CHAPTER 3

ELECTROPHYSIOLOGICAL TESTS AND THEIR USE IN THE ASSESSMENT OF PSEUDOHYPACUSIS

> **AIM OF THE CHAPTER**
>
> To evaluate the usefulness of the electrophysiological tests available, specifically auditory evoked potentials, in the audiological evaluation of pseudohypacusic patients. The main question addressed is: what contribution electrophysiological tests can make to the detection of pseudohypacusis and the determination of thresholds in the difficult-to-test population of mine workers.

3.1 INTRODUCTION

"All diagnostic procedures are designed to identify the presence of the disorder as early as possible. That is, the procedure must accurately identify those patients with the disorder while clearing those patients without the disorder" (Roeser *et al.*, 2000b:12). This requirement for audiological test procedures is met by the tests described in Chapter 2, in that the conventional tests can **identify** pseudohypacusis.

The audiologist's responsibility goes further: it is not only to identify the presence of a disorder, but to quantify it, thus to determine frequency-specific hearing thresholds for all patients assessed, in order to provide guidance for the rehabilitation process, as well as to facilitate recommendations and decisions regarding patient referrals (Stach, 1998; Roeser *et al.,* 2000b). Schmulian (2002) supports this position, commenting that poor and inaccurate diagnostic procedures result in sub-standard recommendations regarding the rehabilitation of the disorder.

In the field of medico-legal investigations, there is a further reason for not only identifying but also quantifying the hearing loss, namely financial loss. Coles

and Mason (1984:71) clarify the importance of true hearing threshold estimation as follows: "In medico-legal investigations of all kinds, precautions have to be taken against falsification of disability by the patient since there is a clear motivation for him to exaggerate and thereby obtain greater financial advantage. This is particularly necessary where the disability claimed can only be fully characterized by including subjective aspects, as in the case of hearing loss."

This is certainly of particular relevance for mine workers with noise-induced hearing loss who present with pseudohypacusis. A pseudohypacusic worker's lack of co-operation confounds efforts to obtain accurate frequency-specific information, and often leads to large numbers of pending cases. These workers have to be retested, which increases the cost of audiological and other specialist assessments. Retesting workers also leads to additional expenditure (further financial implications), since these workers miss shifts and the mining company thus loses production. Additional transport costs may also be involved if workers are referred for further assessments.

The lack of the availability of accurate hearing thresholds results in situations where compensation is not paid to deserving cases and in overcompensation of genuine noise-induced hearing loss where hearing threshold inconsistencies are not detected. The frustration of audiologists, occupational health centre staff and the mining industry in general is understandable.

Abramovich (1990), Martin (1994) and Schmulian (2002) state that a lack of patient co-operation, irrespective of the cause or motivation, necessitates the use of additional, more objective (and sometimes more costly) procedures, and that other responses apart from behavioural responses to acoustic signals should be explored for the estimation of hearing thresholds.

In the assessment of hearing, audiologists have always used a test battery approach (Hall & Mueller, 1997) to ensure acceptable service delivery to clients. The various tests available to audiologists are used in conjunction

with each other and allow for cross checks to confirm results. With a pseudohypacusic patient, such efforts generally confirm the presence of pseudohypacusis without quantifying its extent, in other words, tests fail to provide frequency-specific hearing thresholds.

The most reliable means of cross checking is provided by test procedures that require no voluntary response from the patient (Schmulian, 2002). Gorga (1999) indicates that assessments of pseudohypacusic patients require the use of test procedures that do not rely on voluntary behavioural responses. The quest for measures not requiring a behavioural response has led to the development of electrophysiological tests, which provide an objective assessment of auditory sensitivity (Hall, 1992). Rintelmann *et al.*, (1991); Stach, (1998) and Roeser *et al. (*2000b) also promote the use of physiological tests for difficult-to-test populations.

Today, audiologists have a wide range of electrophysiological assessment tools to select from (Roeser *et al.*, 2000b). These are examined and evaluated in this chapter. Particular attention is focused on auditory evoked potential (AEP) methods, which have been shown to provide estimates of hearing thresholds. The objective is to identify and evaluate audiological solutions and test procedures for the population of mine workers, in which noise-induced hearing loss is frequent and pseudohypacusis is rife.

