2000 Hz with the ASSR predicted thresholds being the lower value in this instance. The frequencies of 1000 Hz and 4000 Hz yielded the same results on these two measurements.

4.2.1.6 Subject 6: Results for sub-aim 1

The background information and test results for subject 6 are presented in Table 4.6 and Figure 4.7.

Table 4.6 Background information and test results for subject 6

Sex	**Male**			
Risk factors	None			
Age at time of hearing loss identification	Six months			
Degree of hearing loss	Profound sensory neural hearing loss bilaterally			
Age at time of hearing aid fitting	Six months			
Type of hearing aid	High power digital hearing aids binaurally			
Age at time of behavioral assessment	8 months			
ABR results	**Tone burst** R = NR L = NR		**Click** R = NR L = NR	
ASSR predicted results	**500 Hz** R=105 dB L=105 dB	**1000 Hz** R=105 dB L=115 dB	**2000 Hz** R=105 dB L=115 dB	**4000 Hz** R = NR L = NR
Behavioral assessment results	**500 Hz** R=105 dB	**1000 Hz** R=110 dB	**2000 Hz** R=105 dB	**4000 Hz** R = NR

	L=105 dB	L=110 dB	L=110 dB	L = NR

NR = No Response

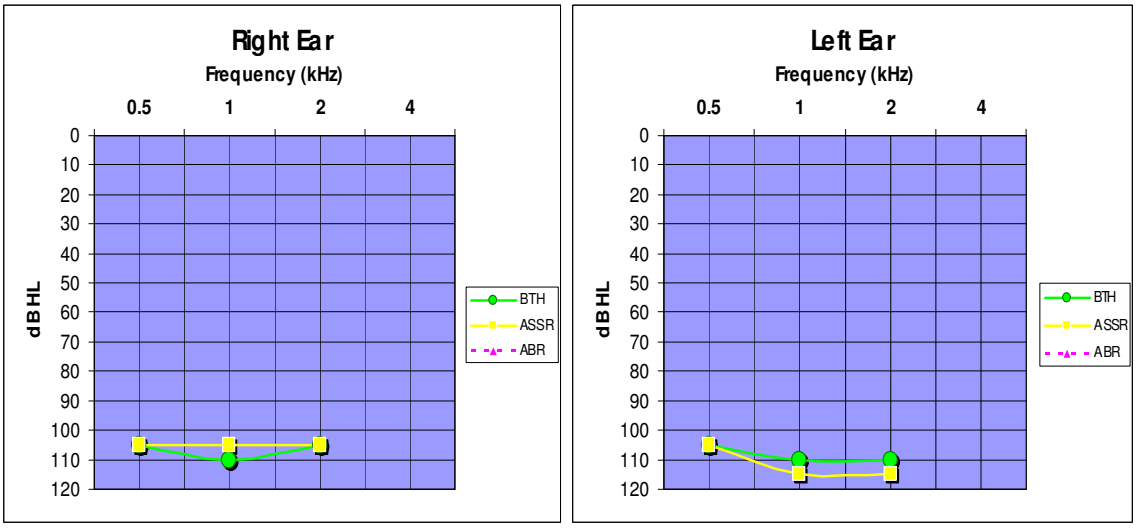

Figure 4.7 Schematic representations of the ABR, ASSR predictions and BT results for subject 6

No responses for subject 6 could be measured on either the tone burst ABR or the click ABR at the maximum output of the equipment (90 dBnHL). Both the ASSR and behavioral measures yielded no response at 4000 Hz.

The threshold prediction on the ASSR and the measured behavioral thresholds in the right ear differed with only 5 dB at 1000 Hz - with the ASSR having the lower value. Results at the other frequencies yielded the same threshold values.

Similar results were obtained in the left ear, with a 5 dB difference at 1000 Hz and 2000 Hz between the ASSR predicted thresholds and behavioral thresholds. In this case the behavioral thresholds were the lower levels.

In conclusion, when considering the results of the individuals, indications are that the ASSR may prove to be a very useful addition to the pediatric audiology test battery – 80.5 % of the frequencies predicted by the ASSR, estimated behavioral thresholds within 10 dB as oppose to the 57% of the ABR. Yet, it is only when considering the results for a number of individuals that a particular trend may be identified. In the following section the results that concern the early diagnosis as it is based on measurements for all six subjects (12 ears), are described, compared and discussed.

4.2.2 Collective results for all six subjects concerning sub-aim 1

The collective results for all six the subjects concerning sub-aim 1 are summarized in Table 4.7. Focusing on the collective results for all ears measured, a further comparison of the three evaluation procedures were done taking into account the dispersion, the central tendency and the relation of the collective data provided by the different evaluation procedures. The absolute threshold measurements of each ear measured and the arithmetic mean values for the number of ears measured, per stimulus frequency, determined by each of the three procedures, are also included in Table 4.7, as well as the calculated range and the standard deviation of the absolute threshold values and the number of ears measured for a particular stimulus frequency. Table 4.8 summarizes the mean of the responses to all stimulus frequencies presented per ear, as recorded by the three different procedures, as well as the standard deviation, and the number of data points used for this calculation.

Table 4.7 Summary of unaided thresholds for the six subjects as determined by the ABR, ASSR and BT.

	ABR		ASSR				Behavioral thresholds			
	Tone Burst	**Click**	**500 Hz**	**1000 Hz**	**2000 Hz**	**4000 Hz**	**500 Hz**	**1000 Hz**	**2000 Hz**	**4000 Hz**
Subject 1	R=65dBnHL L =NR	R=50dBnHL L=NR	R=55dB L=NR	R=55dB L=NR	R=65dB L=NR	R=70dB L=NR	R=50dB L=NR	R=55dB L=NR	R=65dB L=NR	R=75dB L=NR
Subject 2	R=60dBnHL L=70dBnHL	R=75dBnHL L=60dBnHL	R=60dB L=40dB	R=50dB L=50dB	R=65dB L=55dB	R=NR L=50dB	R=70dB L=50dB	R=65dB L=60dB	R=80dB L=75dB	R=95dB L=95dB
Subject 3	R=90dBnHl L=90dBnHL	R=70dBnHL L=95dBnHL	R=90dB L=95dB	R=105dB L=95dB	R=95dB L=85dB	R=80dB L=80dB	R=80dB L=80dB	R=70dB L=75dB	R=70dB L=90dB	R=80dB L=80dB
Subject 4	R=75dBnHL L=75dBnHL	R=75dBnHL L=75dBnHL	R=90dB L=80dB	R=85dB L=85dB	R=85dB L=85dB	R=80dB L=70dB	R=80dB L=85dB	R=80dB L=75dB	R=75dB L=80dB	R=90dB L=80dB
Subject 5	R=NR L=NR	R=NR L=NR	R=105dB L=105dB	R=115dB L=105dB	R=105dB L=105dB	R=100db L=110dB	R=95dB L=95dB	R=105dB L=105dB	R=100dB L=110dB	R=100dB L=110dB
Subject 6	R=NR L=NR	R=NR L=NR	R=105dB L=105dB	R=110dB L=115dB	R=105dB L=115dB	R=NR L=NR	R=105dB L=105dB	R=110dB L=110dB	R=105dB L=110dB	R=NR L=NR
Mean	**75dBnHL**	**71.4dBnHL**	**84.6dB**	**87.3dB**	**87.7dB**	**87.5dB**	**81.4dB**	**82.7dB**	**87.3dB**	**87.8dB**
Range	**30**	**45**	**65**	**65**	**60**	**40**	**55**	**55**	**45**	**35**
SD	**11.5**	**14.06**	**23.07**	**24.73**	**19.54**	**16.69**	**18.99**	**20.90**	**16.49**	**11.76**
Number of ears measured	**7**	**7**	**11**	**11**	**11**	**8**	**11**	**11**	**11**	**9**

NR = No Response

ASSR = ASSR predictions

SD = Standard Deviation

Table 4.8 Average of all frequencies tested on the three procedures

	ABR	ASSR predictions	BT
Mean	73.2	86.71	82.74
SD	12.5	20.78	18.75
Number of data points	21	41	42

Click ABR results were completed on 12 ears (six subjects). Of those 12 ears, five had no response to clicks at the maximum intensity limit (90 dBnHL) of the equipment. Toneburst ABR to 500 Hz was completed on all 12 ears to which five had no response at the limits of the equipment (90 dBnHL).

ASSR's measurements were completed on all 12 ears. Only one ear had no response at any frequency of the ASSR except 4000 Hz, where another three ears had no response at the maximum intensity of the equipment.

The behavioral assessment showed one ear with no response at all frequencies on the behavioral testing. Another two ears had no response at 4000 Hz. The results from all the subjects are shown in Table 4.7.

4.2.2.1 Comparing the unaided ABR *and unaided ASSR*

As indicated in Table 4.7, the **range** of the absolute measurements values for the 500 Hz ASSR's is 35 dB broader than the range for the tone burst ABR. The range for the 2000 Hz ASSR predictions is 20 dB broader than the range for the click ABR. The range of the 4000 Hz ASSR predictions is however 5 dB smaller than that of the click ABR. The number of ears taken into account is again seven on the ABR, 11 on the 2000 Hz ASSR, but eight

on the 4000 Hz ASSR prediction. Although the range of the threshold that was determined with the ASSR seems in most cases broader than the range of measurements determined with the ABR, it would also seem as if the difference between the range may be influenced by the number of ears measured (See Table 4.7). It is therefore difficult to draw any conclusions based on the range of the threshold measured with the ASSR and ABR. The **SD** values seem to confirm the range values. It is however risky to draw any conclusions from the SD data since the number of data points for the ABR measurements were limited to seven and considering the inevitable individual differences, variation in responses can be expected to be high and would inevitably have an affect on the SD values for such a small sample.

Comparing the ABR results for both tone bursts and clicks with the 500 Hz, 2000 Hz and 4000 Hz ASSR, it was noted that the majority of comparable thresholds - 14 of the 21 (67%) – showed a difference of 10 dB or less. These results are summarized in Figure 4.8.

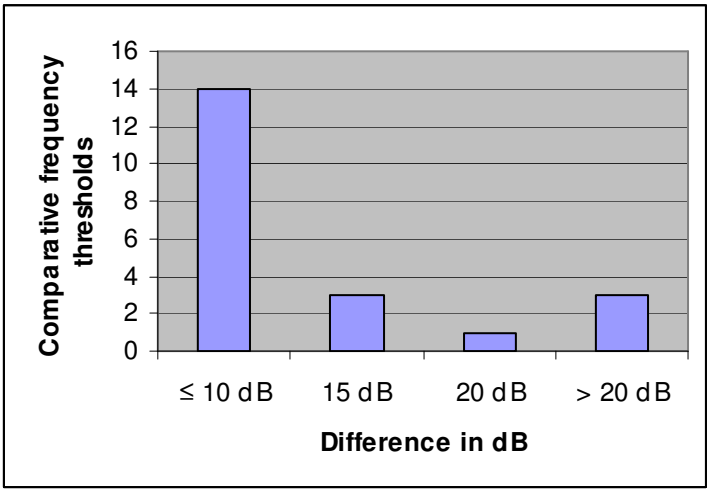

Figure 4.8 Representation of comparative frequency thresholds between the ABR and ASSR

Further insight was gained by calculating the **mean** and considering the difference between the mean of the absolute values for each of the evaluation procedures. The mean of the unaided click ABR's ranged from 71.4 dBnHL for the click ABR and 75 dBnHL for the unaided tone burst ABR. The mean ASSR predicted thresholds levels ranged from 84.6 dB HL to 87.7 dB HL. The mean of all the tone burst ABR thresholds were 10 dB lower than the mean of all the 500 Hz ASSR predicted thresholds (see Table 4.7). When comparing the click ABR with the 2000 Hz ASSR and 4000 Hz ASSR, the mean results indicate that the ABR measurements again had the lower response level, with a difference of approximately 17 dB. It is relevant though, to take into account the number of ears tested with each procedure (Table 4.7). Only seven ears represent the results on the ABR, where 11 are represented on the ASSR average. The five ears not represented on the ABR results are the ones that had no response on this procedure and therefore fall in a category more severe than could be measured by the ABR, thus inflating the calculated mean of the ASSR measurements.

