CHAPTER 7

CONCLUSIONS AND RECOMMENDATIONS

AIM

To integrate the findings of the study and to critically evaluate the results of this study against the theoretical framework supplied in Chapters 1 to 4. The value of this study is discussed in terms of the application of auditory steady state response testing in the mining industry in general and in the testing of workers with pseudohypacusis in particular.

7.1 INTRODUCTION

Mine workers who have noise-induced hearing loss and believe that they may qualify for financial compensation may be unco-operative patients. This lack of co-operation during audiological assessments leads to an inability on the side of audiologists to establish reliable pure-tone hearing thresholds. If feigning of hearing loss or the exaggeration of an existing hearing loss is not identified by the clinician it is logical to conclude that the financial impact on employers originating from fallacious claims and overcompensation is considerable. If on the other hand the pseudohypacusis is identified but not quantified, the number of pending cases is likely to escalate, thus impeding efforts to finalise genuine claims for noise-induced hearing loss. It has been the experience in the clinical situation that in many instances follow-up assessment procedures also fail to provide the accurate hearing thresholds needed to finalise a claim, putting the clinicians in a position of having to make debatable recommendations with regard to rehabilitation, fitness for work and compensation.

One or all of the following complications can follow from the clinical problem of pseudohypacusis in the mining industry (De Koker, 2003):

- frustration is experienced on the part of audiologists and occupational health personnel. There develops a mistrust on the part of workers, with retesting and counselling failing to make a difference in eliciting their co-operation (Franz, 2003);
- escalating costs for audiological assessments, often without a successful diagnosis other than confirmation of pseudohypacusis (De Koker, 2003);
- greater number of specialist referrals is generated due to the failure of current audiological procedures to finalise cases, including many that have been referred previously and remain inconclusive due to a lack of patient co-operation (Geyser, 2003);
- claims from workers who genuinely deserve to be compensated, but that are not settled due to the absence of reliable hearing thresholds;
- the compensation of workers with normal hearing;
- further exposure of workers with severe hearing loss who should have been declared unfit for work in noisy areas, to the detriment of their remaining hearing and quality of life, as well as to their safety and that of their fellow workers (De Koker, 2003);
- the overlooking or misdiagnosis of cases of a sudden onset of hearing loss and ear pathology due to the audiologist's inability to obtain hearing thresholds in unco-operative clients; and
- the impossibility to make a differential diagnosis without reliable pure-tone thresholds (Roeser *et al*., 2000b).

It is clear that above stated problem of pseudohypacusic mine workers exaggerating and feigning hearing loss makes the audiological assessment of these workers problematic as can be seen in the above description. This is however a responsibility that cannot be disregarded as Roeser *et al.* (2000b) said. "Today audiologists are the primary health care professional involved in the identification, prevention, and evaluation of auditory and related disorders". The responsibility therefore also lies with the audiologist to find a solution to the time

consuming and costly problem. An audiologist needs to find a solution in the interest of audiology as a profession, the individual worker, the insurance companies and mine management.

A possible solution to the problem of pseudohypacusis was addressed in this research project by studying pseudohypacusis as a phenomenon and by researching the previous audiological solutions in difficult-to-test populations. A literature review of auditory evoked potential procedures, the most common solution in unco-operative patients, has lead to the possibility that a new auditory evoked potential could bring a solution to the described problem. ASSRs, an objective evoked potential was researched and experimented with.

The question asked was: **Is there an audiological technique available that cannot only identify pseudohypacusis but, more importantly, estimate the true behavioural thresholds of pseudohypacusic mine workers with noise-induced hearing loss?** In the definition (and realisation) of the aim of the study there was emphasis placed on what the clinical value of ASSR testing would be in the described population.

Clinical value was defined as the accuracy in predicting or estimating thresholds and the time-effectiveness in assessing noise-induced hearing loss in pseudohypacusic workers. The results of the empirical parts of this study have been presented in the previous chapter. However it is necessary to conclude the study by interpreting, evaluating and summarising the findings. Offering recommendations for further research logically emerge from such an evaluation. This final chapter concludes by suggesting the way forward.