3.2   ELECTROPHYSIOLOGICAL (EP) TESTS

3.2.1   QUALITATIVE EP TESTS (USED PRIMARILY FOR <u>DETECTION</u> OF PSEUDOHYPACUSIS)

Discoveries in the field of audiology (and other related fields, including neurology and electronics) have recently led to rapid advances in the development of electrophysiological tests (Ferraro & Durrant, 1994; De Waal, 2000; Roeser *et al.,* 2000b). Audiological assessment techniques no longer need to be limited to traditional behaviour-based psycho-acoustic tests, now

that EP tests can help satisfy the need to assess auditory sensitivity at specific frequencies objectively (Schmulian, 2002).

The EP methods used in the past thirty years have included immittance testing, acoustic reflex (AR) measurements, oto-acoustic emission (OAE) tests and auditory evoked potential (AEP) tests. Of the many electrical responses to auditory stimuli, most originate in the central nervous system. Some are generated in the cochlea, while others are reflexive muscular responses (Glasscock, Jackson & Josey, 1987).

Immittance and OAE measurements are not measures of hearing *per se*, but are means of evaluating the status of the auditory system at specific peripheral levels, although never as an entire system (De Waal, 2000). These measures do not provide frequency-specific thresholds, but merely confirm the suspicion of pseudohypacusis, thus serving as a means of cross checking.

3.2.1.1   Immittance

Acoustic immittance measures (tympanometry, static compliance and acoustic reflex) have been well established as a routine part of audiological evaluation (Rintelmann *et al.*, 1991). The primary application of acoustic immittance is the evaluation of organic hearing disorders. It can also be useful in the detection of pseudohypacusis.

Martin (1994) claims that the sophistication of automated middle ear tests may discourage pseudohypacusis, and is therefore very valuable in the detection or prevention of pseudohypacusis. Clinicians should thus remember to suggest to the patient that the test is fully automatic and that no response is needed, thereby removing the temptation to feign a hearing loss. It is therefore generally good practice to perform an immittance test first if this test can be used to avoid pseudohypacusis. This is a valid approach, but goes against the recommendation of Rintelmann *et al.* (1991) that supra-threshold tests should be performed after air- and bone-conduction tests. Experience

has shown that completing threshold testing before embarking on supra-threshold tests does save time and prevents unco-operative patients from finding a supra-threshold reference level (Dobie, 2001; De Koker, 2003).

The AR threshold is the most useful measurement in the detection of pseudohypacusis. In persons who have normal hearing, an acoustic reflex is usually elicited by means of contralateral stimulation at sensation levels that range from 70 to 95 dB. For persons with cochlear lesions, as in mine workers exposed to noise, the reflex may be obtained between 15 and 60 dB (Rintelmann *et al.*, 1991). When the difference between the AR threshold and the voluntary threshold is extremely low (5 dB or less), the pure-tone threshold must be questioned on the basis of organic pathology (Martin, 1994; 2000). Claims of a profound unilateral or bilateral hearing loss can be refuted if the AR is present at normal stimulus levels, but the phenomenon of recruitment may limit the usefulness of AR measurements in estimating hearing thresholds, especially in cases of noise-induced hearing loss.

Tympanometry provides an immediate evaluation of the middle ear status. Present ARs and normal middle ear function are not compatible with conductive hearing loss (Qiu *et al.*, 1998). If conductive hearing loss is present with normal middle ear function pseudohypacusis can be expected. The reason being mine workers' unfamiliarity with bone conduction testing.

AR measurements may be useful in estimating actual hearing thresholds by performing the sensitivity prediction with the acoustic reflex test (SPAR). Middle ear reflex thresholds for pure tones are compared with those for wide-band noise, as well as for filtered low- and high-frequency wide-band noise (Martin, 1994; 2000). In the researcher's experience, the high incidence of absent ARs in this population makes the use of the SPAR test impossible. Dobie (2001) also claims that the SPAR test has no clinical utility in pseudohypacusic populations. Some reasons for this, although Dobie (2001) does not mention them, could be elevated and absent ARs.

In conclusion as was the case with the behavioural tests described in Chapter 2 immittance testing predicts and detects pseudohypacusis but is not quantitative in nature.

3.2.1.2   Oto-acoustic emissions (OAE)

Small changes in the biomechanical function of the cochlea can be monitored by measuring OAEs, which are generated within the cochlea by active non-linear processes involving the outer hair cells (Kvaerner *et al.,* 1996).

It is impossible for a patient with compensable hearing loss to have normal OAEs, and OAE testing is thus advocated as a quick and objective means of confirming hearing status in suspected cases of pseudohypacusis (Qiu *et al.,* 1998). A patient with normal OAEs should have normal hearing thresholds. Unfortunately, the usefulness of OAE testing is limited in cases of noise-exposed patients, as such individuals often exhibit abnormal or absent OAEs with normal hearing as a result of pre-symptomatic cochlear damage (Hall, 2000; De Koker *et al.*, 2003). So far, it has also been difficult to correlate OAEs and behavioural thresholds (Hall, 2000). OAEs are another qualitative assessment tool which is useful in the detection of pseudohypacusis.