Additional analyses provided a collective view of thresholds to all stimulus frequencies as determined by a specific procedure. As indicated in Table 4.8, the **mean** of all frequencies tested on the ABR was 73.2 dBnHL in comparison with a mean of the 86.71 dB on the ASSR. The standard deviation on these two measuring techniques differed - with the SD 12.5 dB on the ABR and 20.78 dB on the ASSR, indicating a wider dispersion of ASSR measurements. Due to the output limitations of equipment, the ABR could not render responses on all subjects resulting in a smaller number of available ABR measurements (21), as opposed to available ASSR measurements (41). Although a higher number of data points were

available the SD values for all measurements per procedure should again be interpreted with caution.

Statistical analyses of the mean data – using the Exact Wilcoxon Rank Sum Test - indicated that no statistically significant difference exist between the mean thresholds measured with the ABR and the ASSR. Table 4.9 summarizes the results of the inferential statistical analysis of average for all the ears measured with the tone burst ABR vs. 500 Hz ASSR and the click ABR vs. 2000 Hz and 4000 Hz ASSR.

Table 4.9 Statistical analysis of ABR and ASSR predicted results

Stimulus	P value
• **Click ABR vs. 2000 Hz ASSR**	P = 0.4074
• **Click ABR vs. 4000 Hz ASSR**	P = 1.0000
• **500 Hz tone burst vs. 500 Hz ASSR**	P = 0.4991

For a difference to be significant the p-value should be smaller than 0.05 (Steyn, Smit, Du Toit & Strasheim, 2003:596). In this case none of the p-values were smaller than 0.05 and therefore no significant statistical difference was noted between thresholds determined by the unaided ABR and by the unaided ASSR.

The results provided by the ABR and ASSR were also compared with regard to its relation. Figure 4.9 shows the relationship or correlation coefficient between the 500 Hz toneburst ABR (TB) and the ASSR predicted threshold, using a 500 Hz carrier frequency. It is important to note that a large proportion of ears (5 of 12) had no response to the 500

Hz tone burst ABR at 90 dBnHL; therefore, only 7 ears are represented in the equation. The data indicate that there is a moderate to marked positive correlation between ASSR thresholds at 500 Hz and the 500 Hz tone burst ABR thresholds (r = .77).

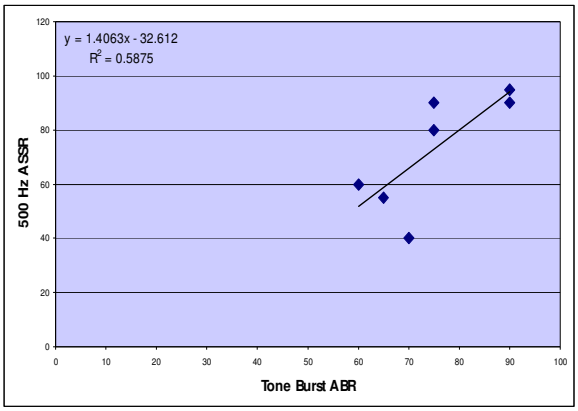

Figure 4.9 Relationship between 500 Hz tone burst ABR and ASSR prediction based on the measurement for seven ears

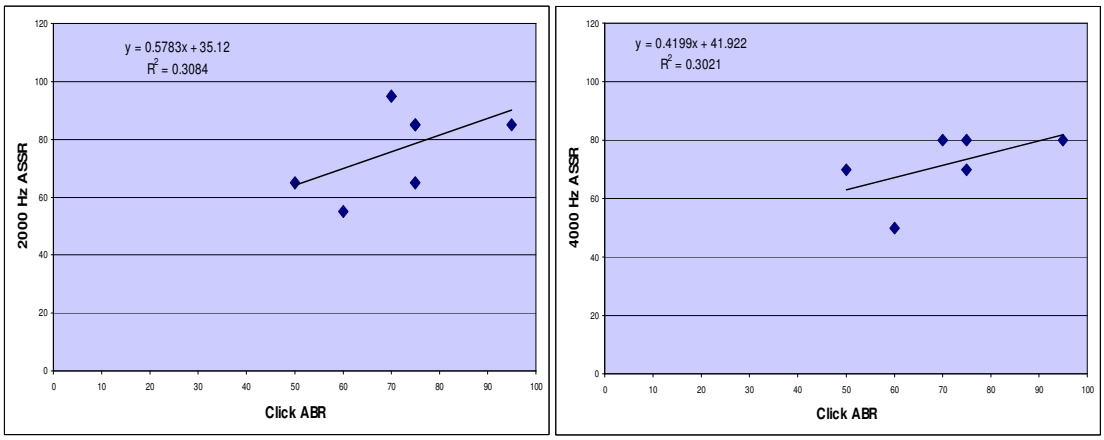

Figure 4.10 Relationship between the click ABR and 2000 and 4000 Hz ASSR prediction based on the measurement of seven ears

Figure 4.10 shows a comparison matrix between the thresholds for seven ears as obtained with the click ABR to the 2000 Hz and 4000 Hz ASSR. It is important to note that 5 of the ears tested, had no response to clicks at 90

dBnHL; therefore only 7 ears are represented in figure 4.8. The data indicate that there is a fair degree of positive correlation between the click ABR and the 2000 Hz ASSR threshold (r = .56). A similar degree of positive correlation is found between the 4000 Hz ASSR threshold and the click-evoked ABR threshold (r = .57). The correlation results are therefore a confirmation of what was indicated by the inferential statistics.

To summarize:

- Results indicate that it was in more instances possible to determine thresholds with the ASSR than with the ABR
- In 67% of the frequencies tested the thresholds between the ABR and ASSR corresponded within 10 dB of each other.
- ASSR thresholds for the six subjects show a bigger variation than the ABR thresholds, but it is impossible to come to a clear conclusion as to what this may indicate.
- Differences between mean thresholds measured with the ASSR and the ABR exist, but it shows no statistical significance
- Results confirm that there is a moderate to fair positive correlation between the thresholds determined by the ASSR and ABR respectively (Leedy & Ormrod, 2005:306).

4.2.2.2 Unaided ASSR vs. unaided behavioral thresholds

The number of ears tested was similar on these two approaches. When analyzing the **range** information on these two measurements, the range of the results also seems similar (see Table 4.7). A difference of 5 dB in the range of the 4000 Hz comparison is present, with a difference of 15 dB at 2000 Hz, 10 dB at 1000 Hz and 10 dB at 500 Hz. The SD values seem to

confirm the range values – the SD values on the ASSR varied from 16.69 to 24.73. The SD values on the behavioral thresholds varied from 11.76 to 20.90. Interpretation of the SD values on such a small sample however is risky.

Figure 4.11 illustrates the **mean** unaided ASSR predicted thresholds and unaided behavioral thresholds obtained at each frequency for all the ears tested (n=12). The mean unaided ASSR predicted threshold levels ranged from 84.6 dB HL to 87.7 dB HL. The mean behavioral threshold levels ranged from 81.4 dB HL to 87.8 dB HL (Table 4.7). One ear showed no response on either of the two procedures at all frequencies. Another three ears had no response at 4000 Hz on the ASSR and two of these ears had no response at 4000 Hz on the behavioral evaluation.

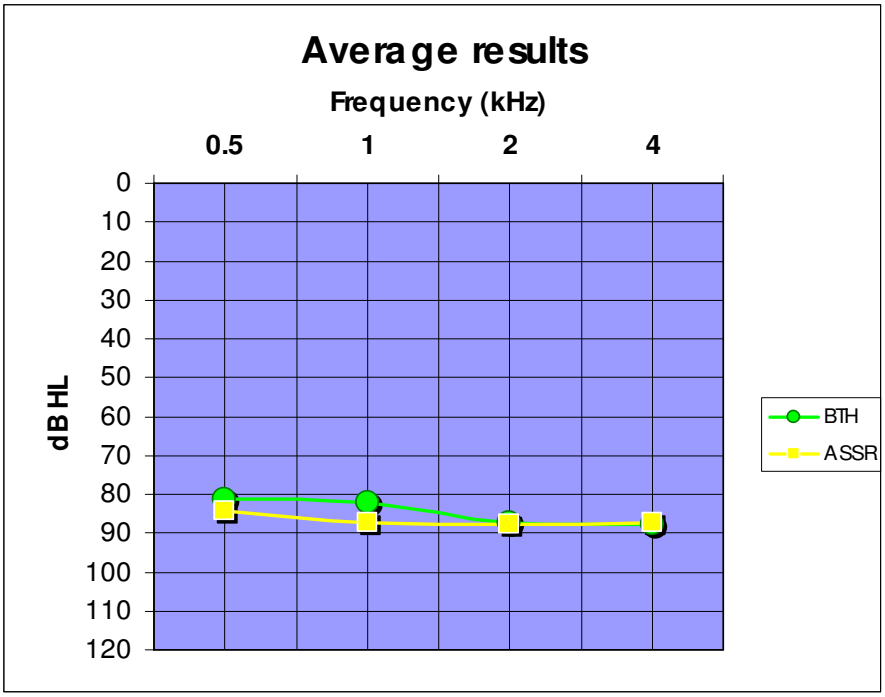

Figure 4.11 Mean unaided ASSR thresholds and unaided behavioral thresholds obtained at each frequency for all the ears tested (n=12).

A difference of 5 dB was noted at 500 Hz and 1000 Hz and 10 dB at 4000 Hz between the **mean** of the thresholds determined by the ASSR prediction and behavioral measurements. In the low frequencies the behavioral thresholds were slightly lower and at 4000 Hz the ASSR predicted thresholds were minimally lower. Results show that the averages of thresholds for all the ears, determined with the ASSR and behavioral assessments, were very similar (see Table 4.8).

Comparing the ASSR predicted thresholds with behavioral thresholds for all frequencies tested, it was noted that the majority of comparable thresholds - 33 of the 41 (80.5%) – showed a difference of 10 dB or less. These results are summarized in Figure 4.12.

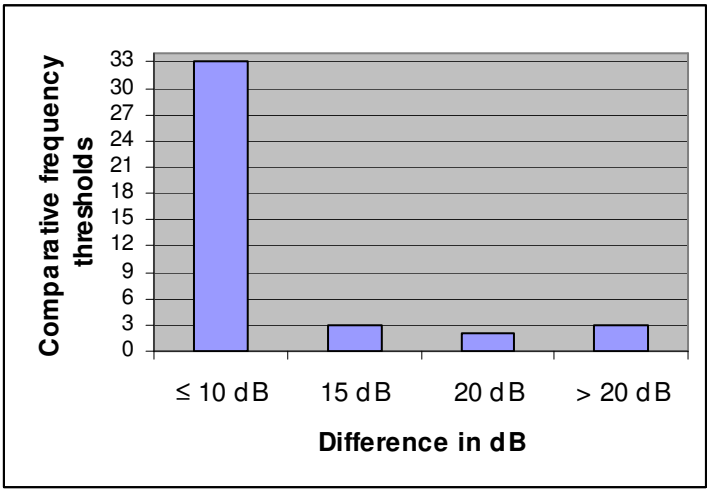

Figure 4.12 Representation of comparative frequency thresholds between the ASSR predicted thresholds and behavioral thresholds

Statistical analyses (Exact Wilcoxon Rank Sum Test) of the mean data are summarized in Table 4.10. No statistical difference between the thresholds determined by the unaided ASSR and unaided behavioral assessment was found, as all p-values were more than 0.05.

Table 4.10 Statistical analysis of ASSR predictions and behavioral measures

Stimulus	P - value
• 500 Hz ASSR vs. behavioural threshold	P = 0.8128
• 1000 Hz ASSR vs. behavioural threshold	P = 0.7475
• 2000 Hz ASSR vs. behavioural threshold	P = 0.7440
• 4000 Hz ASSR vs. behavioural threshold	P = 0.5039

The results provided by the ASSR and behavioral assessment were also compared with regard to its relation. The following scatter plots in Figure 4.13 represent the relationship or correlation coefficient between each frequency tested during the ASSR evaluation and the subsequent behavioral measurement. A highly dependable to moderate positive correlation is identified for three of the test frequencies, namely r = .93 at 500 Hz; r = .82 at 1000 Hz; r = .79 at 2000 Hz, determined with the ASSR and behavioral assessments. Thresholds determined with the two procedures indicates a moderate to fair degree of positive correlation at 4000 Hz (r = .59).