7.2 RESEARCH FINDINGS

The findings of the present study, considering all the sub-aims (Phase 1) where different ASSR procedures were evaluated, can be summarised as follows:

7.2.1 CONCLUSIONS BASED ON THE RESULTS FROM CO-OPERATIVE MINE WORKERS WITH NOISE-INDUCED HEARING LOSS

The most important result was that all procedures were within 10 dB of the pure-tone threshold. From this it can be concluded that:

- ASSRs (all procedures) offer an accurate alternative to behavioural methods for determining/estimating pure-tone thresholds for adult mine workers with noise-induced hearing loss, a type of sensory neural hearing loss (ASSR and pure-tone thresholds within 10 dB from each other);
- ASSRs offer accurate threshold estimates across the range from normal to severe sensory neural hearing loss however ASSRs were found to favour pathological ears;
- The biggest difference between pure-tone and ASSR thresholds were found at lower frequencies as is the case in other research (500 Hz: 8,20 dB in the right ears) (Lins *et al*., 1996 and Schmulian, 2002);
- 10 dB intervals (decrements and increments) used in ASSR threshold estimation did supply accurate estimates of pure-tone thresholds. It can be concluded that it will thus not be necessary to lengthen an already long procedure by using 5 dB intervals;
- The Audera testing system (SF- and monotic) enabled an objective test procedure that could not be manipulated by the clinician or the subject;
- The SF-monotic technique was found to be more time-efficient than the MF- method (51,56 minutes versus 84,14 minutes), and also yielded more accurate threshold estimates at 500 Hz. (right-ear SF=8,39 (mean): MF=16,66 (mean); p=0,0014);
- In comparing the modulation rates it was found that the 80 to 110 Hz was 33 minutes longer than the average test time for the 40 Hz procedure. It seems to be clear that the 40 Hz rate is more time-efficient when applied to adults with sensory neural hearing loss;

- Sedation did not improve the sensitivity or reduce it, nor reduce the test time for the SF- or MF-methods and thus is there no motivation for using sedation if passive co-operation can be obtained from the patient;
- ASSR results were, as was found in other research, not influenced by the age of the subjects (Stapells *et al*., 1984; Rane *et al.*, 1995);
- Subject related factors such as movement, coughing and fidgeting seem to influence the quality of the ASSR recordings as found by Aoyagi *et al*., (1994) as well. This behaviour needs to be prevented, especially if there is an intention on the side of the patient to confound results. A single room set-up, where the audiologist is seated in the testing room with the patient, offers a solution to this possibility.

7.2.2 CONCLUSIONS BASED ON RESULTS WITH PSEUDOHYPACUSIC MINE WORKERS

These findings for the co-operative group of 81 subjects with noise-induced hearing loss indicated that the principal aim of the study could be addressed next, in other words to determine the clinical value of ASSR methods for evaluating pseudohypacusic mine workers with noise-induced hearing loss:

- ASSR tests confirmed the diagnosis of pseudohypacusis;
- It has been found that the use of ASSRs in a pseudohypacusic population with noise-induced hearing loss could conclude audiological procedures (in 96,5 per cent of cases) and lead to correct recommendations with regard to compensability, differential diagnosis and amplification;
- The overwhelming majority (82, 8 per cent) of pseudohypacusic workers had some hearing loss. It is thus important for audiologists not to keep on re-scheduling workers with hearing loss without correct recommendations with regard to specialist referrals and rehabilitation;
- The majority (82,8 per cent) of the pseudohypacusic patients had hearing loss but only 48,3 per cent were compensable. From this observation it is

clear that ASSR testing made differential diagnosis possible and it is thus incorrect to assume that all workers with hearing loss are compensation candidates due to the fact that they work in noise;

- The use of ASSRs made it clear that 20,7 per cent of the workers in the pseudohypacusic sample were unfit for their work. The inability to diagnose the organic component in pseudohypacusis thus does cause workers to work in conditions detrimental to their health and safety;
- Less than half (48,3 per cent) of the ASSR thresholds correlated well with the results of previous screening tests. This is a worrying finding since very often previous results are all that an audiologist has to base recommendations on. A possible explanation of this phenomenon is that pseudohypacusic behaviour might have been present for a number of years but more serious that there might have been a sudden deterioration of hearing which leads to the following finding that;
- Disturbingly 30,1 per cent of the pseudohypacusic subjects have experienced a sudden deterioration in hearing if one studies their previous thresholds. Due to the possible serious nature of sudden hearing loss audiologists are obliged to make the diagnosis;
- The ASSR procedure has proven to be lengthy in comparison to conventional testing (approximately 60 minutes including preparation time, compared with the 17 minutes typically required for pure-tone audiometry, an otoscopic examination and immittance measurements). It is nevertheless advantageous if it is considered that the 17 minutes is not standard in the case of pseudohypacusis and how many times pseudohypacusic workers need repetitive testing;