3.2.2 QUANTITATIVE ELECTROPHYSIOLOGICAL TESTS (ESTIMATION OF HEARING <u>THRESHOLDS</u> IN PSEUDOHYPACUSIS)

3.2.2.1   Introduction

Despite the considerable interest that has been generated by all the conventional tests described in Chapter 2 and the electrophysiological tests of immittance and oto-acoustic emissions, as the foregoing discussion has indicated, none have provided accurate hearing thresholds in the case of pseudohypacusic mine workers. The problem faced when compensation is involved is that the audiologist must obtain ten hearing thresholds (South African legislation) that are accurate enough to be duplicated in a second test. The focus is thus on quantitative data.

Accordingly, attention needs to be paid to auditory evoked potential methods as the most useful and effective electrophysiological measure of auditory system function (Rance *et al*., 1998) with due consideration to both the peripheral and central auditory systems. Hood (1998) emphasises that EP tests are not tests of hearing, but tests of synchronous neural function and the ability of the central nervous system (CNS) to respond to external stimuli in a synchronous manner. Nevertheless, numerous authors have shown how closely thresholds from AEP testing correspond with behavioural thresholds (Reneau & Hnatiow, 1975; Rance *et al*., 1998; Barrs *et al*., 1994). This fact, combined with the statement of Abramovich (1990) that the verification of hearing loss and the validation of the pure-tone audiogram is important in dealing with compensation claims, supports the necessity of evaluating AEP tests within the framework of this study.

Hyde *et al.* (1986) argue even more strongly that, if AEPs are accepted as the ultimate arbiter in medico-legal evaluations, the rationale for interposing confirmatory tests (detection) between a suspicion of and the quantification of pseudohypacusis is suspect.

3.2.2.2   Background: the development of the use of AEPs

AEP procedures are not really a "new" technique. Glasscock *et al.* (1987) trace the origins of auditory brainstem response (ABR) testing to animal experiments in the nineteenth century, citing Caton, who reported electrical activity in the brain of a rabbit in 1875. They also mentioned other researchers who investigated electrical activity in the brains of other animals between 1883 and 1891.

Not only the technique but also the apparatus used to evoke and record the electrical responses has developed over the years. Pravdich-Neminsky photographed an apparatus to record animal electro encephalograms (EEGs) using a string galvanometer (Glasscock *et al*., 1987). During the 1930s, oscilloscope images were bright enough and electrical amplifiers stable

enough to allow neurophysiologists to concentrate on experimental work rather than on equipment problems (Abramovich, 1990).

Berger first observed spontaneous electrical activity of the type now routinely recorded during EEGs in 1929 (Abramovich, 1990; Ferraro & Durrant, 1994). In searching for electrical activity in the inner ear, Wever and Bray (1930) recorded potentials in response to auditory stimuli from the round window of a cat. These potentials have since been termed cochlear microphonic or CM (Abramovich, 1990).

The main problem facing early researchers was the difficulty of measuring very small potentials in isolation from other electrical activity within the brain. Particular difficulty was experienced when the stimuli were of low intensity, as EEG voltage was much greater than the voltage of the evoked potential (Reneau & Hnatiow, 1975). The development of averaging computers has facilitated more accurate analysis of small bio-electrical signals (Abramovich, 1990). Glasscock *et al.* (1987) note that Davis acquired a digital computer in 1961, after which he began using it in his electrophysiological experiments. The ABR, currently the most popular AEP used in clinical contexts, was first described and defined by Jewett and Williston in the early 1970s (Glasscock *et al.,* 1987).

In 1963, the New York Academy of Arts and Sciences sponsored a symposium of investigators of averaged potentials (including visual, somatosensory, auditory, myogenic and neurogenic), followed by the founding of the International Electrical Response Audiometry study group in 1968 (Abramovich, 1990).

Much of the research in the field of AEPs tries to correlate the electrical responses with auditory behavioural thresholds. Reneau and Hnatiow (1975) cite difficulties in relating physiological thresholds (such as evoked responses) to behavioural response thresholds. It was believed that behavioural responses are binary measures in which a subject decides between "yes" or

"no", while physiological thresholds are graded, or quantitative, and that graded measures are mathematically different from binary ones. It was concluded that these two types of tests can be expected to yield different results. Nevertheless, as a result of subsequent advances in electronics, and a far greater understanding of brain function, there has been a move in the field of AEPs, supported in this study, to relate behavioural and physiological thresholds.