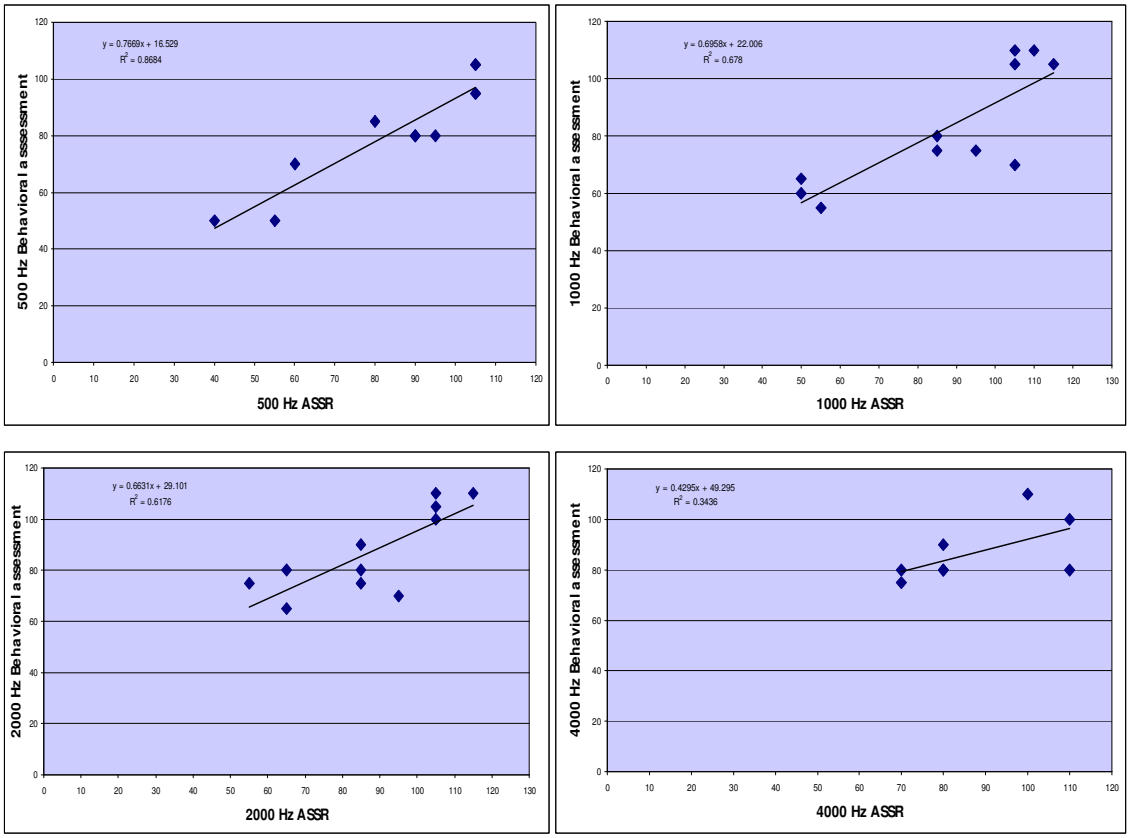

Figure 4.13 Relationship between thresholds determined with ASSR predictions and behavioral responses for a specific number of ears.

In summary:

- The number of frequencies where thresholds could be determined with ASSR compares favorable with that of the behavioral assessments.
- In 80.5% of the frequencies tested, the thresholds between the ASSR and behavioral assessment corresponded within 10 dB of each other.
- The range of the measurements determined with the two procedures compares well.

- There is no statistical difference between averages determined with the ASSR predictions and behavioral thresholds
- Results indicate a highly dependable to fairly positive correlation between thresholds determined by ASSR and behavioral assessments.

4.2.2.3 Unaided ABR vs. unaided behavioral thresholds

As indicated in Table 4.7, the **range** of the absolute measurements values for the 500 Hz behavioral threshold is 25 dB broader than the range for the tone burst ABR. The range for the click ABR and 2000 Hz behavioral response are both 45 dB. The range for the click ABR was 10 dB broader than the range for the 4000 Hz behavioral thresholds. The number of ears taken into account is seven on the ABR and 11 on the 2000 Hz behavioral thresholds assessment, but nine on the 4000 Hz behavioral assessment. It would seem as if the range of the threshold that were determined with the 500 Hz behavioral threshold assessment is broader than the range of the tone burst ABR. This is not the case however with the range of threshold determination between the click ABR and 2000 Hz behavioral threshold assessment. It is therefore difficult to draw any conclusions based on the range of the thresholds measured with the ABR and behavioral threshold assessments. It is again risky to draw conclusion from the SD values. These values seem to confirm the range values. The number of data points for the ABR measurements were limited to seven and considering the inevitable individual differences, variation in responses can be expected to be high and would have an affect on SD values for such a small sample.

Comparing the tone burst and click evoked ABR thresholds with the behavioral thresholds, it was noted that only 12 of the 21 (57%) of the comparable thresholds, showed a difference of 10 dB or less. These results are summarized in Figure 4.14.

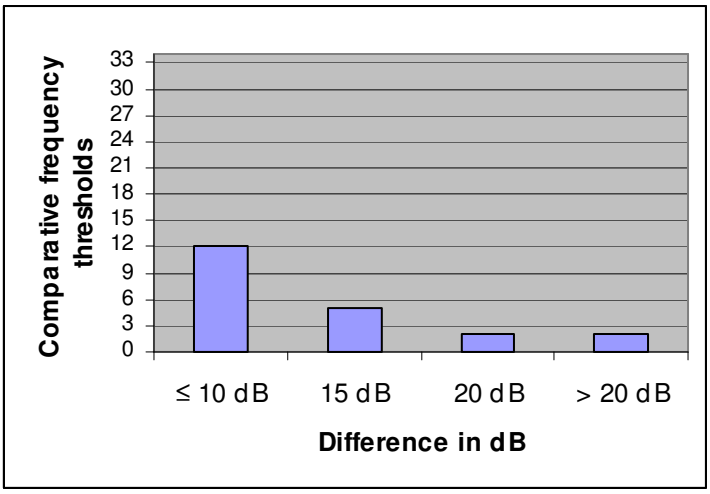

Figure 4.14 Representation of comparative frequency thresholds between the ABR and behavioral thresholds

Further insight was gained by again calculating the **mean** and considering the difference between the mean of the absolute values for each of the evaluation procedures. The mean of the ABR ranged from 71.4 dBnHL for the click ABR to 75 dBnHL for the tone burst ABR. The mean of the behavioral thresholds ranged from 81.4 dB HL to 87.8 dB HL. The mean of the tone burst ABR thresholds differed with 6.4 dB from the 500 Hz behavioral thresholds (see Table 4.7). The tone burst ABR had the lower value. When comparing the click ABR with the 2000 Hz and 4000 Hz behavioral thresholds, the average results indicate that the ABR again had the lower response level – with a difference of approximately 16.3 dB. It is relevant though, to consider again the number of ears tested on each

procedure (Table 4.7). Only seven ears represent the results on the ABR, where 11 are represented on the 500 Hz and 2000 Hz behavioral threshold measurement and nine ears are represented on the 4000 Hz behavioral threshold measurement. The five ears not represented on the ABR results are the ones that had no response on this procedure and therefore fall in a category more severe than could be measured by the ABR.

Additional analyses provided a collective view of thresholds to all stimulus frequencies as determined by a specific procedure. As indicated in Table 4.8, the mean of all frequencies tested on the ABR was 73.2 dBnHL in comparison with the mean of 82.74 dB on the behavioral assessment. The SD on these two measuring techniques differed – with the SD 12.5 dB on the ABR and 18.75 on the behavioral assessment, indicating a wider dispersion of behavioral thresholds. Due to the output limitations of equipment, the ABR could not render response on all subjects resulting in a smaller number of available ABR thresholds (21) as opposed to available behavioral thresholds (42). Although a higher number of data points were available, the SD values for all measurements per procedure should again be interpreted with caution.

Statistical analysis of the mean data – using the Exact Wilcoxon Rank Sum Test – indicated that no statistical significant difference exists between the mean thresholds measured with the ABR and behavioral threshold assessments. Table 4.11 summarizes the results of the inferential statistical analysis of the average for all the ears measured with the tone burst ABR vs. 500 Hz behavioral assessment and the click ABR vs. 2000 Hz and 4000 Hz behavioral threshold assessment.

Table 4.11 Statistical analysis of ABR and behavioral measures

Stimulus	P - value
• 500 Hz behavioural threshold vs. tone burst ABR	P = 0.1563
• 2000 Hz behavioural threshold vs. click ABR	P = 0.5000
• 4000 Hz behavioural threshold vs. click ABR	P = 0.2188

The results provided by the ABR and behavioral assessment were also compared with regard to its relation. Figure 4.15 shows the relationship or correlation coefficient between the tone burst ABR and the 500 Hz behavioral threshold assessment. It is important to note that a large proportion of the ears (5 of 12) had no response to the tone burst ABR at 90 dBnHL; therefore, only seven ears are represented in this equation. The data indicate that there is a moderate to marked positive correlation between behavioral threshold assessment at 500 Hz and the tone burst ABR ($r = .77$).

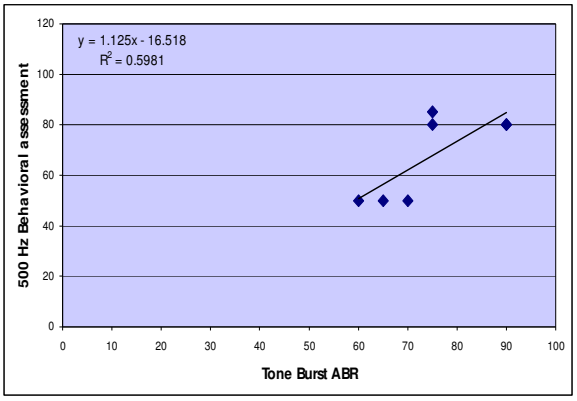

Figure 4.15 Relationship between tone burst ABR and 500 Hz behavioral threshold assessment based on the measurement for seven ears

Figure 4.16 shows a correlation matrix between the thresholds for seven ears as obtained with the click ABR to the 2000 Hz and 4000 Hz behavioral threshold assessment. Again it should be noted that only seven ears are represented in the equation as five ears had no response to the ABR at 90 dBnHL. The data indicate that there is a dependable positive correlation between the click ABR threshold and 2000 Hz behavioral threshold assessment (r = .89). A fair degree of positive correlation is also found between the 4000 Hz behavioral threshold and the click ABR (r = .40). The correlation results are therefore a confirmation of what was indicated by the inferential statistics.

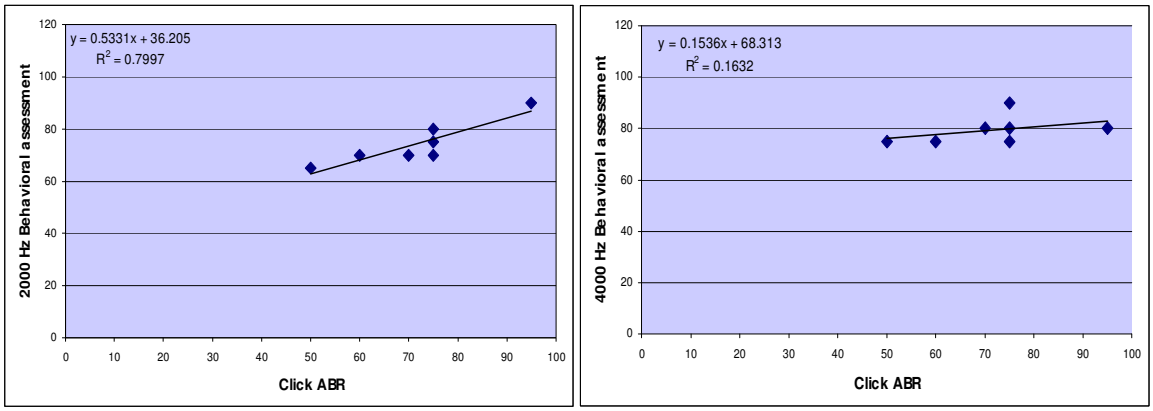

Figure 4.16 Relationship between click ABR and 2000 Hz and 4000 Hz behavioral threshold assessment based on the measurement for seven ears respectively

To summarize:

- Results indicate that it was not possible to determine thresholds with the ABR in all the cases.
- In only 57% of the frequencies tested the thresholds between the ABR and behavioral assessment corresponded within 10 dB of each other.