To summarise: the findings indicate scientific support for the use of ASSR methods as a more reliable alternative to pure-tone testing of adults with noise-induced hearing loss, and that ASSRs can serve as a once-off procedure to conclude the diagnosis of pseudohypacusis and make the correct handling of the

case possible. ASSR results met the requirements for accurate threshold estimates at all the frequencies required for compensation and fitness-for-work evaluations.

7.3 CRITICAL EVALUATION OF THE RESEARCH

7.3.1 RELIABLE ALTERNATIVE TO PURE-TONE METHODS

The norm adopted in this study of a reliable difference between two different hearing tests of 10 dB (RMA guidelines, 2003) is audiometrically acceptable. The threshold seeking procedure of 10 dB threshold bracketing (Picton *et al.,* 2003) used in this study can probably be improved when one uses 5 dB intervals which is possible with the equipment used in this study. Nevertheless the study has shown that ASSRs can be used as an alternative to pure-tone testing in adults with hearing loss.

Furthermore, the reliability of the use of ASSR thresholds is enhanced by a positive critique on this study namely the number of subjects used (in Phase 1 a sample of 81 was used). Picton *et al.* (2003) summarised studies (done up to 2003) that used the 40 Hz response (11 studies) and indicated that the number of subjects used in these studies varied between six and 40 per study.

It can be seen as a limitation of the present study that no indication of inter-test repeatability was provided, because the need to avoid interference with production schedules precluded any repetition of the lengthy testing procedures by a second clinician. It was also not possible to compare the same subjects' performance on different ASSR protocols due to the same time constraint. These limitations may well have influenced the results, or more probably the generalisation of the results.

7.3.2 THRESHOLD ESTIMATES ACROSS THE SEVERITY RANGE

ASSR testing proved to be accurate in estimating hearing thresholds that ranged from normal to profound. Picton *et al*. (2003) cite 22 studies done with ASSR methods. Only six of these studies used a sample of primarily hearing impaired subjects. The present study thus adds to the limited research on ASSR testing applied to hearing impaired subjects. Furthermore, since the subjects had noise-induced hearing loss, a specific type of sensory neural hearing loss, it is possible that these results could be generalised to adults with sensory neural hearing loss derived from other types of etiology.

It was also concluded that the lack of algorithms for sloping sensory neural hearing loss in the multiple dichotic stimulation was a negative factor that needs to be addressed.

7.3.3 FEWER ASSR THRESHOLDS OBTAINED IN COMPARISON WITH PURE-TONE THRESHOLDS

The influence of patient-generated noise on electrophysiological techniques is an ongoing clinical concern (Abramovich, 1990; Ferraro & Durrant, 1994). Artefacts from high levels of background EEG activity can lengthen ASSR procedures and there is a lack of standardisation for the testing environment, patient instructions and permissible level and number of artefacts. These should be specified on the basis of current knowledge and they should be published, to enable inter-study comparisons and a further refinement of ASSR techniques. In the case of an unco-operative client it is recommend that the clinician be placed in the same room as the subject to prevent deliberate movement and coughing. Sedation might also still be needed in a subject who refuses to co-operate.

Apart from the electrophysiological noises influencing threshold estimation, one needs to ask whether limitations of the equipment used also impeded the study. Multiple-frequency methods would not be practical in the mining industry, since

only eight out of the ten thresholds required can be covered in a single test run. That means that a MF-technique must be repeated to get all the required thresholds and thereby a lengthy procedure is prolonged even further.

Finally, in the planning of the research it was deemed important to select equipment that can test all the frequencies specified by current South African legislation. The Audera equipment that was available during the initial phases of the experimental research could not test 3 000 Hz which is problematic since this frequency is legally required (Workmen's Compensation, 1995).