The enthusiasm for auditory evoked potentials in the 1970s resulted in this type of testing, being incorporated in test batteries for unco-operative patients such as small children (Martin, 1994). It is thus logical that the use of this quantitative procedure was also extended to cases of pseudohypacusis (Roeser *et al.*, 2000b).

As early as 1990, the use of auditory evoked potentials was recommended in the assessment of pseudohypacusic patients by Abramovich (1990), who also cites the use of slow vertical responses, auditory brain stem response, middle latency responses and transtympanic electrocochleograms as possible auditory evoked potentials to be used with pseudohypacusic patients. Today, a mere decade, later is it predicted that in future, AEPs will become even more prominent in the field of Audiology (Roeser, Buckley & Sichney, 2000).

3.2.2.3   Nomenclature and definitions

Picton and Scherg (1990) argue that one of the most important clinical applications of AEPs is their use in objectively evaluating the hearing of patients who are unable to respond during conventional testing. However, in order to evaluate this application, it is important first to define auditory evoked potentials and to highlight controversial issues.

Stach (1998:293) describes the measurement of AEPs as follows:

The brain processes information by sending small electrical impulses from one nerve to another. This electrical activity can be recorded by placing sensing electrodes on the scalp and measuring the ongoing changes in electrical potentials throughout the brain. This technique is called electroencephalography, or EEG, and is the basis for recording evoked potentials. The passive monitoring of EEG activity reveals the brain in a constant state of activity; electrical potentials of various frequencies and amplitudes are measured continually. If a sound is introduced to the ear, the brain's response to that sound is just another of a vast number of electrical potentials that occur at that instant of time. Evoked potential measurement techniques are designed to extract these tiny signals from the ongoing electrical activity.

This described electrical activity can be spontaneous or event-related (Picton, 2001). Responses that are time-linked to some event or stimulus are called event-related potentials (ERPs), and can be responses to a sensory stimulus (such as a visible flash or a sound), a mental event, or the interruption, delay or omission of a stimulus (Picton, 2001).

Auditory evoked potentials (AEP) are a type of ERP in which the stimulus is a sound, and the response takes the form of very small electrical potentials originating in the nervous system and recorded at the scalp (Picton, 2001). AEPs originate from structures such as the auditory cortex, the auditory brainstem and the auditory cranial nerve (VIII or 8th). These electrical potentials are very small: 2 to 10 micro volts for cortical AEPs, and less than one microvolt for deeper brainstem structures (Picton, 2001).

The measurement of these potentials in response to auditory stimuli has become a valuable diagnostic tool (Stach, 1998) but is still an evolving field in which there are problematic issues that need to be resolved.

3.2.2.4   Problematic issues in the field of AEP

It should be noted that the terms "evoked potential" and "evoked response" are used interchangeably in the literature (Hood, 1998). The term "response" is derived from the procedure of pure-tone audiometry in which a stimulus is presented and a response (motor action) is subsequently recorded. In AEP testing, a response is not recorded, but a potential is measured. Furthermore, electrical activity is elicited by a signal, and not a stimulus (Goldstein & Aldrich, 1999).

The term "stimulus" implies perception, but in tests of auditory brain stem response and auditory steady state response, electrical activity is measured sub cortically and only up to brainstem level.   It should therefore be remembered that the terms "stimulus" and "signal" are interchangeable, as are "potential" and "response" (Schmulian, 2002).

The field of evoked potentials has been burdened with inconsistencies in terminology and definitions and its classification system has lacked uniformity and clarity (Ferraro & Durrant, 1994; Schmulian, 2002).   Schmulian (2002) attributes this lack of clarity to the presence of specialists from the different fields of audiology, neurology and otolaryngology who all work in the field of evoked potentials. Classifications of AEPs in the literature can be divided into those based on anatomical generators, on the type of potential, on the types of stimuli used, on the location of recording electrodes and on latency characteristics (the time between stimulus onset and response) (Schmulian, 2002).

The most common classification of AEPs is based on their time domain (Goldstein & Aldrich, 1999), in which the time between the stimulus and the response is termed the "latency epoch". Ferraro and Durrant (1994) mention that, although this classification system is the easiest to apply, the classification of latency is not standardised. A familiar method is to classify response latency as short, middle or late latency responses, depending on the

time between the presentation of the stimulus and the responses' becoming evident as an AEP. Short latency is referred to as "fast" by Glasscock *et al.* (1987), and as "early" by Abramovich (1990), while "late" latency responses are also referred to as "slow". These types of inconsistency create confusion.

