CHAPTER 6

RESULTS

AIM

To present, discuss and interpret the results of the study and to evaluate these against the framework of the body of knowledge set out in the literature review.

6.1 INTRODUCTION

Roeser *et al.* (2000b) stated that the value of any diagnostic test depends on its ability to fulfil its intended purpose. The principal aim of the present study was to assess the clinical value of ASSR methods in the audiological evaluation of pseudohypacusic mine workers, particularly those with noise-induced hearing loss. Accurate estimations of hearing thresholds for the purposes of assessing compensability and fitness for work was the norm for deciding the clinical value of ASSRs.

The present study differs from previous work on ASSRs, in that it considered subjects with abnormal hearing, namely those with noise-induced hearing loss, a very specific form of sensory neural hearing loss (SNHL). Various protocols and instruments were compared in order, to identify the most appropriate and practicable procedure for assessing pseudohypacusic mine workers with noise-induced hearing loss. Because such individuals are often inclined to withhold co-operation during test procedures, the use of sedation in such testing was also evaluated. Another important criterion for evaluating the practicability of possible assessment procedures was the time required for testing, along with the overall cost of implementation of a procedure for the industry. This chapter is structured using the sub-aims of the study. These the sections are presented individually as they were in Chapter 5 (Sections 5.2.2.1 to 5.2.2.5).

The results are described and summarised using tables and figures. Consequently the results are discussed. Finally the findings are interpreted as suggested by Mouton (2001).

6.2 CO-OPERATIVE MINE WORKERS WITH NOISE-INDUCED HEARING LOSS (PHASE ONE)

6.2.1 SUB-AIM: TO COMPARE ASSR AND PURE-TONE THRESHOLDS IN A CO-OPERATIVE POPULATION OF ADULT MINE WORKERS WITH SENSORY NEURAL HEARING LOSS

In the assessment of the results the ASSR thresholds are compared to the relevant pure-tone thresholds in order to determine whether ASSR thresholds can predict pure-tone thresholds accurately. The norm used in this case was a 0 to 10 dB difference between any two threshold tests, which in clinical practice is generally seen as an acceptable inter-test difference (RMA guidelines, 2003).

In order to realise the aim it is thus necessary to determine what the difference is between pure-tone and ASSR thresholds for every individual subject as well as the mean difference in a whole experimental group. The significance of any differences was determined using statistical procedures (the sample t-test and two way analysis of co-variance).

All the subjects were required to have potentially compensable hearing loss and, thus, a binaural pure-tone average exceeding 25 dB over the range of 500, 1 000, 2 000 and 3 000 Hz (Workmen's Compensation Commissioner, 1995). As has already been mentioned the abnormal pure-tone thresholds obtained from subjects varied from mild through to severe hearing thresholds (see Chapter 5, p98). Because noise-induced hearing loss is sensory neural in nature, the subjects' hearing was most severely affected at the higher frequencies and, thus, some subjects had normal hearing at the lower frequencies. This finding was not anticipated but it was eventually included in the data thus providing a base line of normal hearing thresholds with which the ASSR thresholds could be evaluated as a starting point. A breakdown of

the pure-tone thresholds obtained for the 81 subjects has been given in order to enable some understanding of the nature and extent of noise-induced hearing loss and to indicate in what severity range of hearing loss the ASSR procedures were used (see Section 5.5.4.1).

The clinical value of ASSR thresholds was evaluated using the norm of a 10 dB inter-test variance, which is seen as acceptable in the mining industry (RMA guidelines, 2003). All the pure-tone thresholds obtained for the 81 subjects were compared to the ASSR thresholds obtained for the same subjects for both ears and at all the frequencies tested. The overall mean pure-tone threshold obtained for the frequencies tested in the group of 81 co-operative subjects was also compared to the overall mean ASSR threshold.

To gain further insight into the clinical value of ASSR thresholds an analysis was also done on how much ASSR thresholds differed from the pure-tone thresholds (for example, between 0 to 10 dB; 10 to 20 dB etc.).

Although the participating workers, had been selected because they have noise-induced hearing loss, it was found that the pure-tone thresholds obtained varied throughout the severity range from normal to severe hearing thresholds. The following figures (6.1 – 6.4) give an indication of the number of thresholds per frequency obtained in the normal, mild hearing loss, moderate hearing loss and severe hearing loss categories.

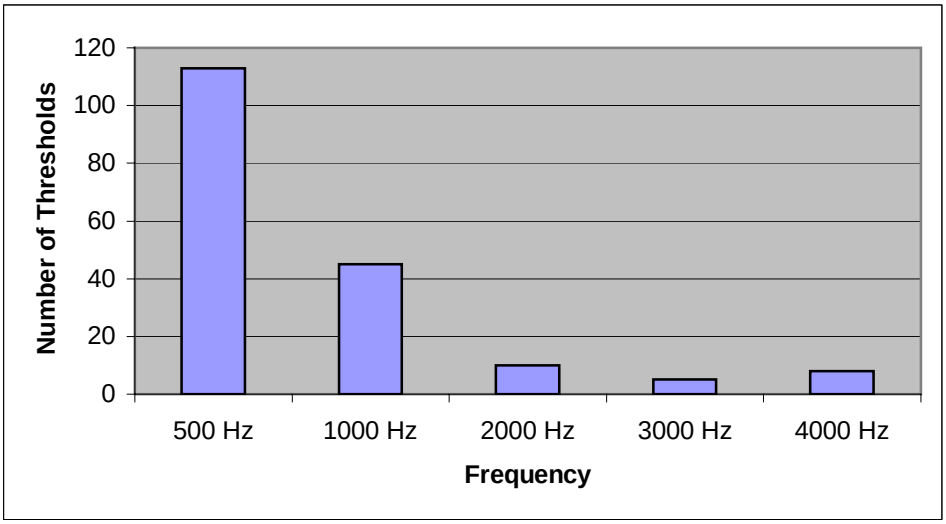

FIGURE 6.1 NUMBER OF NORMAL (≤25 dB) PURE-TONE THRESHOLDS FOR TEST FREQUENCY (n=181).