- Differences between averages of thresholds measured with the ABR and behavioral threshold assessments exist, but it shows no statistical significant difference.
- Results confirm that there is a fair to dependable positive correlation between the thresholds determined by the ABR and behavioral threshold assessment respectively.

Considering the comparative results described in *4.2.2.1, 4.2.2.2* and *4.2.2.3,* it seems that the ASSR measurement compare well to the measurements done with the other two procedures, although there seems to be a slightly higher correlation between the ASSR and the behavioral assessments than what exist between the ABR and the behavioral assessments. 80.5% of the frequencies tested through the use of ASSR corresponded within 10 dB with the behavioral thresholds. Only 57% of the frequencies tested through the use of the ABR corresponded within 10 dB of the behavioral thresholds – even though no corrections were made for the ABR thresholds.

4.3 RESULTS FOR SUB-AIM 2: TO INVESTIGATE THE CLINICAL VALUE OF THE ASSR FOR RELEVANT EARLY FITTING OF HEARING AIDS IN INFANTS BY DETERMINING AND COMPARING AIDED ASSR AND AIDED BEHAVIORAL THRESHOLDS.

Except in the case of subject 1, responses were recorded while the subject was wearing binaural hearing aids. The thresholds recorded are therefore an indication of the aided thresholds of the best response at each frequency of the best ear.

Responses for the ASSR were recorded at carrier frequencies of 500, 1000, 2000 and 4000 Hz in this group of six hearing impaired infants using hearing aids. The same frequencies were evaluated during the behavioral assessment. The results from the individual subjects will be discussed first, followed by the collective results.

4.3.1 Individual subject results for sub-aim 2

Each individual subject's aided results will now be reported on. In the individual tables (See Tables 4.12 to 4.17) an indication is given of both the unaided ASSR results – the measured thresholds and the predicted thresholds. Both these threshold values will be taken into account as the normative data from which predicted thresholds are calculated, were not compiled for aided ASSR's. Therefore a true comparison can be made between the unaided and aided ASSR results. The behavioral results will be compared with both values on the aided ASSR.

4.3.1.1 Subject 1: Results for sub-aim 2

The aided test results for subject 1 are presented in Table 4.12 and Figure 4.17.

Table 4.12 Unaided ASSR, aided ASSR and aided behavioral thresholds measurements for subject 1

Unaided ASSR results	500 Hz **70 dB**	1000 Hz **65 dB**	2000 Hz **75 dB**	4000 Hz **80 dB**
Unaided ASSR predicted results	**500 Hz** 55 dB	**1000 Hz** 55 dB	**2000 Hz** 65 dB	**4000 Hz** 70 dB
Aided ASSR results	**500 Hz** NR	**1000 Hz** 50 dB	**2000 Hz** 30 dB	**4000 Hz** 45 dB
Aided ASSR predicted results	**500 Hz** NR	**1000 Hz** 30 dB	**2000 Hz** 20 dB	**4000 Hz** 15 dB
Aided Behavioral assessment results	**500 Hz** 25 dB	**1000 Hz** 20 dB	**2000 Hz** 25 dB	**4000 Hz** 30 dB

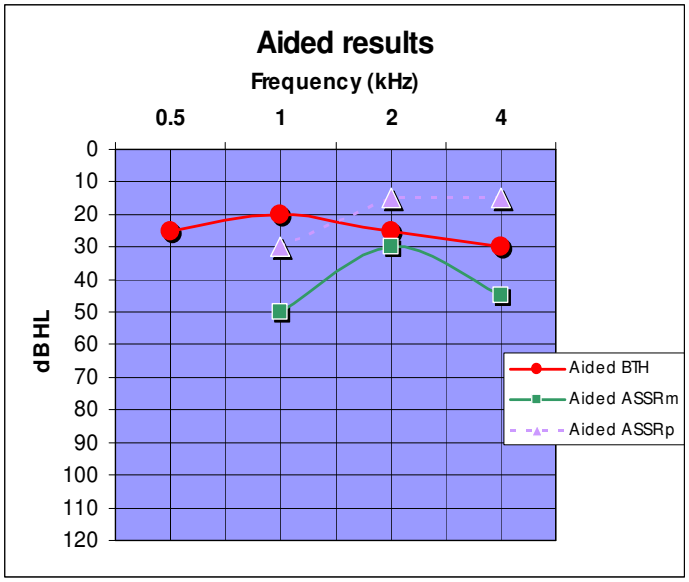

Figure 4.17 Aided results for subject 1 including behavioral thresholds and ASSR thresholds – measured and predicted

A recognizable difference was noted between the unaided and aided ASSR responses (see Table 4.12). When comparing the *measured* thresholds, a difference of between 15 to 45 dB across the frequency range was noted. When considering the difference in the aided and unaided *predicted* ASSR thresholds, the difference is approximately 10 dB

more. No aided response could be measured at the maximum outset of the equipment at 500 Hz.

When comparing the aided ASSR with the aided behavioral thresholds, a difference of 30 dB was noted between the *measured* aided ASSR and the behavioral threshold at 1000 Hz. A difference of 5 dB was present for the same comparison at 2000 Hz and a 15 dB difference was present for the 4000 Hz comparison. On all of these comparisons, the aided behavioral thresholds had the lower value.

When comparing the aided ASSR – using the *predicted* thresholds with the aided behavioral thresholds, a difference of 10 dB was noted at 1000 Hz, 5 dB at 2000 Hz and 15 dB at 4000 Hz. In this case the ASSR had the lower values for the 2000 Hz and 4000 Hz comparison.

4.3.1.2 Subject 2: Results for sub-aim 2

The aided test results for subject 2 are presented in Table 4.13 and Figure 4.18.

Table 4.13 Unaided ASSR, aided ASSR and aided behavioral thresholds

measurements for subject 2

Unaided ASSR results	500 Hz **60 dB**	1000 Hz **60 dB**	2000 Hz **60 dB**	4000 Hz **65 dB**
Unaided ASSR predicted results	**500 Hz** 40 dB	**1000 Hz** 50 dB	**2000 Hz** 55 dB	**4000 Hz** 50 dB
Aided ASSR results	**500 Hz** 50 dB	**1000 Hz** 35 dB	**2000 Hz** 35 dB	**4000 Hz** 30 dB
Aided ASSR predicted results	**500 Hz** 25 dB	**1000 Hz** 20 dB	**2000 Hz** 20 dB	**4000 Hz** 5 dB
Aided Behavioral assessment results	**500 Hz** 30 dB	**1000 Hz** 35 dB	**2000 Hz** 35 dB	**4000 Hz** 40 dB

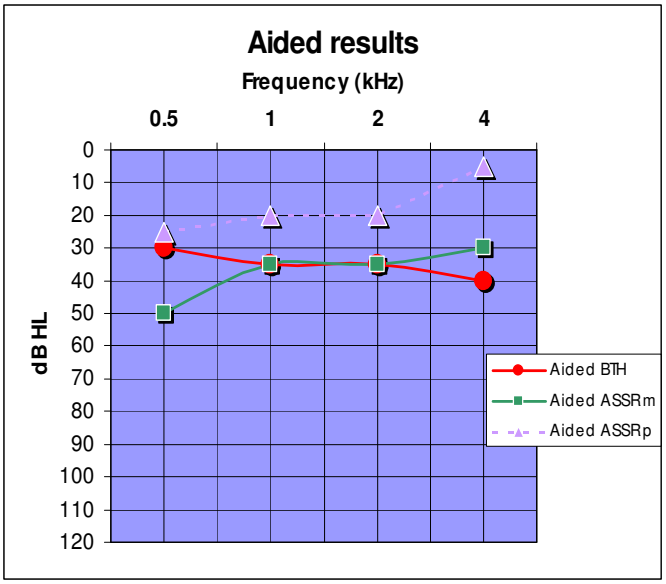

Figure 4.18 Aided results from subject 2 including behavioral thresholds and ASSR thresholds – measured and predicted

A recognizable difference was noted between the unaided and aided ASSR thresholds (see Table 4.13). When comparing the *measured* thresholds, a difference of between 10 to 35 dB across the frequency range was noted. When considering the difference in the aided and unaided *predicted* ASSR thresholds, the difference between the values were 15 to 45 dB.

When comparing the aided ASSR threshold with the aided behavioral thresholds, a difference of 20 dB was noted between the *measured* aided ASSR threshold and the behavioral threshold at 500 Hz. No difference was present at 1000 Hz and 2000 Hz. At 4000 Hz a 10 dB difference was noted. For the 500 Hz comparison, the aided behavioral thresholds had the lower value. For 4000 Hz comparison, the ASSR value had the lower value.

When comparing the aided ASSR – using the *predicted* thresholds with the aided behavioral thresholds, a difference of 5 dB was noted at 500 Hz, 15 dB at 1000 Hz, 15 dB at 2000 Hz and 35 dB at 4000 Hz. In this case the ASSR had the lower values across the frequency range.

4.3.1.3 Subject 3: Results for sub-aim 2

The aided test results for subject 3 are presented in Table 4.14 and Figure 4.19.

Table 4.14 Unaided ASSR, aided ASSR and aided behavioral thresholds measurements for subject 3

Unaided ASSR results	500 Hz **100 dB**	1000 Hz **100 dB**	2000 Hz **90 dB**	4000 Hz **90 dB**
Unaided predicted ASSR results	**500 Hz** 90 dB	**1000 Hz** 95 dB	**2000 Hz** 85 dB	**4000 Hz** 80 dB
Aided ASSR results	**500 Hz** NR	**1000 Hz** 50 dB	**2000 Hz** 60 dB	**4000 Hz** 50 dB
Aided predicted ASSR results	**500 Hz** NR	**1000 Hz** 35 dB	**2000 Hz** 45 dB	**4000 Hz** 35 dB
Aided Behavioral assessment results	**500 Hz** 35 dB	**1000 Hz** 35 dB	**2000 Hz** 40 dB	**4000 Hz** 40 dB

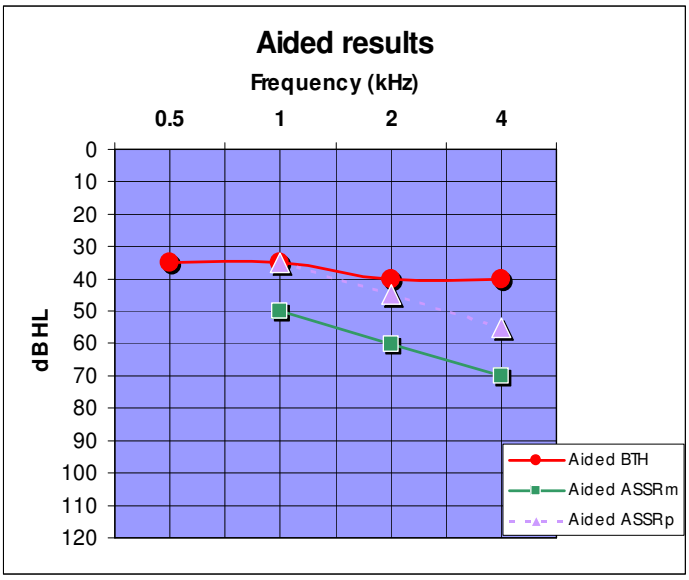

Figure 4.19 Aided results from subject 3 including behavioral thresholds and ASSR thresholds – measured and predicted

Again a recognizable difference was noted between the unaided and aided ASSR thresholds (see Table 4.14). When comparing the *measured* ASSR threshold, a difference of between 40 to 50 dB across the frequency range was noted. When considering the difference in the aided and unaided *predicted* ASSR thresholds, the difference between the values were 25 to 60 dB. No aided ASSR response at 500 Hz could be measured on this subject.