Because latency varies according to stimulus intensity, temporal characteristics and pathology, it has been found that authors attribute different latency epochs to different AEPs. So, for example, according to Picton (2001), the ABR is seen 1.5 to 15 milliseconds (ms) after the stimulus, which contradicts Abramovich (1990), who states that an auditory brain stem response (ABR) is seen within the first 10 ms after the stimulus. Different nomenclatures are also used to identify major peaks for AEPs, for example Roman and Arabic numerals are used for ABR waves, and "No" or "SN10" are used to identify the slow negative wave appearing in the ABR after 10 ms.

3.2.2.5 The use of different potentials in pseudohypacusis

The use of auditory evoked potentials in the estimation of hearing in patients that cannot or will not co-operate during behavioural tests has been advocated by numerous authors (Abramovich, 1990; Mc Pherson & Starr, 1993; Stach, 1998). Schmulian (2002) expresses a stronger opinion, saying that AEP testing is the only procedure in the audiologists' test battery that can quantify the hearing sensitivity of unco-operative patients.

If an audiologist has to rely on a single test in a battery (due to an unco-operative patient), AEP testing needs to meet the following requirements (Roeser *et al.*, 2000b):

- The test should diagnose the nature of the hearing loss (conductive or sensory neural).
- The degree of hearing loss (from normal hearing to profound hearing loss) has to be established.

- The configuration of the hearing loss (across a range from 250 to 8 000 Hz) is important clinical information and must be determined.

- Frequency-specific hearing thresholds need to be estimated for both ears.

The above requirements are used in the discussion below to evaluate the use of different auditory evoked potentials in pseudohypacusic patients.

3.2.2.5.1   Early potentials

The first three AEPs identified (cochlear microphonic (CM); action potential (AP) and summating potential (SP) are very early-stage potentials seen during the first 5 ms after stimulation with a sound (Stach, 1998). Responses to sound originate in the cochlea and the distal portion of the auditory nerve. They are also grouped together in clinical use as the electrocochleogram (EcochG). Tone burst and click stimuli are used to elicit responses, and two different electrode placements for near-field measurements are possible, namely

- transtympanic placement, where an electrode is invasively placed through the tympanic membrane onto the promontory of the temporal bone; and

- the external auditory meatus (EAM) near the tympanic membrane (Abramovich, 1990).

The value of the EcochG lies in its usefulness for assessing the hearing of young children who are difficult to control in clinical situations, and in the fact that these potentials are not altered by anaesthesia. The EcochG provides information on inner ear function (Abramovich, 1990) in conditions such as tinnitus, Meniere's disease and sudden hearing loss (Halliday, 1993). Its disadvantages are that low frequency function is almost impossible to assess, and the surgical procedures required for transtympanic placement make the EcochG invasive (Abramovich, 1990).

The use of electrocochleography in pseudohypacusic populations (Qiu *et al.,* 1998; Rintelmann *et al.*, 1991; Abramovich, 1990*)* has been reported. Rintelmann and his co-authors opine that EcochG does not measure the ability to hear. The invasive nature of the surgical procedures for the EcochG and the resultant need for an Ear-, Nose- and Throat (ENT) specialist (Schmulian, 2002), together with the ability of the test to measure only the most peripheral functions of the auditory system limit its clinical use to a small number of highly specialised diagnostic centres (Abramovich, 1990; Stach, 1998).

It can be concluded that pseudohypacusic patients are not adequately evaluated by early potential testing, as it fails to include all of the frequencies required for compensation assessments, and the invasiveness of the procedure is unacceptable for Occupational Health applications.

3.2.2.5.2   ABR

ABR is a big misnomer in the field of AEPs (Schmulian, 2002). Since the ABR is the most widely used AEP (Hood, 1995), all AEPs have come to being perceived as ABRs, irrespective of the latency epoch and the equipment used (Goldstein & Aldrich, 1999).   Ferraro and Durrant (1994) have found ten different names for ABRs in a literature review, including "brainstem auditory evoked potential", "brainstem auditory evoked response", and "auditory brainstem evoked response", to list but a few.