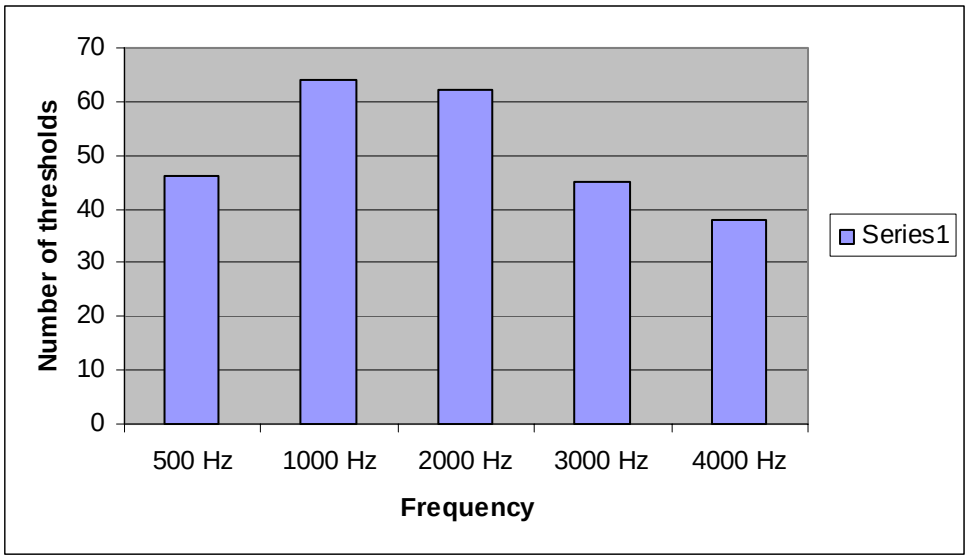

FIGURE 6.2 NUMBER OF PURE-TONE THRESHOLDS INDICATIVE OF MILD HEARING LOSS - PER FREQUENCY, (n=251)

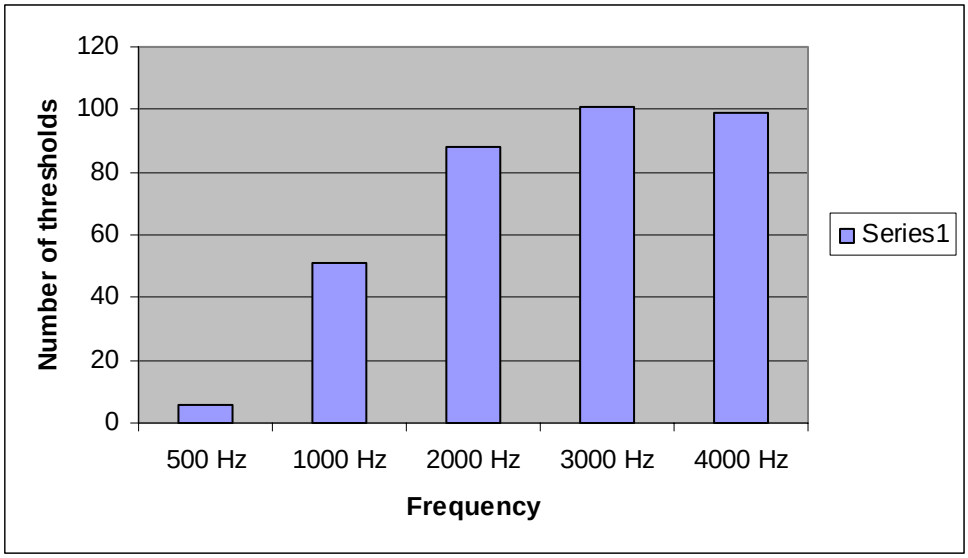

FIGURE 6.3: NUMBER OF PURE-TONE THRESHOLDS INDICATIVE OF MODERATE HEARING LOSS- PER FREQUENCY (n=345)

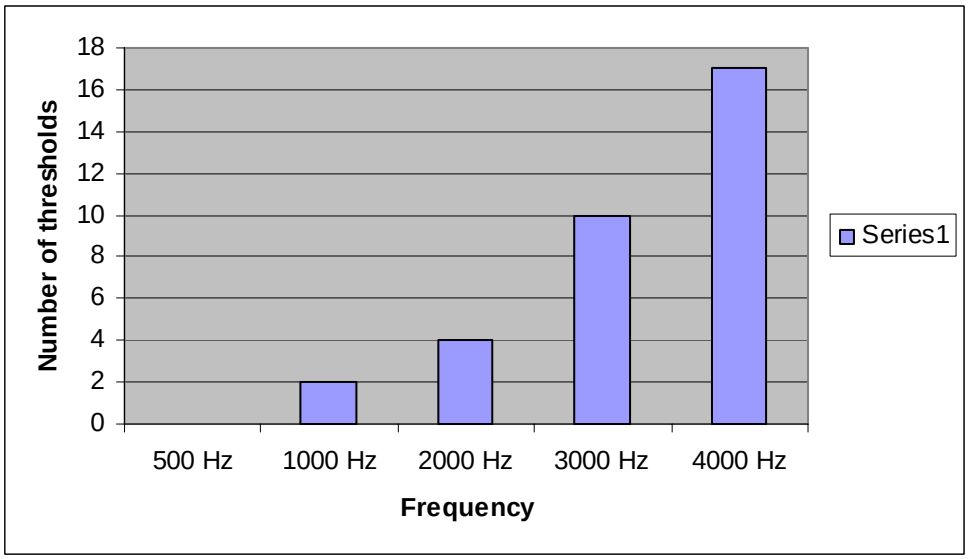

FIGURE 6.4 NUMBER OF SEVERE PURE-TONE THRESHOLDS- PER FREQUENCY (n=33)

As can be seen from Figure 6.1 the ASSR technique was unintentionally, tested in normal hearing thresholds (n=181). The known sloping character of noise-induced hearing loss makes the finding of the majority of normal thresholds in the 500 and 1000 Hz area an expected result. Mild hearing thresholds (n=251) (Figure 6.2) were obtained in subjects in all tested frequencies despite significant years of noise exposure (see Figures 5.7 to

5.11). Thresholds obtained in the moderate range were the highest in numbers (n=345) as seen in Figure 6.3. Significant moderate thresholds were obtained at 1 000, 2 000, 3 000, and 4000 Hz. It can be deducted that noise-induced hearing loss as seen in mine workers in the majority of cases presents as a moderate sensory neural hearing loss. Only a few (n=33) thresholds were obtained in the severe range as can be seen in Figure 6.4. From the above figures it can be concluded that the value of ASSR thresholds can be evaluated throughout the severity range of hearing loss, varying from mild to severe hearing loss. In Table 6.1 below the mean differences between ASSR- and pure-tone thresholds are highlighted.