When comparing the aided ASSR threshold with the aided behavioral thresholds, a difference of 15 dB was noted between the *measured* aided ASSR threshold and the behavioral threshold at 1000 Hz. A difference of 20 dB was noted at 2000 Hz and a 30 dB difference at 4000 Hz. In this comparison the aided behavioral thresholds had the lower value.

When comparing the aided ASSR – using the *predicted* thresholds with the aided behavioral thresholds, no difference was noted at 1000 Hz, 5 dB at 2000 Hz and 15 dB at 4000 Hz. In this case the ASSR had the higher value for 2000 Hz and the lower value for 4000 Hz.

4.3.1.4 Subject 4: Results for sub-aim 2

The aided test results for subject 4 are presented in Table 4.15 and Figure 4.20.

Table 4.15 Unaided ASSR, aided ASSR and aided behavioral thresholds measurements for subject 4

Unaided ASSR results	500 Hz	1000 Hz	2000 Hz	4000 Hz

	90 dB	90 dB	90 dB	80 dB
Unaided predicted ASSR results	**500 Hz**	**1000 Hz**	**2000 Hz**	**4000 Hz**
	80 dB	85 dB	85 dB	70 dB
Aided ASSR results	**500 Hz**	**1000 Hz**	**2000 Hz**	**4000 Hz**
	NR	50 dB	60 dB	50 dB
Aided predicted ASSR results	**500 Hz**	**1000 Hz**	**2000 Hz**	**4000 Hz**
	NR	35 dB	45 dB	35 dB
Aided Behavioral assessment results	**500 Hz**	**1000 Hz**	**2000 Hz**	**4000 Hz**
	30 dB	35 dB	25 dB	25 dB

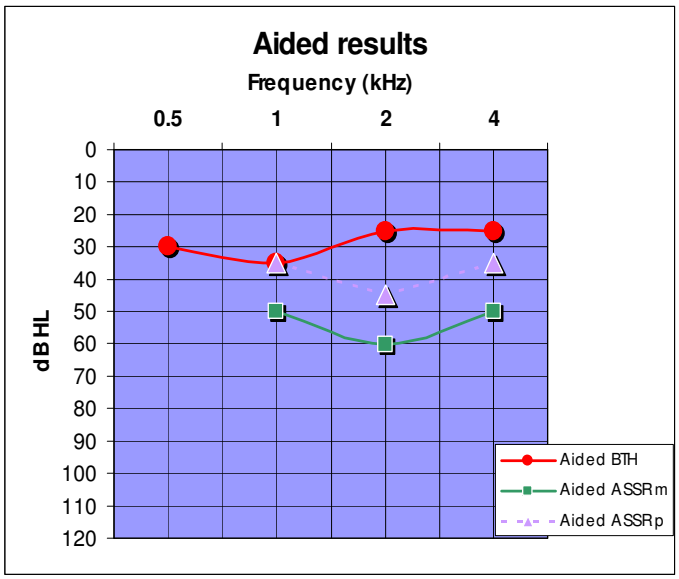

Figure 4.20 Aided results from subject 4 including behavioral thresholds and ASSR thresholds – measured and predicted

Again a recognizable difference was noted between the unaided and aided ASSR responses (see Table 4.15). When comparing the *measured* thresholds, a difference of between 30 to 40 dB across the frequency range was noted. When considering the difference in the aided and unaided *predicted* ASSR thresholds, the difference between the values were 35 to 50 dB. No aided ASSR response at 500 Hz could again be measured on this subject.

When comparing the aided ASSR with the aided behavioral thresholds, a difference of 15 dB was noted between the *measured* aided ASSR and the behavioral threshold at 1000 Hz. A difference of 35 dB was noted at 2000 Hz and a 25 dB difference at 4000 Hz. In this comparison the aided behavioral thresholds had the lower value.

When comparing the aided ASSR – using the *predicted* thresholds with the aided behavioral thresholds, no difference was noted at 1000 Hz, 20 dB at 2000 Hz and 10 dB at 4000 Hz. In this case the ASSR had the higher value for 2000 Hz and 4000 Hz.

4.3.1.5 Subject 5: Results for sub-aim 2

The aided test results for subject 4 are presented in Table 4.16 and Figure 4.21.

Table 4.16 Unaided ASSR, aided ASSR and aided behavioral thresholds measurements for subject 5

Unaided ASSR results	500 Hz **110 dB**	1000 Hz **110 dB**	2000 Hz **110 dB**	4000 Hz **105 dB**
Unaided predicted ASSR results	**500 Hz** 105 dB	**1000 Hz** 105 dB	**2000 Hz** 105 dB	**4000 Hz** 100 dB
Aided ASSR results	**500 Hz** NR	**1000 Hz** 60 dB	**2000 Hz** 70 dB	**4000 Hz** 80 dB
Aided predicted ASSR results	**500 Hz** NR	**1000 Hz** 45 dB	**2000 Hz** 60 dB	**4000 Hz** 65 dB
Aided Behavioral assessment results	**500 Hz** 45 dB	**1000 Hz** 50 dB	**2000 Hz** 55 dB	**4000 Hz** 60 dB

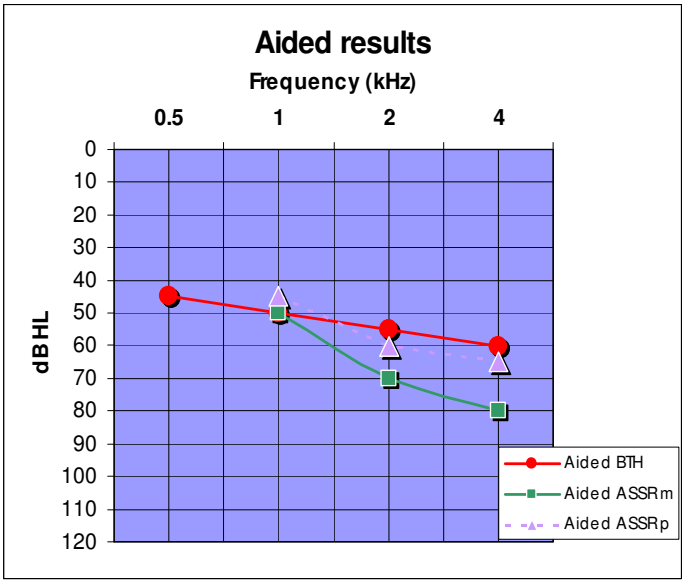

Figure 4.21 Aided results from subject 5 including behavioral thresholds and ASSR thresholds – measured and predicted

Again a recognizable difference was noted between the unaided and aided ASSR responses (see Table 4.16). When comparing the *measured* thresholds, a difference of between 30 to 50 dB across the frequency range was noted. When considering the difference in the aided and unaided *predicted* ASSR thresholds, the difference between the values

were 35 to 60 dB. No aided ASSR response at 500 Hz could again be measured on this subject.

When comparing the aided ASSR with the aided behavioral thresholds, a difference of 10 dB was noted between the *measured* aided ASSR and the behavioral threshold at 1000 Hz. A difference of 15 dB was noted at 2000 Hz and a 20 dB difference at 4000 Hz. In this comparison the aided behavioral thresholds had the lower value.

When comparing the aided ASSR – using the *predicted* thresholds with the aided behavioral thresholds, a 5 dB difference was noted at all the frequencies measured (1000 Hz – 4000 Hz). In this case the ASSR had the higher value for 2000 Hz and 4000 Hz.

4.3.1.6 Subject 6: Results for sub-aim 2

The aided test results for subject 4 are presented in Table 4.17 and Figure 4.22.

Table 4.17 Unaided ASSR, aided ASSR and aided behavioral thresholds measurements for subject 6

Unaided ASSR results	500 Hz **110 dB**	1000 Hz **110 dB**	2000 Hz **110 dB**	4000 Hz **NR**
Unaided predicted ASSR results	**500 Hz** 105 dB	**1000 Hz** 105 dB	**2000 Hz** 105 dB	**4000 Hz** NR
Aided ASSR results	**500 Hz** 50 dB	**1000 Hz** 40 dB	**2000 Hz** 70 dB	**4000 Hz** NR
Aided predicted ASSR results	**500 Hz** 25 dB	**1000 Hz** 25 dB	**2000 Hz** 60 dB	**4000 Hz** NR
Aided Behavioral assessment results	**500 Hz** 40 dB	**1000 Hz** 50 dB	**2000 Hz** 65 dB	**4000 Hz** NR

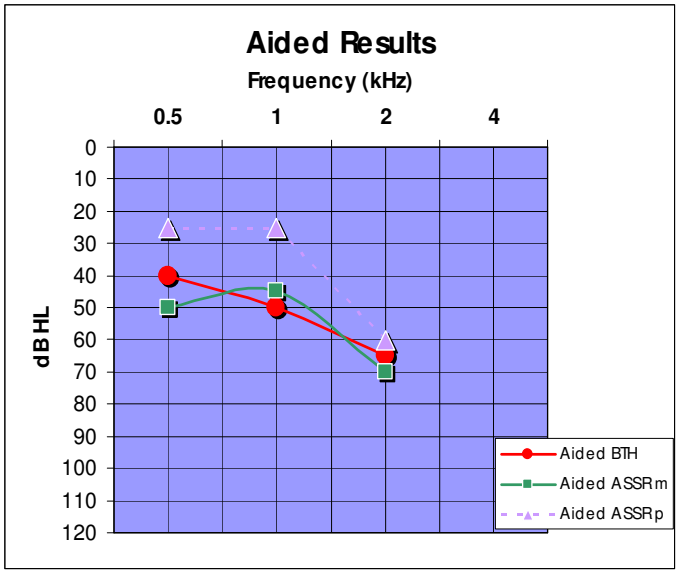

Figure 4.22 Aided results from subject 6 including behavioral thresholds and ASSR thresholds – measured and predicted

A recognizable difference was noted between the unaided and aided ASSR responses (see Table 4.17). When comparing the *measured* thresholds, a difference of between 40 to 70 dB across the frequency range was noted. When considering the difference in the aided and unaided *predicted* ASSR thresholds, the difference between the

thresholds were 45 to 80 dB. No aided ASSR response at 4000 Hz could be measured on this subject.

When comparing the aided ASSR with the aided behavioral thresholds, a difference of 10 dB was noted between the *measured* aided ASSR threshold and the behavioral threshold at 500 Hz. A difference of 10 dB was noted at 1000 Hz and 2000 Hz. In this comparison the aided behavioral thresholds had the lower value for 500 and 2000 Hz.

When comparing the aided ASSR – using the *predicted* thresholds with the aided behavioral thresholds, a 15 dB difference was noted at 500 Hz, 25 dB at 1000 Hz and 5 dB at 2000 Hz. In this case the ASSR had the lower thresholds for the frequencies tested.

Looking at these aided results of the individual subjects, it would seem that the ASSR may proof a valuable contribution to the process of pediatric hearing aid fittings. In the following section, the results that concern validation of hearing aid fittings in infants as it is based on the measurements for all six subjects are described, compared and discussed.

4.3.2 Collective results for all six subjects concerning sub-aim 2

All of the subjects showed recognizable aided ASSR responses above their unaided ASSR thresholds. In Table 4.18 the results of the aided ASSR – the measured threshold and the predicted ASSR threshold (using the prediction formulae devised by Melbourne University: Rance et al., 1995) as well as the aided behavioral thresholds are provided. Four subjects showed no response on the ASSR at 500 Hz aided response at the maximum output of the speaker (77,7dB). Only one subject had no

response to 4000 Hz aided ASSR (94,9dB). Responses were recorded at carrier frequencies of 500, 1000, 2000 and 4000 Hz in this group of six hearing impaired infants using hearing aids. The same frequencies were tested during the behavioral assessment, namely 500 Hz, 1000 Hz, 2000 Hz and 4000 Hz.

Table 4.18 Summary of aided thresholds for the six subjects as determined by ASSR and behavioral assessments respectively.