In ABR testing, electrical potentials are generated by the VIII (8th) cranial nerve and neural centres within the brainstem (Stach, 1998). The ABR uses far-field potentials recorded at the scalp (vertex), and comprises five or more waves generated in the auditory pathway up to the level of the inferior colliculus.   The procedure is firmly established in clinical practice for estimating audiometric thresholds and for neurological/neuro-otological diagnosis (Abramovich, 1990). In South Africa, ABR has for many years been the test of choice among the available AEP procedures, particularly for

difficult-to-test patients for whom the configuration and severity of hearing loss have to be determined. The waves are robust and easily recorded, and are unaffected by the patient's state of consciousness (the patient can even be asleep or sedated).

ABR potentials are minute, rarely reaching amplitudes greater than 1 micro volt (µV), and thus it requires a great deal of averaging to distinguish potentials from background noise and other artefacts (Arnold, 2000). Furthermore, ABR tests rely on transient responses elicited by brief acoustic stimuli (Arnold, 2000), as the more abrupt the stimulus, the more clearly defined the ABR. The most widely used stimulus is a broadband click, because of its rapid onset (100 µsec) and broad frequency content, which stimulates a large portion of the basilar membrane to give a reasonable indication of hearing thresholds between 2 000 and 4 000 Hz. However, due to the structural and mechanical properties of the cochlea, ABR can only predict auditory sensitivity in the upper part of this range to within 5 to 20 dB of behavioural thresholds (Rance *et al.,* 1998). This limitation has led to the development of other stimuli, including tone bursts, filtered clicks and various masking techniques to provide more precise information on narrower frequency ranges (Hood, 1998).

According to Swanepoel (2001), tone bursts are the stimulus of choice where low frequency threshold information is required. Tone bursts are more frequency-specific than clicks, and their gradual stimulus onset ensures good frequency specificity (Weber, 1994). Unfortunately, the resulting stimulus does not elicit a clear ABR and, therefore, an abrupt stimulus onset is necessary to improve the quality of the response. However, this introduces high-frequency energy into the test stimulus, necessitating the use of masking techniques to eliminate the effects of unwanted high frequency energy. Stapells *et al.* (1990) have obtained good agreement between ABR and behavioural thresholds by using tone burst stimuli embedded in notched noise.

Unfortunately, the time needed to obtain a single ABR threshold for each ear exceeds 30 minutes, making a full audiogram impractical (Weber, 1994). With children the test often lasts for as long as the child sleeps and, even with adults, a long test is tiring and undesirable (Swanepoel, 2001). At the moment, the best method for determining hearing loss configuration is to present first a low-frequency tone burst and then a click ABR. This procedure is an attempt to shorten the procedure, but should still allow the audiologist to get an idea of the configuration of the hearing loss.

An advantage of ABR is that the latencies of the various waves are quite stable within and among different patients (Abramovich, 1990). In addition, time intervals between peaks are prolonged by auditory disorders central to the cochlea, making ABR useful in differentiating cochlear and retrocochlear pathology (Weber, 1994).

A disadvantage is that the interpretation of wave forms is subjective (Martin, 1994), and the interpretation of tone bursts requires considerable expertise and experience (Abramovich, 1990; Swanepoel, 2001). The ABR is also time-consuming, and the maximum stimulus level for clicks and tone bursts is restricted, resulting in a risk that the audiologist may fail to identify residual hearing at high loudness levels. Furthermore, the high cost of instrumentation and software are added negative considerations (Schmulian, 2002). Qiu *et al.* (1998) point out the further disadvantage that involuntary responses are generated only by sub-cortical structures and, hence, can never provide a measure of true hearing thresholds. These authors also criticise the great technical demands with regard to stimulus, filter settings, recording methods and response interpretation with bone-conduction ABRs. This limits the clinical application of the technique.

In a study by Barrs *et al.* (1994), it was found that an ABR was a useful procedure in the threshold confirmation needed in cases of noise-induced hearing loss, but that middle latency responses were more useful than the ABR because of the ABRs tendency to overestimate hearing loss in down-

sloping audiograms. Middle latency responses were also more frequency specific which is important in the case of noise-induced hearing loss evaluations.

From the preceding discussion, it is apparent that the ABR has up to now been the most widely used electrophysiological procedure, and is the only electrophysiological procedure prescribed in South Africa for the formal assessment of pseudohypacusic patients (RMA guidelines, 2003). Despite the limitations discussed above, frequency-specific threshold determinations are possible, but only through a long and expensive process requiring a great deal of skill and experience on the part of the audiologist. These are two important limitations that hinder the consistent use of ABRs in hearing assessment in the mining industry.