TABLE 6.1: COMPARISONS BETWEEN ASSR AND PURE-TONE THRESHOLDS ACCORDING TO SEVERITY OF HEARING LOSS

FREQUENCY Hz	EAR	NORMAL HEARING 0-25 dB		MILD HEARING LOSS 26-40 dB		MODERATE HEARING LOSS 41-65 dB		SEVERE HEARING LOSS 66+ dB		P VALUE
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	
500	**Left**	4,22	13,93	3,75	10,41	5	0	-	-	0,99
1 000	**Left**	8,53	11,01	2,59	7,63	0,53	7,80	-	-	0,02
2 000	**Left**	-	-	8,54	11,75	-0,97	8,18	-2,5	3,54	0,00
4 000	**Left**	10,0	12,91	1,92	6,30	2,5	6,96	4	9,62	0,28
500	**Right**	9,79	15,74	3,57	10,82	2,5	3,53	-	-	0,33
1 000	**Right**	9,75	10,57	2,71	7,52	0,65	7,28	-5	0	0,00
2 000	**Right**	10	22,91	4,62	9,37	2,35	7,71	10	0	0,43
4 000	**Right**	3,33	5,77	0,42	7,53	1,84	7,66	5	21,21	0,85

From the above table it can be deducted that there is evidence that the sensitivity of ASSR estimates does depend on the category of hearing loss

(L, 1 000 Hz; L, 2 000 Hz; R, 1 000 Hz). The overall differences between ASSR- and pure-tone thresholds are greatest at normal hearing. These findings support that of numerous other researchers (Rance *et al.*, 1995; Sininger & Cone-Wesson, 1994; John & Picton, 2000 and Schmulian, 2002) that ASSR thresholds favour pathological ears. This finding has been explained due to the phenomenon of recruitment.

If all the pure-tone and ASSR thresholds of all the subjects in Phase 1 of the study (co-operative workers) were compared, it resulted in 810 pure-tone thresholds (81 subjects x 2 ears x 5 frequencies) that were compared with 542 ASSR threshold estimates (see Appendix N). The discrepancy in numbers was due to the fact that the Audera Beta (prototype) instrument failed to make provision for testing at 3 000 Hz, affecting 24 readings (12 subjects x 2 thresholds = 24), and that the Biologic instrument only had the capacity to determine eight thresholds at once, making it necessary to test one frequency separately, thereby extending what was already a lengthy procedure.

The specific comparison between pure-tone and ASSR thresholds will be set out in the following Tables 6.2 to 6.4 and in Figure 6.5.

TABLE 6.2 COMPARISON OF ASSR AND PURE-TONE THRESHOLDS BY TEST FREQUENCY

TEST FREQUENCY (HZ)	THRESHOLD ESTIMATION TECHNIQUE	MEAN THRESHOLD/SD (dB)	DIFFERENCE IN THRESHOLDS (dB)
Left ear			
500 Hz	ASSR	24,8/15,5 n=64	
	PT	21,38/11,70 n=81	3,42
1 000 Hz	ASSR	39,8/12,5 n=66	
	PT	37,06/13,14 n=81	2,74
2 000 Hz	ASSR	48,1/11,2 n=62	
	PT	45/10,61 n=81	3,1
3 000 Hz	ASSR	54,5/14,6 n=20	
	PT	48,50/12,60 n=81	6
4 000 Hz	ASSR	52,96/15,59 n=55	
	PT	50,13/14,16 n=81	2,83
Right ear			
500 Hz	ASSR	27,81/16,0 n=65	
	PT	20,43/10,65 n=81	7,38
1 000 Hz	ASSR	40/12,19 n=69	
	PT	35,19/13,39 n=81	4,81
2 000 Hz	ASSR	47,27/12,15 n=65	
	PT	42,19/10,96 n=81	5,08
3 000 Hz	ASSR	48/12,40 n=20	
	PT	47,43/11,52 n=81	0,57
4 000 Hz	ASSR	50,73/14,95 n=56	
	PT	51,06/14,20 n=81	0,33

Table 6.2 gives the mean pure-tone and ASSR thresholds for all the subjects (Phase 1: n=81). As mentioned before, the same number pure-tone and ASSR thresholds were not obtained. The differences between the mean ASSR and pure-tone thresholds vary from 0,33 to 7,38 dB (Table 6.2), which was well within the 10 dB variation that was taken to be an acceptable difference between two audiometric tests. The biggest difference was found in the right ear at 500 Hz.

TABLE 6.3: RESULTS FROM THE PURE-TONE AND ASSR TESTING OF LEFT AND RIGHT EARS

FIVE FREQUENCY MEAN FOR GIVEN EAR	THRESHOLD ESTIMATION TECHNIQUE	MEAN THRESHOLD (dB)	SD
Left ear	ASSR n=70	41,73	9,31
	PT n=81	40,41	8,21
Right ear	ASSR n=77	42,18	9,65
	PT n=81	39,26	8,14
Overall mean for both ears	ASSR n=78	42,40	8,91
	PT n=81	39,84	7,52

Table 6.3 compares thresholds from the ASSR (all procedures) and pure-tone testing for all the frequencies combined for the left and right ears respectively. It is again clear that the mean differences of the ASSR and pure-tone tests corresponded to within 10 dBs.

TABLE 6.4: MEAN DIFFERENCE BETWEEN ASSR ESTIMATES AND PURE-TONE THRESHOLDS (dB) PER FREQUENCY TESTED

FREQUENCY (Hz)	DIFFERENCE (dB)	DIFFERENCE (dB)
Ear:	**Left**	**Right**
500 Hz	4,14	8,20
1 000 Hz	3,53	3,97
2 000 Hz	2,66	3,75
3 000 Hz	4,75	-1,25
4 000 Hz	3,06	1,72
All frequencies	1,69	2,50

Table 6.4 indicates the differences between the mean thresholds from the ASSR- and pure-tone testing. On average all the ASSR and pure-tone thresholds obtained only differed 1,69 dB in the left ear and 2,50 in the right ear.