	Aided ASSR (measured)				Aided ASSR (predicted)				Aided BT			
	500 Hz	**1000 Hz**	**2000 Hz**	**4000 Hz**	**500 Hz**	**1000 Hz**	**2000 Hz**	**4000 Hz**	**500 Hz**	**1000 Hz**	**2000 Hz**	**4000 Hz**
Subject 1	NR	50 dB	30 dB	45 dB	NR	30 dB	15 dB	15 dB	25 dB	20 dB	25 dB	30 dB
Subject 2	50 dB	35 dB	35 dB	30 dB	25 dB	20 dB	20 dB	5 dB	30 dB	35 dB	35 dB	40 dB
Subject 3	NR	50 dB	60 dB	70 dB	NR	35 dB	45 db	55 dB	35 dB	35 dB	40 dB	40 dB
Subject 4	NR	50 dB	60 dB	50 dB	NR	35 dB	45 dB	35 dB	30 dB	35 dB	25 dB	25 dB
Subject 5	NR	50 dB	70 dB	80 dB	NR	45 dB	60 dB	65 dB	45 dB	50 dB	55 dB	60 dB
Subject 6	50 dB	45 dB	70 dB	NR	25 dB	25 dB	60 dB	NR	40 dB	50 dB	65 dB	NR
Mean	**50 dB**	**46.7 dB**	**54.2 dB**	**55 dB**	**25 dB**	**31.7 dB**	**40.8 dB**	**35.5 dB**	**34.2 dB**	**37.5 dB**	**40.8 dB**	**39 dB**
Range	**O**	**15**	**40**	**50**	**0**	**25**	**45**	**60**	**20**	**30**	**40**	**35**
Number	**2**	**6**	**6**	**5**	**2**	**6**	**6**	**5**	**6**	**6**	**6**	**5**

NR = No Response

P = prediction

The **range** of response determined with the ASSR (measured and predicted) and behavioral measurements was similar between different measurements. At 500 Hz the range was the same between the two different ASSR results, as only two ears had responses and the response level was the same for the ears. The range was 20dB on the behavioral measurement, but six values are calculated as opposed to two. The range at 1000 Hz was 15dB on the measured ASSR, 25dB on the predicted ASSR and 30dB on the behavioral assessment. At 2000 Hz the same range was noted for the measured ASSR and behavioral assessment. The predicted ASSR was 5 higher than these measures. At 4000 Hz the measured ASSR had a range of 50dB, the predicted ASSR 60dB and the behavioral assessment 35dB.

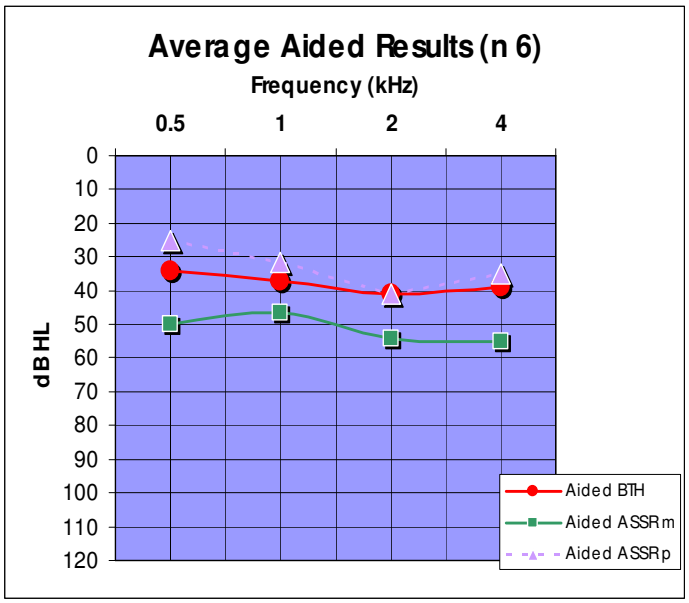

Figure 4.23 Comparison of average aided results for all measured ears based on aided behavioral assessment, measured and ASSR predicted values

Figure 4.23 represents the average aided results. The **mean** aided ASSR measured thresholds ranged from 0 to 55 dB HL. The mean aided ASSR predicted thresholds ranged from 25 to 40.8 dB HL and the mean aided behavioral thresholds ranged from 34.2 to 40.8 dB HL. A recognizable difference was noted between the mean unaided and mean aided ASSR thresholds. When using the *measured* values, an average difference of between 20 to 40 dB across the frequency range was noted. When looking at the difference in the *predicted* values, the differences between the aided and unaided values were 45 to 60 dB.

When comparing the **mean** aided ASSR *measured* thresholds with the aided behavioral thresholds, a difference of 15.8 dB was noted between the aided ASSR measured thresholds and the behavioral threshold at 500 Hz. A difference of 9.2 dB was noted at 1000 Hz, 13.4 dB at 2000 Hz and 16 dB at 4000 Hz. In this comparison the aided behavioral thresholds had the lower value.

When comparing the **mean** aided ASSR – using the *prediction* values with the average aided behavioral thresholds, a 9.2 dB difference was noted at 500 Hz, 5.8 dB at 1000 Hz, no difference at 2000 Hz and 4 dB differences at 4000 Hz. In this case the ASSR had the lower values for the frequencies tested.

Comparing the aided ASSR measured thresholds with aided behavioral thresholds for all the frequencies tested, it was noted that only 8 out of 19 comparable aided thresholds corresponded within 10 dB of each other. These results are represented in Figure 4.24.

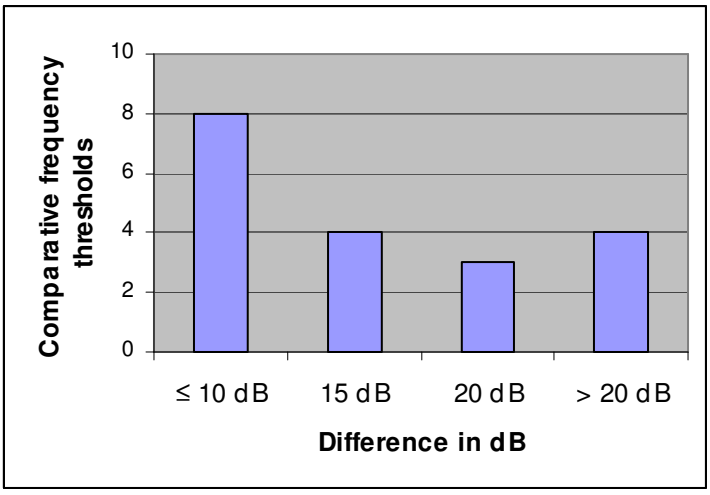

Figure 4.24 Representation of comparative frequencies on aided ASSR measured thresholds and aided behavioral thresholds

Comparing the aided ASSR predicted thresholds with aided behavioral thresholds for all the frequencies tested, it was noted that 11 of 19 comparable aided thresholds corresponded within 10 dB of each other. Figure 4.25 represents these results.

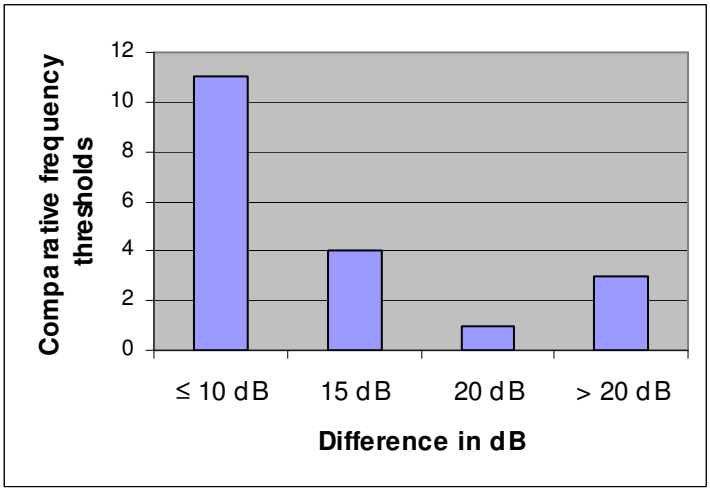

Figure 4.25 Representation of comparative frequencies on aided ASSR predicted thresholds and aided behavioral thresholds

Statistical analyses (Exact Wilcoxon Rank Sum Test) of the results for differences in average thresholds as determined by the Aided ASSR *measured* thresholds and behavioral thresholds are summarized in Table 4.19. No statistical difference between any of the aided results determined with these two procedures was found, as all p-values were more than 0.05. However the p-value on the 2000 Hz showed a smaller value than the other frequency values. It would seem that although the p-value still indicates no statistically significant difference, there seems to be a tendency towards a difference being present on this specific measurement. No analyses could be made at 500 Hz as responses on the aided ASSR could be measured only on two subjects.

Table 4.19 Aided ASSR measured responses vs. aided behavioral responses

Stimulus	P - value
• **Aided 500 Hz ASSR vs. aided behavioural threshold**	N.A. (only 2 values)
• **Aided 1000 Hz ASSR vs. aided behavioural threshold**	P = 0.1875
• **Aided 2000 Hz ASSR vs. aided behavioural threshold**	P = 0.0625 **
• **Aided 4000 Hz ASSR vs. aided behavioural threshold**	P = 0.1250

N.A. not applicable

**** Tendency toward difference**

The results provided by the aided ASSR measured thresholds and aided behavioral thresholds were also compared with regard to its relation. The following scatter plots in Figure 4.26 represent the relationship or correlation coefficient between each frequency tested during the aided ASSR *measured* evaluation and the subsequent aided behavioral

measurement. A positive correlation was noted on each individual frequency tested. A moderate to marked correlation was noted at 2000 Hz (r = .70) and at 4000 Hz (r = .63). A change relationship between the results of the procedures is indicated at 1000 Hz (r = .07).

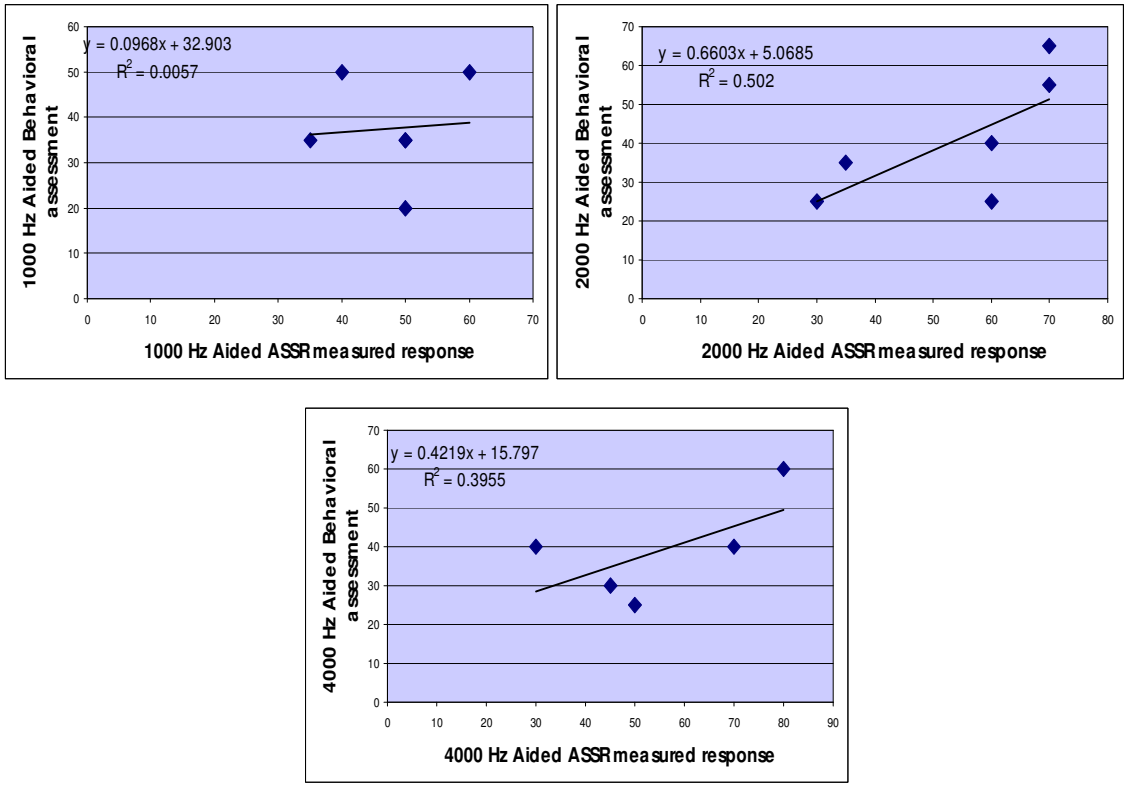

Figure 4.26 Relationship between aided behavioral thresholds and aided ASSR measured responses based on the measurements for six subjects

Statistical analyses (Exact Wilcoxon Rank Sum Test) of the results for differences in average thresholds as determined by the Aided ASSR *predicted* values and behavioral thresholds are summarized in Table 4.20. No statistical difference between any of the aided results determined with these two procedures was found, as all p-values were more than 0.05. No

analyses could be made at 500 Hz as responses on the aided ASSR could be measured only with two subjects.