3.2.2.5.3   Middle latency responses

It is generally accepted that there are two main reasons for the use of auditory electrophysiological tests, namely the need to make inferences regarding hearing thresholds and the need to obtain information regarding the functional and structural integrity of the auditory pathway's neural components (Kraus, Kileny & McGee, 1994). The purpose of this section is to provide a basis for understanding the principles and applications of middle latency response (MLR) testing and to evaluate the contribution of MLRs in meeting the above two aims.

An MLR is a series of waveforms occurring 10 to 80 ms after the onset of an auditory stimulus (Kraus *et al*., 1994). Here, again, contradictory classifications abound in the literature. Abramovich (1990) classifies MLR as having a latency of 8 to 50 ms, while Picton (2001) and Glasscock *et al*. (1987) set latency at 25 to 50 and 12 to 50 ms respectively. Within the continuum of components comprising scalp-recorded AEPs, MLRs follow ABRs and precede late latency responses (LLRs), while evoked potentials No, Po, Na, Pa, Nb and Pb are classified as MLRs (Kraus *et al*., 1994).

According to Kraus *et al.* (1994), Geisler and his co-workers were the first investigators to describe MLRs (in 1958). MLRs are measured at the scalp, using an electrode montage identical to that used for ABR recordings, and MLR generators include many brain structures central to the midbrain, as well as structures outside the primary auditory pathway, such as the auditory thalamocortical pathway, the reticular formation and the multi-sensory divisions of the thalamus (Kraus *et al.,* 1994).

MLR is used clinically for electrophysiological determination of hearing thresholds at lower frequencies, for the assessment of cochlear implants and auditory pathway function, and for the localisation of auditory pathway lesions. They are also used intra-operatively (McPherson & Ballachanda, 2000). It is thus clear that MLR has many applications in audiology, but unfortunately, the disadvantages of MLRs overshadow the advantages.

The most important limitations include:

- the inconsistency of responses as specifically observed in the paediatric population (Kraus *et al.*, 1994);
- highly specialised equipment requirements (Schmulian, 2002), including EEG for example;
- the need for the patient to be awake, co-operative and alert (Hood, 1995). Ferraro and Durant (1994) state that sensitivity to the patient's state of consciousness limits the acceptance of MLR techniques; Thorton *et al.* (1984) show that MLRs are distorted and delayed during sedation, and those potentials are poorly detected in stage IV sleep;

- a perception that MLRs are not considered a mainstream electrophysiological test (Mc Pherson & Ballachanda, 2000), and are regarded as difficult to record (Abramovich, 1990), causing a lack of facilities where these procedures could be tested; and

- reports that MLR potentials can be contaminated by muscle potentials from the neck or peri-auricular region (McPherson & Ballachanda, 2000).

The question that needs to be answered is whether MLRs can be used as a technique to identify pseudohypacusic mine workers and quantify their hearing loss. Abramovich, (1990) advocates the use of MLRs in pseudohypacusic patients. He is of the opinion that a stimulation rate of 40 per second instead of the usual 10 per second can cause a superimposition of the peaks of MLRs and an augmentation of the response. He specifies that MLRs are to be used in this population when slow vertical response (SVR) measurement conditions are poor. Barrs *et al.* (1994) mention the possibility of using MLRs to detect work–related noise-induced hearing loss, stating that MLRs are more effective in threshold estimation than ABRs, as a result of the steepness of the audiometric curve in noise-induced hearing loss. Barrs *et al.* (1994) also advocate the use of MLRs to verify low frequency thresholds.

McPherson and Ballachanda (2000) argue that the biggest problem in testing and verifying these MLRs is the fact that these evoked potentials are not considered to be mainstream electrophysiological tests in audiology practice. Hence, equipment and facilities are not readily available.

3.2.2.5.4 Late latency responses (LLR)

As indicated previously, confusing nomenclature also exists regarding the potentials evoked at later latencies. These potentials are described as "slow" (Halliday, 1993), while Stach (1998) favours the term "late latency response" (LLR). "Slow vertical response" (Abranovich, 1990) and "cortically evoked responses" (Rickards *et al.*, 1996) are other nomenclature in the existing literature. The confusing nomenclature stated above is further compounded by a lack in uniformity in the latency epochs of LLRs. Ferraro and Durrant (1994) define LLRs as potentials manifesting 50 to 800 ms after the stimulus, while Glasscock *et al.* (1987) and Picton (1991) relate latencies in this sub-class to 250 to 600 and 50 to 200 ms, respectively.

These potentials have been found to be greatly affected by subject state (Abramovich, 1990; Stach, 1998), and the potentials are best recorded when the patient is awake and attending carefully to the sounds presented. It is thus understandable that these methods are only used in adult, difficult-to-test populations. Stach (1998) mentions that LLRs are robust and easily recorded in adults and that the response can estimate auditory sensitivity independently of behavioural response.