Another way to obtain an idea of the clinical value of ASSR tests, (the ability to predict pure-tone thresholds) is set out in Figure 6.5. The number of pure-tone and ASSR thresholds that corresponded within a range of 10 dB, 15 dB, 20, dB and 25 dB is illustrated in the following Figure 6.5.

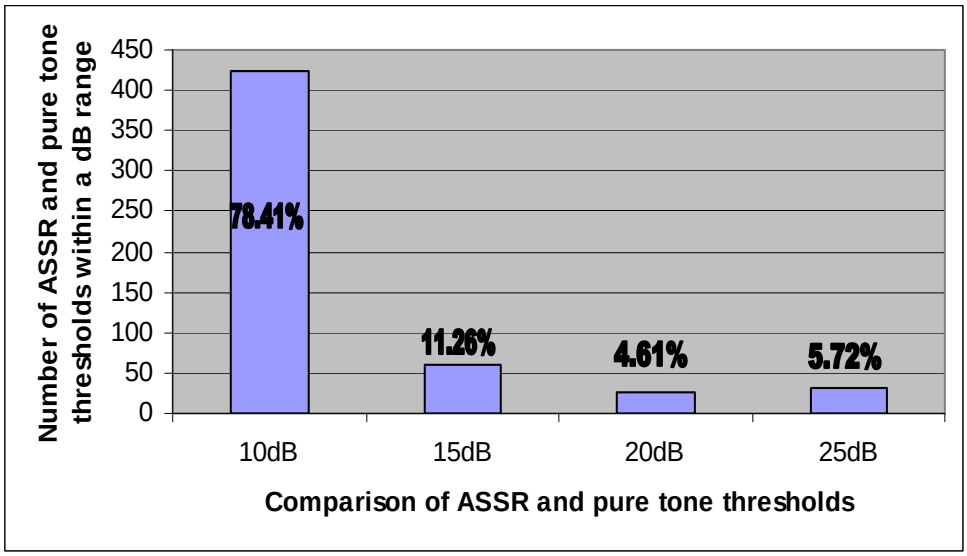

FIGURE 6.5: CORRELATION OF PURE-TONE AND ASSR THRESHOLDS

In the overwhelming majority (78, 41 per cent) of thresholds obtained, the ASSR and pure tone thresholds correlated within the 10 dB range as needed.

From the preceding three tables, it is apparent that the ASSR thresholds and pure-tone thresholds correlated within the acceptable 10 dB range (Workmen's Compensation Commissioner, 1995 and 2000), thus making ASSR testing a clinically acceptable measure to predict pure-tone thresholds. The largest difference of 8,2 dB occurred at 500 Hz for right ears, which corresponds with findings by other authors (John *et al*., 2001; Lins *et al.,* 1996; Schmulian, 2002; Herdman & Stapells, 2001). Rance *et al.* (1993) have described larger response amplitudes for higher carrier frequencies. This reduced ability to estimate lower frequency thresholds accurately has been explained as a result of an intrinsic jitter, where the activation pattern along the basilar membrane covers a larger area for lower frequency stimuli or lower carrier frequencies (Schmulian, 2002). Lins *et al*. (1996) also refer to the masking effect of background noise on 500 Hz steady-state stimuli. This explanation is possibly not relevant to the present study, since testing was done in an acoustically treated booth, as was also the case with the pure-tone testing.

The same authors also postulate that stimuli at 500 Hz may be masked by higher frequency signals during MF-ASSR testing. This could have affected the present study, since sensory neural hearing loss made it necessary to use high-intensity stimuli at the higher test frequencies. Another explanation is that the ASSR thresholds for the lower test frequencies, particularly 500 Hz, were the closest to normal hearing (172 normal thresholds). Many studies have indicated that ASSRs tend to favour abnormal hearing – that is a closer correlation with abnormal pure-tone thresholds as a result of recruitment. (John & Picton, 2000; Schmulian, 2002) (See Table 6.1).

To reduce test time, the present study used 10 dB intervals during threshold-seeking procedures for both the MF- and SF-ASSR tests, in accordance with accepted practice for auditory evoked potential methods (Picton *et al.*, 2003). SF- and MF- techniques allow the use of 5 dB steps to provide greater accuracy than that achieved in the present study, but it is important to note that the mean differences between the pure-tone and ASSR thresholds obtained here were smaller than those obtained in many previous studies (30-34 dB: Swanepoel, 2001; 8-18 dB: Lins & Picton, 1995; 28-34 dB: Aoyagi *et al.,* 1994). One explanation for the smaller mean differences in the present study is that ASSR instrumentation and algorithms have improved in recent years. During the course of this study the Audera equipment was upgraded from the Beta to the commercial version. John *et al.* (2001) have also noted better response detection with the introduction of mixed modulation methods, which were used in the present study.

This research strove to use an objective procedure- thus to avoid any influence by the clinician on the determination of thresholds. The only variables that could be manipulated by the clinician during MF-testing were the number of sweeps and the extent of averaging. Swanepoel (2001) and Schmulian (2002) have both noted the current lack of standards for the latter parameter, and have stated that more averaging is needed for stimuli with intensities near the threshold level. The Audera system, unlike the Biologic system, uses built-in algorithms to control the number of samples, thereby

eliminating any possibility that the clinician could influence this test parameter. Clearly, testing for clinical purposes should employ standardised sampling and averaging methods that are uniformly controlled by algorithms in the test system.

To summarise: the data indicate that ASSR thresholds can predict pure-tone thresholds to within 10 dB in more than 70 per cent of the cases and that the mean ASSR and pure-tone thresholds of 81 subjects correlated to within 1,69 and 2,50 dB for the respective ears (see Table 6.4).

The previously limited clinical validation of ASSR testing has been extended by the present study's demonstration of ASSR thresholds that were well within 10 dB of pure-tone thresholds, for a large population of subjects with noise-induced hearing loss (sensory neural in nature) across the entire severity range.