Table 4.20 Aided ASSR predicted responses vs. aided behavioral responses

Stimulus	P - value
• **Aided 500 Hz ASSR vs. aided behavioural threshold**	N.A. (only 2 values)
• **Aided 1000 Hz ASSR vs. aided behavioural threshold**	P = 0.1249
• **Aided 2000 Hz ASSR vs. aided behavioural threshold**	P = 0.2438
• **Aided 4000 Hz ASSR vs. aided behavioural threshold**	P = 0.2504

N.A. not applicable

The comparison with regard to the relation between the aided ASSR predicted thresholds and aided behavioral thresholds are represented in the following scatter plots. Figure 4.27 represent the relationship or correlation coefficient between each frequency tested during the aided ASSR *predicted* evaluation and the subsequent aided behavioral measurement. A positive correlation was noted on each individual frequency tested. A marked correlation was noted at 2000 Hz (r = .76) and at 4000 Hz (r = .61). A slight relationship between the results of the procedures in indicated at 1000 Hz (r = .28).

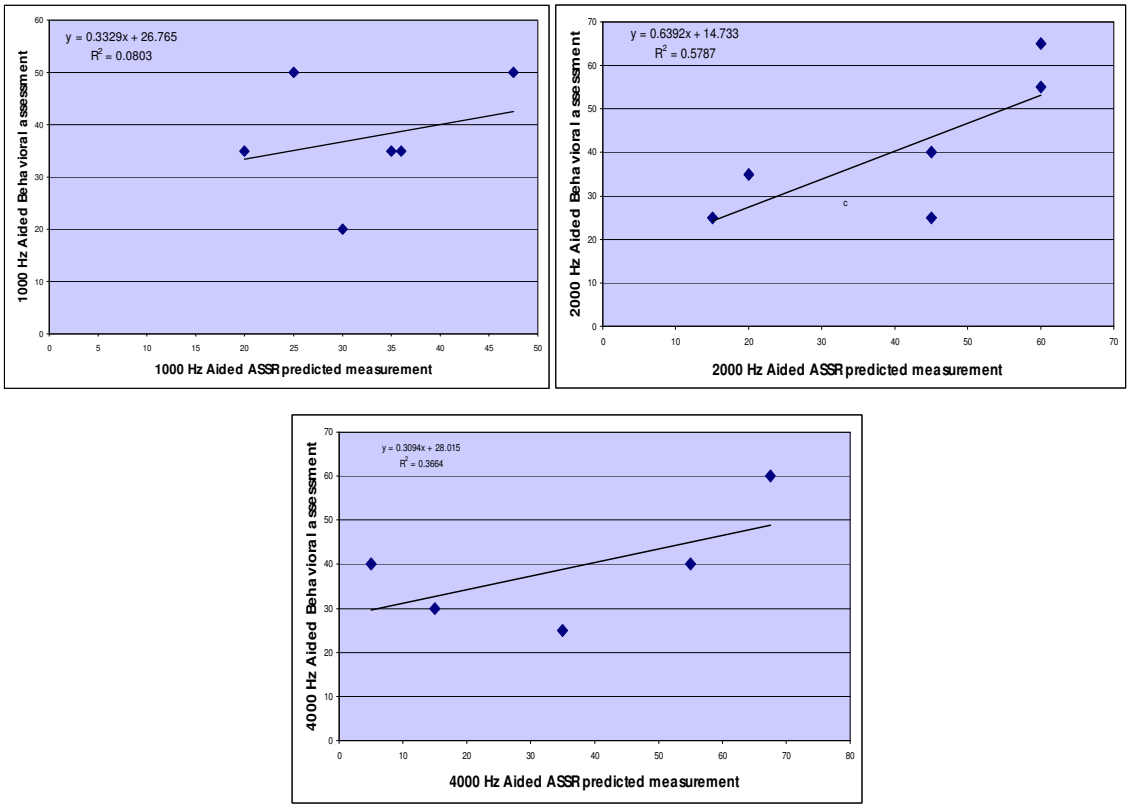

Figure 4.27 Relationship between aided behavioral thresholds and aided ASSR predicted responses based on the measurements for six subjects

To summarize:

- The same amount of frequencies tested, demonstrated results with aided ASSR *measured* and the aided ASSR *predicted* thresholds.
- In only 42% of the aided frequencies tested, the aided ASSR *measured* thresholds and aided behavioral thresholds corresponded within 10 dB of each other.
- In 58% of the aided frequencies tested, the aided ASSR *predicted* thresholds and aided behavioral thresholds corresponded within 10 dB of each other.

- No statistically significant differences were evident between aided averages of ASSR *measured* thresholds and aided behavioral thresholds.
- No statistical significant differences were evident between aided averages of ASSR *predicted* thresholds and aided behavioral thresholds.
- Results confirm that there is a moderate to change correlation between the aided ASSR *measured* response and aided behavioral assessment.
- Results confirm that there is a fair to moderate positive correlation between the aided thresholds determined by the behavioral assessment and the ASSR *predicted* response.

Analysis of the data led to comparative results which indicated that both the aided ASSR (measured and predicted) results compare favorably to that of aided behavioral assessments, although there is a higher correlation between the aided ASSR predictions and the aided behavioral assessments.

4.4 DISCUSSION

The purpose of this study was to determine the clinical value of the ASSR for early diagnosis and amplification of infants with hearing loss. This was done by using both ABR and ASSR measurements to predict hearing thresholds and to compare these results obtained in infants with hearing loss. Aided ASSR thresholds were measured in order to validate the hearing aid fitting. These results were compared with behavioral measurements. In the following sections the results of this study will be discussed according to the sub-aims.

4.4.1 Sub-aim 1: To investigate the potential clinical value of the ASSR in early diagnosis of hearing loss in a group of infants by determining and comparing unaided ASSR, ABR and behavioral thresholds.

Sub-aim 1 will be discussed in the following section.

4.4.1.1 ABR vs. ASSR

Although some discrepancies were noted between these two measuring techniques in the individual subjects (subject 2 and subject 4: tone burst ABR vs. 500 Hz ASSR and subject 3: click ABR and 2000 Hz ASSR), the results from this study show that the tone burst ABR and 500 Hz ASSR have a strong positive correlation (r = .77). Similar results were obtained with the click ABR and 2000 Hz ASSR comparison (r = .62). Johnson and Brown (in Vander Werff et al., 2002:233), tested a small group of hearing impaired adults with a range of hearing losses and compared toneburst ABR thresholds with ASSR thresholds. These researchers found a strong positive correlation of r = .91 between ABR and ASSR thresholds. The study by Vander Werff et al. (2002:233) agrees well with the previous study mentioned. The study conducted by Cone-Wesson et al. (2002:184) concluded that tone-ABR and ASSR could both be used to estimate hearing thresholds as positive correlations were found between these two measurements. This is confirmed by the results of the current study. In this current study however, no correction were made for the ABR results.

The population for whom ASSR threshold estimation procedures may prove particularly beneficial is children with severe to profound hearing losses. The continuous tones used to elicit the ASSR resemble the stimuli used in behavioral testing and can therefore presented at higher levels

than the ABR. The ASSR is therefore well suited to quantify hearing loss in the severe to profound range (Rance et al., 2005:298). This present study reported on five ears for which no click ABR or 500 Hz tone burst ABR was recorded at the maximum stimulation levels. Four of these ears had measurable ASSR thresholds at 500 and 2000 Hz. Two ears also had responses at 4000 Hz on the ASSR. Only one ear had no response on either of the measurements. These findings of potential advantages of ASSR over ABR for severe to profound losses are consistent with results of previously reported studies (Rance et al., 2005:294; Swanepoel et al., 2004:534; Vander Werff, 2002:233; Rance et al., 1998:57; Rance et al., 1995:505). These studies have shown that error in prediction of hearing loss decreases with increasing degree of hearing loss. The evidence from this study further indicates that absent ASSR implies no usable hearing at that frequency. That is not true of ABR, for which evidence has shown that absent ABR does not rule out useful residual hearing (Rance et al., 1998:48).

Both the ASSR and tone burst ABR have demonstrated clinical value for estimating the pure-tone audiogram in infants with hearing loss (Cone-Wesson et al., 2002:185). The data from this present study and those of other studies (Stueve & O'Rourke, 2003; Vander Werff, 2002) suggest that there are no significant differences in threshold determination between the two techniques.

4.4.1.2 ASSR vs. Behavioral measures

The results from this study show that the ASSR procedure can accurately identify and quantify hearing loss in infancy. For these subjects there was a strong relationship between the ASSR thresholds obtained during infancy and their subsequently established behavioral audiograms. The difference

between the average ASSR threshold prediction and the average behavioral threshold was 0 – 10 dB (Figure 4.11), with correlation values of .93 at 500 Hz; .82 at 1000 Hz; .79 at 2000 Hz and .59 at 4000 Hz. In studies that have compared the ASSR with behavioral thresholds, very strong positive correlations were also found between these two measures (Rance et al., 2005:295).

In a study to determine the effect of audiometric configuration on thresholds and suprathreshold ASSR, a highly significant correlation between pure-tone behavioral and ASSR thresholds for individuals with either sloping or flat audiometric configurations was revealed (Vander Werff & Brown: 2005:319). In the present study of 12 ears, it was found that the ASSR results were accurate in determining the configuration of the loss. As with the study by Rance et al. (1998:58) and Rance et al. (2005:295), the findings for individual frequencies translated into accurate descriptions of the subjects' hearing losses. The difference in thresholds differed between 0 – 20 dB, with the ASSR in most of the cases being slightly higher than the behavioral threshold – especially in the low frequencies (excluding subject 2 & 3). Rance et al. (1998:58) found a similar pattern in their subjects with the ASSR thresholds slightly overestimating the behavioral levels and mirroring the audiogram configuration. These findings are similar to the findings of Lins et al. (1996:95) when they found a significant difference in mean threshold at 500 Hz in a group of adult subjects. These researchers also showed a general tendency across frequency for ASSR thresholds in infants to be higher than for adults.

In this present study, the results from subject 2 showed inaccurate thresholds predictions. The ABR thresholds and ASSR prediction thresholds

correlated well at time of diagnosis, but subsequent behavioral thresholds were 10 dB to 35 dB lower at different frequencies than previous electrophysiological results. There is evidence of deterioration in hearing level in this subject. This aspect is being evaluated further. The results from the behavioral assessment impact negatively on the results of this study. The electrophysiological assessment in subject 3 indicated to a greater hearing loss than what was subsequently determined with behavioral audiometry. No apparent reason for these discrepancies could be found. A possible influence may be the presence of abnormal tuning curves in the cochlea, caused by impairment. Picton et al. (1998:329) found that the presence of abnormal tuning curves in the cochlea caused the impaired system to have place and frequency specificity discrepancies. This mechanism might not lead to well synchronized steady state responses and the physiologic thresholds may be elevated relative to the behavioral thresholds (Picton et al., 1998:329).

The audiograms shown of each individual subject also reflects one of the particular advantages of the ASSR assessment in subjects with minimal amounts of residual hearing (subject 5 & 6). The continuous tones used to elicit the ASSR resemble the stimuli used to elicit behavioral responses and can be presented at higher levels than is possible for brief stimuli. The ASSR is therefore especially well suited for quantifying hearing loss of a severe to profound nature (Rance et al., 2005:298). Of the five hundred and fifty-six subjects with either normal hearing or sensorineural hearing loss, only four showed ASSR thresholds at levels > 10 dB lower than their subsequently established behavioral thresholds.