It is thus invisaged that as equipment improve in reaction to further research that ASSR method will gain acceptance into standard audiological procedures. In the words of *Roeser et al.* (2000b:p10):

> Auditory evoked responses have been used in diagnostic audiology for more than 3 decades, and as more knowledge is being made available in this area, it is clear that auditory electrophysiological measures will become an even more prominent tool in audiology in future.

7.3.4 THE DIFFERENCE BETWEEN ASSR AND PURE-TONE THRESHOLDS AT 500 HZ

The ASSR test has, as was the case with other researchers, proven to be less accurate at 500 Hz (Rickards *et al.*, 1994). It is important for clinicians to remember this fact when testing patients and to be aware that using 5 dB increments and decrements in testing might improve the threshold estimates' accuracy.

Clinicians should also do everything in their power to limit background noise since background noise can influence threshold estimates at 500 Hz. The most

important requirement is certainly to test subjects in a calibrated sound proof environment.

7.3.5 INTERVALS OF TEN dB IN ASSR THRESHOLD ESTIMATION

In the above paragraph it was mentioned that 5 dB increments could improve the accuracy of ASSR techniques. It must nevertheless be remembered that 10 dB threshold estimation techniques were proven to supply threshold estimates that were within the required 10 dB variance. This finding gives a clinician the freedom to assess a clinical situation and to choose the decrements accordingly depending on the time constraints and the patient's needs.

7.3.6 THE AUDERA SYSTEM

The fact that the Audera system (Biologic Systems Corporation, 2002) had a test procedure in place where the number of sweeps and averages were controlled by computer algorithms made the use of this equipment more objective (neither the audiologist nor the patient do decide on the results). It is very important that ASSR testing should be an objective procedure, particularly where clinicians may be inexperienced and in working with a population where thresholds are used to calculate the compensation to be paid out. It is understandable that the more objective and accurate these thresholds are, the less chance there is of distributing the available monetary resources incorrectly. This objectivity is also a very important finding in a population that is traditionally unco-operative.

A problem with the Biologic system was that the clinician could select how many averages and sweeps to use (which is obviously important in research settings). In this specified population these parameters should be held constant at the researched best parameters in order to ensure objectivity and to be able to compare different research endeavours.

7.3.7 THE SF-MONOTIC TECHNIQUE

The conclusion is that SF-ASSR procedures proved to be the method of choice for pseudohypacusic patients with noise-induced hearing loss, due to the robustness of the 40 Hz response and the fact that the procedure eliminated any need to expose subjects to high-intensity stimulation at the low test frequencies. In conjunction with this, it was also found that the SF-testing also provided for manual control of the stimulus intensity, allowing the intensity level to be adjusted where a response could not be obtained, as with conventional pure-tone tests. The SF-technique could thus prevent high intensity stimulation in high frequencies from influencing the thresholds at other frequencies. This was not possible with the MF-procedure (Picton, *et al.,* 2003).

7.3.8 THE 40 Hz MODULATION

Since most of the members of difficult-to-test populations are usually infants, there has there been a tendency for researchers to move away from the 40 Hz response (Rance *et al*., 1995; Herdman & Stapells, 2001; John *et al.*, 2002). However, the present research seems to indicate that this stimulation rate was still the best to use in an adult population and thus confirms the opinion of Galambos *et al*. (1981) and Dobie and Wilson (1998) in this regard.

7.3.9 SEDATION

The fact that sedation did not improve or have a negative effect on the sensitivity or reduce the test time of ASSR methods leads to the conclusion that there is limited justification using it when passive co-operation can be obtained from a patient. This was a welcome result, in view of the ethical and medical constraints with regard to the use of sedation.

On the other hand particularly in the case of pseudohypacusic mine workers from whom passive co-operation cannot be obtained, it is reassuring that sedation has

been seen not to affect the ASSR thresholds and time negatively and thus sedation can still be used if electrophysiological noise is found to affect the results.

7.3.10 CONCLUSION OF AUDIOLOGICAL PROCEDURES

It has previously been shown that there is a very high incidence of pseudohypacusis in the South African mining industry (De Koker, 2003). The lack of cooperation from workers leads to a high case load of unresolved cases. The fact that these cases could have been diagnosed and completed with the use of ASSR methods leads one to conclude that it would be unethical not to use this tool available to audiologists to resolve pending cases. The audiologist, as a professional, is obliged to give an accountable service.