As previously mentioned, 536 ASSR thresholds were obtained in comparison to 810 threshold results for pure-tone testing, due to shortcomings in both the Audera Beta and Biologic systems. South African compensation assessments require 10 thresholds (RMA guidelines, 2003) but the Biologic system can only determine eight thresholds in a single test run. Subject-related factors such as noise from body movement and myogenic noise were also found to influence the difference in thresholds obtained as mentioned above. Influences such as movement, fidgeting, coughing and sneezing accounted for some of the shortfall in ASSR thresholds, as was found in previous studies (Aoyagi *et al*., 1994) where test procedures were also lengthened by such interventions. ASSR tests were performed with the clinician in an adjacent room and, although visual contact was possible through the booth's window, the booth and test room were both darkened, limiting the audiologist's awareness of coughing, sneezing and movement by the subject. The system identified any substantial occurrence of noise artefacts, but the audiologist had no direct control over this potential source of error. This raises the possibility that the clinician's presence in the same room could have limited

subject movement and fidgeting, as well as any deliberate disregarding of instructions on the part of unco-operative subjects.

The preceding presentation and discussion of results indicates that ASSR testing is a reliable and accurate method for objectively estimating frequency-specific hearing thresholds and that it can be successfully applied as an alternative to pure-tone testing for adults with noise-induced hearing loss. The present results have also confirmed previous findings that ASSR methods are not influenced by the age of the subject (Picton, 1991) and that ASSR thresholds are more accurate in pathological ears (Schmulian, 2002).

In order to analyse the clinical usefulness of ASSR testing further, various test protocols, including the effect of sedation, are considered in the sections below.

6.2.2 TO COMPARE THE CORRELATION OF MULTIPLE-FREQUENCY (DICHOTIC) AND SF-(MONOTIC)-ASSR STIMULATION METHODS IN ESTIMATING PURE-TONE THRESHOLDS IN A MINE WORKER POPULATION

Single-frequency (monotic) stimulus tests were performed on 41 subjects using the Audera system (single-frequency). Multiple-frequency (dichotic) stimulus testing of 40 subjects was done using the Biologic Master, which provided for simultaneous stimulation at four test frequencies in each ear. Table 6.5 indicates the average number of test frequencies at which a threshold was determined using each technique.

TABLE 6.5: AVERAGE NUMBER OF FREQUENCIES COMPLETED USING SF-AND MF- TESTING PER SUBJECT

STIMULATION TECHNIQUE	NUMBER OF FREQUENCIES	PAIRED "t" AND "p" VALUE
Single-frequency (Audera)	6	t =-2,39
Multiple-frequency (Biologic)	7,4	p>0,0193

As can be seen from the preceding table, the Biologic completed more threshold estimates (7,4 versus 6), possibly due to its ability to complete eight frequencies simultaneously. In addition the Audera Beta prototype (single-frequency method) also did not provide for testing of 3 000 Hz which placed this test procedure at a disadvantage. The difference in the number of threshold estimates obtained was statistically significant with a p-value of 0, 01.

Table 6.6 indicates the average time taken for the two stimulation techniques, independent of the number of thresholds obtained, while Table 6.7 shows the time taken normalised for the number of thresholds obtained.

TABLE 6.6: TIME TAKEN FOR SF- AND MF-TESTS, INDEPENDENT OF THE NUMBER OF FREQUENCIES COMPLETED

STIMULATION TECHNIQUE	TIME (MINUTES)	PAIRED "t" AND "p"VALUES
SF (Audera)	50,44	t= -7,19
MF (Biologic)	85,4	p=0,00

TABLE 6.7: TIME TAKEN FOR SF- AND MF -TESTS, NORMALISED FOR THE NUMBER OF FREQUENCIES COMPLETED

STIMULATION TECHNIQUE	TIME (MINUTES)	PAIRED "t" AND "p" VALUES
SF (Audera)	51,56	t=-6,56
MF (Biologic)	84,18	p=0,000

The two preceding tables show that the stimulation technique used (monotic SF- or dichotic MF) is a highly significant factor (p=0, 00 in Table 6.6 and 6.7), with the SF- technique being the more time-efficient. This finding contradicts previous findings (Perez-Abalo *et al*., 2001). Several researchers have suggested that it would take the same time to test eight different frequencies

using the MF-technique as for a single frequency using the SF-method. One possible explanation for this apparent anomaly is that most previous studies looked at subjects with normal hearing, implying that threshold-seeking procedures would start at 40 dB, after which only two or three descending steps would be required. For subjects with hearing loss, a multi-frequency technique would start at 40 dB and, after obtaining no response, stimuli would then be presented at higher intensities thereby lengthening the test procedure.

It must also be considered that the SF-technique employs the 40 Hz response, which is more robust in adults than in children. The use of higher stimulation rates, as with the Biologic system, is specifically intended to address the 40 Hz response's sensitivity to infants' maturation and state of consciousness, which was not a concern in the present context.

Furthermore, there are discrepancies in previously reported test times for MF-procedures. Herdman and Stapells (2001) have reported an average time of 83 minutes, three times longer than the 21 minutes reported by Perez-Abalo *et al.* (2001), while Swanepoel (2001) has reported test times between 15 and 31 minutes. It is also relevant to note that Perez-Abalo *et al. (*2001) and Swanepoel (2001) both tested normal hearing subjects. Herdman and Stapells (2001) used 5 dB increments to determine thresholds which could explain the longer test time.

Testing during the present study took an average of 84,18 minutes but there are no standards governing the number of sweeps and averages obtained, and it would therefore be invalid to compare the present test times directly with those reported previously. Stimulation at a low intensity increases the number of averages required and, thus, the recording time, indicating a need for internationally accepted standards for averaging methods and algorithm specifications, particularly for clinical applications. Although the SF-technique used in the present study eliminated any influence by the audiologist on averaging, the MF-technique allowed the number of sweeps and averages to

be selected, indicating that the need for objectivity was better met by SF-ASSR testing.