In a recent study Picton, Dimitrijevic, Perez-Abalo and Van Roon (2005:154) concluded their report by stating that the accuracy of

threshold estimation depends on the variability of threshold estimation rather than on any mean difference between physiological and behavioral thresholds. The results from their experiments demonstrated several ways to improve the accuracy of estimating behavioral thresholds from the ASSR – the main factor being to reduce background noise. With time limitation in the clinical setting, the results will typically be thresholds that have a standard deviation of 10 dB – which is similar to the variability obtained using tone burst ABR (Stapells, 2000b:74).

This present study supports the findings of the previous studies. The ASSR assessment demonstrates the clinical value for estimating the pure-tone audiogram in infants with hearing loss. It can thus be seen as a very useful step in the evaluation process for these early-identified infants – allowing the behavioral audiogram to be predicted and intervention processes to be implemented.

4.4.1.3 ABR vs. Behavioral measures

This study also shows that reasonably accurate estimates of 500 Hz and 2000 and 4000 Hz pure tone behavioral thresholds can be obtained by recording tone burst ABR and click ABR. A marked correlation (r = .77) was found between the 500 Hz behavioral assessment and tone burst ABR. Similar findings are well reported on in several studies (Stapells, Gravel & Martin, 1995:361; Stapells, 2000a:20; Gorga, 1999:29). The click ABR showed a dependable correlation with the 2000 Hz behavioral assessment and only a fair degree of positive correlation with 4000 Hz behavioral assessment. This finding agrees with the notion that the click ABR threshold represents hearing in the 2000 to 4000 Hz frequency region.

However it was evident that the severe to profound sensory neural hearing loss will not be identified and evaluated with the ABR. This was evident as only seven of the 12 ears could be evaluated using the ABR. These findings are consistent with previously reported studies (Rance et al., 2005; Vander Werff et al., 2002; Rance et al., 1998; Rance et al., 1995).

Summary:

- This study concludes that both the ABR and ASSR can both be used to estimate hearing thresholds – as positive correlations were found between these two measurements. However the ASSR proved to be more beneficial in the severe to profound hearing loss population to quantify their hearing losses.
- This study indicates that the ASSR procedure can accurately identify and quantify hearing loss in infants as a strong relationship was noted between the ASSR thresholds obtained during infancy and their subsequently obtained behavioral audiograms.
- Although the tone burst ABR and click evoked ABR indicated to provide reasonably accurate estimates of the 500 Hz, 2000 Hz and 4000 Hz behavioral audiogram, it was evident that the severe to profound sensory neural hearing losses will not be identified and evaluated through the use of the ABR.

4.4.2 Sub-aim 2: To investigate the clinical value of the ASSR for relevant early fitting of hearing aids in infants by determining and comparing aided ASSR and aided behavioral thresholds.

Sub-aim 2 will be discussed in the following section.

4.4.2.1 Unaided ASSR vs. aided ASSR responses

All of the subjects showed recognizable aided ASSR responses above their unaided ASSR thresholds. In this study both the measured ASSR and the ASSR using the prediction formulae devised by Melbourne University (Rance et al., 1995) was used. On the measured ASSR, the responses were within 20 - 40 dB above the unaided measured ASSR. Using the prediction formulae, the average difference between the unaided ASSR and aided ASSR was 45 – 60 dB. In only two subjects however could an aided ASSR response be measured at 500 Hz at the maximum output of the speaker (77,7 dB).

The inability in this present study to determine more aided ASSR thresholds at 500 Hz might be explained by hearing aid characteristics and the output of the calibrated speaker. Aided hearing thresholds are limited by the output of the hearing aid (Garnham et al., 2000:277). Saturation and distortion of the output signal when using a high-intensity stimuli in conjunction with moderate to high gains were reported in the study by Garnham and his colleagues. Distortion introduces additional sideband frequencies to those in the input stimuli, thus decreasing the frequency specificity of the response – influencing the response measurement of the ASSR.

An aspect that might have played a further role in the inability to obtain more aided ASSR thresholds at 500 Hz might be the test environment. These measurements were obtained in a quiet room in the practice of the researcher. Results from previously reported studies (Perez-Abalo et al., 2001:210; Swanepoel, 2001:120; Lins et al., 1996:95) indicated that acoustic ambient background noise exerts a significant influence on the ASSR

results. Noise levels within this specific test room may not have been sufficiently quiet to establish thresholds in the sound field at 500 Hz (Harrell, 2002:75).

Another possible influence may be the presence of abnormal tuning curves in the cochlea, caused by impairment. Picton et al. (1998:329) found that the presence of abnormal tuning curves in the cochlea caused the impaired system to have place and frequency specificity discrepancies. Despite amplification, the sounds - in this instance 500 Hz - may be processed through areas of the cochlea that are not place specific for 500 Hz. This mechanism might not lead to well synchronized steady state responses and the physiologic thresholds may be elevated relative to the behavioral thresholds (Picton et al., 1998:329).

4.4.2.2 Aided ASSR responses vs. aided behavioral responses

In the group of six subjects, the aided ASSR *measured* responses were on average between 9.2 dB and 16 dB higher than the aided behavioral thresholds. These results are similar to the differences reported by Picton et al. (1998:327), where the aided ASSR responses were on average between 13 and 17 dB higher than the behavioral thresholds. The Picton group of researchers investigated the possible use of the MASTER (multiple auditory steady-state response) technique in the assessment of aided thresholds in the sound field on 38 children (ages 11 – 17 years) with hearing impairment. Most children in their study showed recognizable responses within 10 and 30 dB above their behavioral thresholds with their hearing aids. The physiologic thresholds were quite closely related to the behavioral thresholds except at 4000 Hz where there was a significantly greater variability in the relation between the behavioral and

physiological thresholds. In several of the aided subjects, no responses were found at 4000 Hz even when stimuli were significantly above behavioral thresholds. Picton et al. (1998:322) obtained better thresholds – using the same stimuli – presented singly. The relations between the physiologic and behavioral thresholds became closer. There were no significant differences in the physiologic-behavioral differences among the different audiometric frequencies. The conclusion for their findings was that the physiologic-behavioral difference was probably related to recruitment – the response reaches a level where it is recognizable at intensity closer to threshold.

In the current group of six subjects, the aided ASSR *predicted* thresholds were on average between 4 dB and 9.2 dB lower than the aided behavioral thresholds. These results differ from the Picton group results (1998:327); however, Picton et al. (1998:327) did not use prediction formulae to determine aided ASSR threshold levels. The aided ASSR thresholds in their report were the actual measured thresholds – using the MASTER.

Comparing the mean aided ASSR *measured* and *predicted* thresholds in comparison with the aided behavioral thresholds, it would seem as if the correlation between the aided ASSR *predicted* values and aided behavioral threshold values are more positive by a small margin – especially at 1000 and 2000 Hz. However in the individual cases variations are noted: the aided ASSR *predicted* values for subject 1, 3, 4 and 5 closely approximated the aided behavioral threshold values more so than the aided ASSR *measured* values. The results from subject 2 and 6 indicated to the ASSR *measured* values to approximate the aided behavioral thresholds more closely than the ASSR *predicted* values.

The differences between ASSR (measured thresholds) and behavioral thresholds varied between 0 and 20 dB. The differences between ASSR (predicted values) and behavioral thresholds varied between 5 and 25 dB. The variance might be explainable by inter-subject differences. Subject 1, 2 and 6 showed lower responses on the aided ASSR *predicted* values as on the aided behavioral measurement. These were the subjects who were fitted with digital hearing aids. Subject 3, 4 and 5 were fitted with digitally programmable hearing aids. Their aided ASSR *predicted* responses were between 0 and 20 dB higher than the aided behavioral thresholds. This range is far from optimal; however where there is no other information about aided thresholds, this degree of accuracy is acceptable (Picton et al., 1998:327). It is clear however, that the results from this study indicate to the aided ASSR *measured* responses to be not specific enough and that the aided ASSR *predicted* thresholds overestimate thresholds. New correction figures may be needed for the ASSR to be used for the purpose of estimating functional gain and larger scale studies are needed to validate this approach.

This study has shown that aided ASSR are valuable in the validation of the aided performance in some subjects and can provide valuable functional information. In this group of six subjects, it was the first clear response recorded on these infants. It also clearly indicated possible cochlear implantation candidacy for subject 5 and 6 and confirmed that the unaided thresholds were not based solely on spurious/artificial AASR's at high intensity stimuli (Small & Stapells, 2004:611; Gorga et al., 2004:302; Jeng et al, 2004:67; Picton & John, 2004:541; Dillon, 2001:419). However, some limitations to aided ASSR were found:

- Only the linear operation of the aid can be tested (Garnham et al., 2000:277). Advanced processing features, such as feedback managing systems and noise reduction systems, were deactivated on the digital hearing aids.
- Aided thresholds are not uninformative – clearly if thresholds are below the speech intensities, the aid cannot improve speech perception. Picton et al. (2002:68) cautions that the assessment of aided thresholds is occurring at levels that are not relevant to the perception of amplified speech. Objective assessment of hearing aid measurements at comfort levels may be a more efficient approach to fitting of hearing aids than determining aided thresholds (Picton et al., 1998:328).

Although these limitations are present, aided ASSR's were found to be valuable – especially in the cases of subject 5 and 6 where cochlear implant candidacy was determined at such a young age. Aided ASSR measures may become more valuable as the need arise to determine cochlear implantation candidacy at earlier ages and to manage infants with hearing loss more effectively. However, when performing aided hearing aid threshold measurements it is essential to be aware of limitations in both the hearing aids and the stimuli used to evoke a response.

Summary:

- All subjects showed recognizable aided ASSR responses above their unaided ASSR thresholds. There was an inability to determine aided ASSR's at 500 Hz in four subjects.

- In the group of six subjects, the aided ASSR *measured* thresholds were on average between 9.2 dB and 16 dB higher than the aided behavioral thresholds. The aided ASSR *predicted* were on average between 4 dB and 9.2 dB lower than the aided behavioral thresholds – indicating to the aided *measured* thresholds to underestimate behavioral thresholds and the aided *predicted* thresholds to overestimate the aided behavioral thresholds.

4.5 CONCLUSION

The results from the current study indicate good correlation between the ABR and ASSR as method to predict hearing thresholds in this group of infants. The ASSR however does have the advantage over the ABR in individuals with a severe to profound hearing loss. Responses could be measured in these cases through the use of ASSR in the absence of any ABR responses. Furthermore, the absence of ASSR responses at maximum levels was a reliable indicator of profound or total hearing loss. The ASSR thus allowed for greater degrees of hearing impairment to be evaluated. The frequency specificity of the stimulus tones allowed assessment of residual hearing across the audiometric frequency range.

The ASSR findings for individual frequencies translated into accurate descriptions of the subjects' hearing losses in comparison with behavioral thresholds. The configuration of the hearing loss could be predicted through the use of ASSR. Results such as these can provide the basis for early intervention such as fitting of hearing aids or determining candidacy for cochlear implantation.

Hearing aid fitting in the infant population remains a challenge and aided ASSR have the potential to provide objective information with regards to hearing aid functional benefit in the validation process. Aided ASSR threshold information is valuable and important in the management of challenging children. In this study aided ASSR thresholds provided additional information.

It would therefore seem as if the ASSR has got clinical value in the early diagnosis of hearing loss in infants as the unaided ASSR values correlated well with the ABR at the time of diagnosis and subsequently with the unaided behavioral thresholds.

Furthermore it would seem as if the ASSR has an additional clinical value in the validation of hearing aid fittings for infants as the aided ASSR *measured* and *predicted* values correlated well with the aided behavioral thresholds.

4.6 SUMMARY

This chapter reported and discussed the results obtained in this study according to the two sub-aims. These sub-aims were selected in an attempt to answer the main aim of this study. The results pertaining to each sub-aim were discussed and integrated with literature to ensure the validity thereof. Conclusions were drawn from the results in each sub-aim and summarized at the end of the chapter in order to answer the main aim of the study.