The one unconcluded case in the present study (one ear) was due to electrophysiological noise and therefore the limiting of factors influencing the data is an ongoing clinical and research concern.

7.3.11 PSEUDOHYPACUSIC WORKERS HAD HEARING LOSS

In the past it was common practice that pseudohypacusic workers would be counselled and re-tested at a later date. The fact that such a high percentage of pseudohypacusic workers tested had a true basic hearing loss emphasises the need to raise the awareness with audiologists that it is not acceptable to reschedule a population with pathology for numerous tests over many years without diagnosing the degree and cause of the hearing loss (Roeser *et al.,* 2000b) and without making the correct recommendations with regard to amplification, fitness and compensability (De Koker, 2003).

7.3.12 PSEUDOHYPACUSIC WORKERS WITH HEARING LOSS WERE NOT NECESSARILY COMPENSABLE

In the mining industry workers are mainly referred since their hearing loss is potentially compensable. This leads to a specific focus from the side of the audiologists and other health workers in this sector that is problematic and should change. This study has proven that less than half of the pseudohypacusic workers with hearing loss were compensable. However one can only conclude that ethical audiologists should remember their role in differential diagnosis (Roeser *et al.,* 2000b) and that this population, like any other population, also suffers from other types of hearing loss (not only noise-induced). Certainly pseudohypacusic workers do form part of the client base of audiologists and deserves the best the profession of audiology can offer.

7.3.13 UNFITNESS OF PSEUDOHYPACUSIC WORKERS

In the past the fact that pseudohypacusic cases stayed pending led to the possibility that workers unfit for duty could pose a risk to fellow workers due to their unability to hear danger signals. An unfortunate worker with serious noise-induced hearing loss could also have been exposed indefinitely due to the fact that accurate hearing thresholds were outstanding. This possibility can be eliminated by the use of ASSR techniques.

7.3.14 ASSR THRESHOLDS DID NOT CORRELATE WELL WITH PREVIOUS SCREENING TESTS

In the past the only tools the audiologist had to resolve a long-standing pending case was to do an ABR test or to study previous screening tests. If an ABR could not be done due to monetary constraints, the previous screening tests were the only guideline to base recommendations on. This study has shown the danger of rescheduling pseudohypacusic workers for annual testing if thresholds could not be obtained. It has also been proven that previous screening tests were not a good indicator to use as a basis for recommendations if hearing

thresholds were outstanding. It is thus concluded that every effort should be made to resolve and diagnose pending cases.

7.3.15 PREVALENCE OF SUDDEN HEARING LOSS

A worrying finding was that there was evidence that 30,1 per cent of the pseudohypacusic subjects have experienced a sudden deterioration in hearing. This deterioration would not have been diagnosed without determining or estimating the true pure-tone thresholds. Again the importance of resolving outstanding cases is highlighted with this finding.

7.3.16 ASSR-AN IMPORTANT CONTRIBUTION TO THE MINING INDUSTRY

ASSR methods are more costly than conventional pure-tone tests, but ASSRs can save the mining industry a lot in terms of cost of lost production, transport, referrals and overcompensation. The well-being of the individual worker and his co-workers are promoted in that deserving compensation cases are diagnosed, sudden deterioration in hearing is identified and a worker is notified when he is not fit to work in a noisy environment any longer. ASSR tests can also limit the financial impact of overcompensation and unresolved claims.

Based on the theoretical and empirical results of this study an additional situation analysis pertaining to the financial implications of ASSR methods was executed. The specific details are set out in Appendix Q, but the most important results are:

- It is impossible to know how much pseudohypacusis has cost the industry (Begley, 2003) but it can be unequivocally stated that pseudohypacusis has got financial implications due to lost production and shifts, transport costs, specialist referrals and overcompensation. It is thought to be substantial;

- On information received it was found that an ASSR system can at present cost as much as R154 000,00 (HASS, December, 2003). ASSR systems are thus more expensive than conventional audiometrical equipment;
- However, when comparing costs of overcompensation, transport arrangements, specialist referrals, numerous hearing tests and lost production it is clear that ASSR testing will save the industry.