A further disadvantage of the MF-stimulation technique for individuals with sensory neural hearing loss is that this condition is progressively more severe at higher frequencies, which means that some subjects could have normal hearing at the low frequencies despite severe or even profound hearing loss at higher test frequencies. This made it impossible to select a uniform intensity protocol for the 500 to 4000 Hz range. A level of 100 dB, while possibly suitable for higher frequencies, would have been dangerously loud at a frequency of 500 or 1 000 Hz, making it necessary to use the MF- technique in what was essentially a SF-mode, by first testing at 1 000, 2 000 and 4 000 Hz, and then testing at 500 Hz separately. This partially accounts for the longer times required for the MF-testing.

Table 6.8 indicates the differences in prediction value of the pure-tone thresholds between the SF- and MF- techniques and the levels of significance of the data.

TABLE 6.8: DIFFERENCES IN SENSITIVITY BETWEEN THE SF- AND MF-STIMULATION TECHNIQUES

STIMULATION TECHNIQUE	MEAN DIFFERENCE BETWEEN ASSR AND PT THRESHOLDS		
	500 Hz	500 Hz	1 000 Hz
	Left	Right	Right
SF	7,69	8,39	6,13
MF	11,71	16,66	8,92
t-test	-1,85 p≥0,0694	-3,34 0,0014	-1,83 p≥0,072

From the table it can be seen that SF-testing yielded more accurate estimates of the thresholds than the MF-methods, particularly at the low frequencies. The SF-technique's higher sensitivity may be attributable to the high

stimulation levels required, as mentioned previously. Lins and Picton (1995) found no significant differences in the response amplitude between the MF- and SF-methods, provided intensity was at low-to-moderate levels. John and Picton (2000) also caution against the dangers of high-intensity stimulation.

From the above discussion it can be deducted that, although the SF-method completed fewer threshold estimates in comparison to the MF-method, that the SF-procedure was more accurate in determining thresholds and that it took less time to obtain a threshold. This last finding appears to contradict what one would intuitively expect namely that it would less time to obtain eight thresholds tested simultaneously.

6.2.3 TO COMPARE DIFFERENT MODULATION FREQUENCIES' EFFECTIVENESS IN ESTIMATING PURE-TONE THRESHOLDS

28 subjects were tested using a 40 Hz stimulation rate (the Audera-awake protocol), while 52 subjects underwent testing with the higher rate of 80 to 110 Hz (the Audera asleep protocol and Biologic MASTER). The results are set out in Table 6.9 and 6.10.

TABLE 6.9: TIME TAKEN FOR 40 HZ AND 80-110 HZ TESTS, INDEPENDENT OF NUMBER OF FREQUENCIES COMPLETED

STIMULATION TECHNIQUE	TIME (MINUTES)	PAIRED "t" AND "p"VALUES
40 Hz (Audera)	50,44	t= -7,19
80-110 Hz (Biologic)	85,4	p=0,00

TABLE 6.10: THE TIME TAKEN FOR SF- AND MF-TESTS, NORMALISED FOR THE NUMBER OF FREQUENCIES COMPLETED

STIMULATION TECHNIQUE	TIME (MINUTES)	PAIRED "t" AND "p" VALUES
40 Hz (Audera)	51.56	t=-6,56
80-110 Hz (Biologic)	84.18	p=0,000

From these tables it can be seen that the average testing time (normalised for the number of frequencies evaluated) was 33 minutes longer using the 80 to 110 Hz stimulation rate than with a rate of 40 Hz, but there was statistical evidence in only one frequency that the SF-method was more accurate in determining pure-tone thresholds (500 Hz, see Table 6.8; p=0.001) (The single-frequency technique used a 40 Hz stimulation rate and the multiple-frequency method a 80 to 110 Hz rate, therefore there is referred to Table 6.8).

Stapells *et al.* 1984 have found the amplitude of auditory evoked potential responses to be two to three times greater with a 40 Hz stimulation rate than with a 10 Hz rate while Dobie and Wilson (1998) have also found 40 Hz to be the stimulation rate of choice for alert or sedated adults. The stimulation rate of 40 Hz was also favoured in the present research. Another research team that came to the same conclusion was Rickards and De Vidi (1995) who found the 40 Hz rate to be more suitable for use in adults. These researchers explain the finding by stating that the 40 Hz response did not require compensation or allowance for maturational effects. Other researchers have investigated the use of other stimulation rates to overcome the effect of wakefulness on the 40 Hz response (Herdman & Stapells, 2001; Lins *et al*., 1995). Difficult-to-test populations mainly consists of young children and infants, which may help to explain the move towards higher stimulation rates that are less affected by sleep, sedation and maturation (in these populations).

6.2.4 TO DETERMINE THE EFFECT OF SEDATION ON THE ASSR TEST'S ABILITY TO ESTIMATE PURE-TONE THRESHOLDS

28 non-sedated subjects were tested using the SF-method without sedation, while 13 were tested by the same method while sedated. For the MF-ASSR tests, 20 subjects were sedated and an equal number were not, to determine the effect of this factor on the sensitivity and test time. The significance of the differences between the two methods is set out in Table 6.11 (raw data is seen in Appendix N).

TABLE 6.11: THE SIGNIFICANCE OF TIME COMPARISONS OF MF- AND SF-TECHNIQUES WITH AND WITHOUT SEDATION

TECHNIQUE	T-TEST	P VALUE
SF	1,86	0,19
MF	2,18	0,15

From the above table it is clear that time comparisons between both SF- and MF-testing yielded no significant difference between the test times for sedated and non-sedated subjects (p=0,19 and 0,15)(Table 6.11).

In order to evaluate the effect of sedation further, comparisons were also made between the accuracy of the threshold estimates with and without sedation.

Results are set out in Table 6.12 and 6.13 below.

TABLE 6.12: SIGNIFICANCE OF SENSITIVITY DIFFERENCES BETWEEN SEDATED AND NON-SEDATED SF-ASSRs

FREQUENCY (HZ)	t-TEST	p-VALUE
LEFT EARS		
500	0,4956	0,6251
1 000	-0,9221	0,3660
2 000	-1,0345	0,3132
4 000	0,7614	0,4553
RIGHT EARS		
500	0,1028	0,9190
1 000	1,1867	0,2475
2 000	-0,2813	0,7811
4 000	-0,6505	0,5221

TABLE 6.13: SIGNIFICANCE OF SENSITIVITY DIFFERENCES BETWEEN SEDATED AND NON-SEDATED MF-ASSRs

FREQUENCY (HZ)	t-TEST	p-VALUE
LEFT EARS		
500	1,1208	0,2698
1 000	1,3545	0,1840
2 000	0,1524	0,8798
4 000	0,8331	0,4118
RIGHT EARS		
500	0,8687	0,3911
1 000	1,9412	0,0603
2 000	0,9459	0,3509
4 000	0,9461	0,3535

The same lack of significant differences was found if attention was focused on the threshold estimation accuracy in SF- and MF-techniques when they were compared in terms of the sensitivity with and without sedation. The preceding tables indicate no significant effect from sedation on the sensitivity or test time for SF- and MF-testing (all the p values were higher than 0, 05) and, hence, there is no reason to sedate adults, provided they co-operate and limit their movement during the test procedures. Other researchers have found that sedation significantly diminishes the amplitude of the 40 Hz response (Lins *et al.,* 1995) but this research was done on children.

6.2.5 SUMMARY OF FINDINGS (PHASE 1)

- ASSR threshold estimates were found to be sufficiently accurate to predict pure-tone thresholds;
- ASSR thresholds and pure-tone thresholds correlated to within 10 dB;
- ASSR thresholds prediction value was the poorest at 500 Hz;
- ASSR thresholds favoured abnormal hearing;
- 10 dB decrements, as a threshold estimation technique, was sufficient to predict pure-tone thresholds accurately;
- ASSR methods were objective;
- ASSR methods were accurate in an adult population with sensory neural (noise-induced hearing loss);
- subject related factors such as movement, coughing and fidgeting influenced the quality of ASSR recordings;
- the fact that the audiologist is seated in an adjacent room during testing, makes it difficult to observe patient behaviour and thus precluded control over potential sources of error;
- SF- and MF- methods were not significantly different in their accuracy to estimate pure-tone thresholds but the SF-method were more time efficient;
- there were no significant effect from sedation on the sensitivity or test time of all ASSRs; and
- thus there is no motivation to use sedation if a patient co-operates.

With these results obtained the experimental research could thus now be focused on unco-operative subjects

6.3 UNCO-OPERATIVE MINE WORKERS (PHASE TWO)

6.3.1 TO DETERMINE WHETHER PURE-TONE THRESHOLD ESTIMATES CAN BE OBTAINED FOR UNCO-OPERATIVE WORKERS

6.3.1.1 Introduction

After proving that ASSR methods could accurately estimate pure-tone thresholds in an adult mine worker population with noise-induced hearing loss and after the most efficient modulation frequency and stimulation technique had been decided on, the experimental research could be advanced to the final phase, in which the clinical value of these methods could be tested in an unco-operative sample of mine workers.

6.3.1.2 Revision of Phase 1 procedures: Implications for Phase 2

The 29 subjects in the unco-operative group (Phase 2) were tested using ASSR methods, in particularly the SF-technique with a modulation rate of 40 Hz. Although the findings in the first phase with co-operative subjects had indicated that sedation did not improve sensitivity or reduce test times for co-operative subjects (as reflected in Tables 6.12 and 6.13), common experience with pseudohypacusic workers, who may be motivated by the prospects of noise-induced hearing loss compensation, led to a decision to use sedation for the unco-operative group. A second variation in the procedures from those used for the phase one subjects was the use of a single room for both the subject and the audiologist, to allow control over body movement and other sources of noise from subjects.

6.3.1.3 Results obtained

The results of the pseudohypacusic groups' diagnostic- and ASSR test are set out in Appendix O. The ASSR and pure-tone thresholds of the 29 subjects differed on average from each other by 61, 08 dB. This is in contrast to the less than 10 dB difference with co-operative subjects. The ASSR results have conclusively proven that the pseudohypacusic group's diagnosis was

accurate. This diagnosis was made where there was a discrepancy larger than 15 dB between the same frequency's thresholds during two tests.

Table 6.13 indicates the deductions that were made from the results of the pseudohypacusic group.

TABLE 6.14: DEDUCTIONS MADE FROM THE ASSR THRESHOLDS OBTAINED IN PSEUDOHYPACUSIC WORKERS

PERCENTAGE OF CASES CONCLUDED	ABNORMAL HEARING (>25 dB PTA)	COMPENSABLE LOSS (RMA guidelines)	UNFIT	POOR CORRELATION WITH PRE-VIOUS TESTS	SUDDEN HEARING LOSS
96,5%	82,8%	48%	20,7%	48,3%	31%

Of the 29 pseudohypacusic subjects, 96,5 per cent could be successfully diagnosed and the cases could be concluded on the basis of the ASSR results (Table 6.14 and Appendix O). In only one case of the 29 (subject 2, Appendix O) did ASSR testing fail to estimate hearing thresholds, and this was in one ear only, due to excessive electrical activity that was unrelated to the subject's hearing. These results provide overwhelming support for the use of ASSR testing as a valid method to determine hearing thresholds for pseudohypacusic mine workers with noise-induced hearing loss.

It was also found that 10, 3 per cent of the left ears and 17,2 per cent of the right ears of the pseudohypacusic subjects tested had normal hearing (Table 6.14 shows abnormal hearing of 82,2 per cent). (See Appendix O as well). This is an important and logical finding when it is taken into consideration that as mine workers these subjects had been exposed to hazardous noise for considerable periods (with a mean of 20 years). Audiologists assessing such patients must be aware of the strong likelihood that pseudohypacusic individuals will be hearing-impaired, and failure to conclude a diagnosis may

have moral as well as health and safety implications in such cases. Although 82, 8 per cent of the subjects had abnormal hearing, only 48,3 per cent were compensable according to South African standards (see Table 6.14 and Appendix O), indicating that the determination of all the thresholds necessary (through the use of ASSRs) makes differential diagnosis possible, such as in cases of unilateral hearing loss which is not attributable to noise exposure.