7.3.17 LENGTHY PROCEDURE

The procedure has proven to be a lengthy one in comparison to conventional testing (approximately 60 minutes including preparation time, compared with the 17 minutes typically required for pure-tone audiometry, otoscopic examination and immittance measurements). In the field of auditory evoked potentials it is nevertheless an acceptable time frame. The length of the procedure is a negative point to consider with the general high case loads found in the mining industry. It must nevertheless be remembered that numerous testing of pseudohypacusic workers with conventional tests are also time consuming.

7.4 LIMITATIONS OF THE RESEARCH

The following limitations were experienced in the current research and it is recommended that these issues be addressed in forthcoming research:

- The MF-ASSR (dichotic) procedure had no algorithms (at this point in time) to compensate for the greater hearing thresholds at higher frequencies typical of sensory neural hearing loss. This lead to the fact that the lower frequencies' thresholds were influenced by the high intensity high frequency stimulation.
- Standards are required for the number of sweeps and averages needed to ensure accuracy. In a clinical situation the extent of averaging should be determined by appropriately formulated algorithms and not by the clinician,

to ensure objectivity. The lack of standardisation makes it difficult to compare studies. In the present study, the amount of averaging was controlled in the SF-method but was left to the clinician's discretion in the MF- procedure.

- In selecting experimental subjects with noise-induced hearing loss, it was stated that subjects had sensory neural hearing loss. The "neural" aspect was not investigated to determine, for example any influence of retro-cochlear damage. It has recently been proven that patients with Human Immunodeficiency Virus (HIV) do experience retro-cochlear deterioration (Chandrasekhar *et al.,* 2000). As this condition is currently an African pandemic it is reasonable to recommend that a clinical study be done using ASSR methods in combination with click ABR testing, to allow differential diagnoses which are not possible with ASSRs alone.
- The present study makes no mention of the possible influence of the HIV on the study results. HIV, the causative agent of Acquired Immunodeficiency Syndrome (AIDS), is associated with the development of opportunistic infections and central nervous system disorders known to induce hearing impairment. In addition, a large percentage of patients in the mining industry are also treated with various combinations of ototoxic drugs for the treatment of tuberculosis and HIV-related manifestations. This points to a need for an investigation of the contribution of HIV to hearing problems among mine workers and how a differential diagnosis of multi-factor hearing loss can be made. Since all evoked responses, including ABRs, are highly dependent on the temporal synchronisation of neural activity, it is reasonable to expect alterations in ABR and ASSRs among patients with varying degrees of HIV infection. The preceding point raises the question of the extent to which noise-induced hearing loss compensation is affected by audiological changes due to HIV infection or its complications.

- The present study did not evaluate the accuracy of late cortical evoked responses (CER) in estimating hearing thresholds for pseudohypacusic patients. This procedure has been used in Australia for more than 20 years (Rickards and De Vidi, 1995) but at the time of the research, equipment was not readily available in South Africa. Apart from the unavailability of the equipment did the skill and knowledge required of the clinician in executing CER methods discourage the researcher. However future investigations could well be directed at evaluating this method of audiological assessment.

7.5 THE STUDY IN CONTEXT

In conclusion, ASSR testing offers an objective and accurate means of determining hearing thresholds for pseudohypacusic mine workers. ASSR testing also offers the option of the use of complex stimuli for threshold estimation, thereby stimulating the auditory system in a manner that is more representative of the way in which the hearing sense functions, in comparison to, for instance pure-tone clicks and tone bursts (Picton *et al.,* 2003).

With this study a contribution was made to the field of Audiology in that limited clinical validation of ASSR methods has been extended. This procedure had not previously been tested on mine workers with noise-induced hearing loss and no other study could be found where ASSRs had been used in a pseudohypacusic population. The present research has also made a contribution to the scientific body of knowledge in the South African mining industry and has contributed to the setting of international standards in audiological assessments in the industry. Current research can now be implemented in the industry and a contribution has been made to a best practice procedure for evaluating noise-induced hearing loss.

"As expected, in the 50 years the profession of audiology has been in existence the scope of practice has grown. This metamorphosis has occurred gradually as a result of emerging clinical, technological, and scientific developments, which are now commonplace in our modern world. Whereas only 25 years ago audiologists were primarily performing behavioural tests of auditory function, today the typical audiologist has a wide range of electrophysiological assessment tool to select from" (Roeser *et al.,* 2000b: p1).

The audiologist should use these tools in the interest of the patient, the client and the profession and in a wider sense also in the interest of South Africa as a whole.