Of the pseudohypacusic subjects, 20,7 per cent were found to be unfit for their present duties (Table 6.14 and Appendix O), based on current guidelines (Geyser, 2003). If audiologists fail to adequately assess worker fitness, as can easily occur with conventional screening and diagnostic procedures, the employer and workers are subject to greater safety risks, and there is likely to be a negative impact on productivity. In this respect, accurate once-off threshold estimation using ASSR methods would be beneficial.

Less than half (48,3 per cent) (Appendix O) of the ASSR thresholds correlated well with previous screening results, which is cause for some concern. In dealing with pseudohypacusic patients, audiologists are compelled to make recommendations based largely on previous screening results where this is the only source of additional information. The present finding indicates that previous screening results may be an unreliable indicator of hearing status for more than half of pseudohypacusic workers, possibly because workers have been manipulating their test results over several years. However, a more worrying possibility is that of a sudden deterioration in hearing, that may be present which will invariably progress to compensable levels. In examining subjects' previous screening results, it was found that 31,0 per cent (Appendix O) showed signs of sudden deterioration not attributable to noise exposure and warranting further medical investigation. (This was possible by studying previous screening results).

6.3.1.4 Time required for ASSR testing

After an average time of 8,1 minutes for skin cleaning/preparation and the placement of electrodes, an average of 49.86 minutes was required for the

ASSR recordings in the pseudohypacusic group (Appendix O). This compares very well with the 51.56 minutes (Table 6.7) required to obtain 10 thresholds (5 test frequencies per ear) in the co-operative group (Phase 1). This indicates that one hour would be needed for each ASSR test. This makes it a lengthy procedure in comparison to conventional methods, but it provides more essential information.

In comparing these test times with those for co-operative subjects (Phase 1) it does not appear that the use of a single room for the audiologist and the subjects (as opposed to a separate test booth in Phase 1) made any appreciable difference to the test time. It is also possible that the testing time was very similar due to the fact that the audiologists' presence inhibited negative behaviour from pseudohypacusic subjects. Nevertheless, it is recommended that a single room be used, to discourage deliberate movement and other sources of noise from unco-operative patients.

6.3.1.5 Summary of Phase 2

- ASSR testing confirmed the diagnosis of pseudohypacusis;
- in 96,5 per cent of cases with pseudohypacusis could diagnostic procedures be completed;
- 82,8 per cent of pseudohypacusic subjects had abnormal hearing;
- 48 per cent of abnormal cases were compensable;
- 20,7 per cent of cases were unfit for their current duties;
- in 48,3 per cent of pseudohypacusic cases did ASSR thresholds show poor correlation with previous screening tests;
- there were evidence of sudden hearing deterioration in 31 per cent of pseudohypacusic cases;
- ASSR testing makes differential diagnosis possible;
- previous screening results were not a good indicator of present hearing status
- the time needed for ASSR testing in Phase 2 was very similar to the time required for the co-operative group;

- an hour is sufficient time for ASSR testing if skin preparation procedures is also taken into consideration; and
- it is recommended that a single room set up is followed when testing pseudohypacusic workers.

6.4 RESEARCH RESULTS REALISING THE PRINCIPAL AIM OF THE STUDY

The principal aim of the present research was to determine whether ASSR testing could successfully conclude audiological assessment procedures for pseudohypacusic mine workers. The question that had to be addressed was: **Is there clinical value in using this AEP technique with mine workers with noise-induced hearing loss and more specifically these with pseudohypacusis?**

The inability of conventional procedures to provide accurate thresholds for difficult-to-test individuals who are often unco-operative, commonly leads to a repetition of screening and diagnostic procedures and referral to an Ear-, Nose- and Throat specialist in an effort to resolve possible compensation cases. Very often, ABR testing is recommended. This test provides limited threshold information in the 2000 to 4000 Hz frequency range, but otherwise only confirms the presence of pseudohypacusis without determining the thresholds needed for a compensation claim or for fitness-for-work evaluations. In some instances this leaves deserving claims unresolved, while in others it results in overcompensation due to deliberately exaggerated hearing loss.

Through the current study it has been conclusively proven that ASSR methods have sufficient clinical value in a mine worker population with sensory neural hearing loss (noise-induced hearing loss). Even in a sample of unco-operative workers this auditory evoked potential managed to assist in concluding the diagnostic procedures. The clinical value lies in the fact that it is an accurate and reliable alternative to pure-tone methods for determining thresholds in adult mine workers. It can furthermore serve as a single test in a

battery if co-operation is withheld. The time requirements are certainly reasonable in the field of AEPs.

Further clinical value is also derived from the fact that the use of ASSRs in a pseudohypacusic population with noise-induced could conclude audiological procedures and lead to correct recommendations re compensability, differential diagnosis and amplification. Roeser *et al.* (2000b) alert to the fact that the identification of pseudohypacusis is extremely important to ensure that the patient receives appropriate intervention but also to avoid harmful intervention. The fact that the overwhelming majority of pseudohypacusic workers had hearing loss shows the danger of only rescheduling pseudohypacusic workers for annual testing if thresholds could not be obtained.

An important finding that should be considered by audiologists is the fact that previous screening tests were not a good indicator to use as a basis for recommendations if hearing thresholds cannot be obtained. Very often this is all an audiologist has if a patient withholds co-operation.

Much clinical value is derived from the fact that ASSRs are an objective procedure. The audiologist as well as the patient does not influence the results. Definitely an important finding in a population that is traditionally unco-operative.

Roeser *et al.* (2000b:12) define the effectiveness of audiological tests as follows:

> All diagnostic procedures, whether for the auditory system or any other system, are designed to identify the presence of a disorder as early as possible. When indicated, diagnostic procedures can also help to identify the cause or nature of the disorder. The value of a diagnostic test depends on the ability to perform as intended. That is, the procedure must accurately identify those patients with the disorder while clearing those patients without the disorder.

In summary ASSRs have performed as intended.

6.5 SUMMARY

The results of the experimental research were presented in Tables, Figures and Appendices. The results were discussed and correlated with the current literature in the field of ASSRs and pseudohypacusis and conclusions were finally drawn.

The clinical value of ASSR testing in mine workers with noise-induced hearing loss and pseudohypacusis have thoroughly been researched, tested and evaluated and found to be a reliable alternative to pure-tone testing.