As is the case with other potentials, the late latency response generators are still unknown. Halliday (1993) attributes the P3 or P300 AEP to widespread activity of the frontal cortex involving the parietal association areas.

An important disadvantage of LLRs is the fact that the procedure is time-consuming. Abramovich (1990) estimates the time requirement for four thresholds in two ears at 60 minutes.

With regard to the application of late latency responses to the pseudohypacusic population, it is worth noting that several authors have promoted LLRs as a medico-legal test (Halliday, 1993; Rickards *et al.,* 1996; Rickards & De Vidi, 1995; Abramovich, 1990; Dobie, 2001; McCandless & Lentz, 1968; Hyde *et al.*, 1986; Coles & Mason, 1984).

As early as 1968 McCandless and Lentz tested LLRs on adults with pseudohypacusis using pure-tone stimuli with a 700 msec duration. They found a very good correlation between the electrophysiological and behavioural thresholds (5dB).

Abramovich (1990) claims that SVR testing is the test of choice for assessing non-organic hearing loss. He argues that SVRs most closely approximates the results of conventional frequency-specific audiometry (within 10 dB), and that SVR is insensitive to neurological dysfunction. Pseudohypacusic patients are instructed to pay attention, and those who deliberately exaggerate their level of attention due to anxiety can be clearly identified. The stimulus used is a 100 ms tone burst with rise and fall times of 10 ms.

Coles and Mason (1984) used a 50 to 300 ms latency epoch and have proven that these latency responses have by far the greatest value for verifying pure-tone thresholds in adult patients, in comparison to brainstem and cochlear potentials. The tonal signals that these authors used had a duration of 200 ms and a rise and fall time of 10 ms. A specific advantage of LLRs mentioned by these researchers is the frequency specificity at low frequencies where non-organic overlay is maximal. They also argue for the use of LLRs in medico-legal investigations because of the non-invasive nature of the procedure and because the procedure tests up to a much higher dB level than, for instance, the ABR. Hence, there is a less likelihood of a non-peripheral disorder causing a discrepancy between the AEP and the behavioural threshold.

Hyde *et al.* (1986) have expressed the opinion that the verification of pure-tone audiometry is a long-standing problem in Departments of Veterans' administration, compensation assessment for noise-induced hearing loss and medico-legal evaluation. These authors have found a correlation between the slow vertical response and behavioural thresholds of within 10 dB. The stimuli used are tone bursts with 10 ms rise and fall times, and a 40 ms plateau. Despite a very good threshold estimation ability, and although by 1986 the procedure had been used in the Mount Sinai hospital (Toronto), for a decade, the authors emphasise the following disadvantages of using SVRs:

- testers in a clinical setting need to be experienced and carefully trained audiologists whose performance is monitored (it is clear that the skill requirement is very high);
- the test procedure is demanding and the skill requirements are often underestimated;
- testers need to have an adequate caseload to maintain their skill;
- all clinical interpretation is subjective and on-line;
- slow vertex response audiometry is problematic in 5 per cent of cases due to high levels of rhythmic activity:

- the time exceeds 1.5 hours in 95 per cent of cases (Hyde *et al.,* 1986);

- from the above it is clear there is still a limited acceptance of the technique even in North America (Hyde *et al.,* 1986; Dobie, 2001).

Picton (2001) indicates that the British Columbia Workers Compensation Board has used LLRs, and Rickards *et al.* (1996) state that cortical evoked response audiometry (CERA) has been used to assess noise-induced hearing loss in the Australian state of Victoria for the past 15 years, with 18 per cent of all noise-induced hearing loss cases referred for CERA. This seems to indicate some positive experience with AEP procedures.

CERA thresholds have been found to be within 10 dB of pure-tone thresholds, but, again, the procedure has failed to gain wide acceptance. Rickards *et al.* (1996) indicate that reliance on subjective interpretations of tracings, and the high levels of skill and training required of testers have hampered acceptance of CERA as a routine test for pseudohypacusis.

As far as can be determined, late latency responses have not so far been used in South Africa for the assessment of noise-induced hearing loss or the evaluation of compensation claims. Although it is clear that, as in any clinical population, no single AEP method is always the best (Hyde *et al.,* 1986), the main reason for searching for a better method is a lack of objectivity in deciding whether the evoked potential is present.

3.3 SUMMARY

This chapter has discussed electrophysiological tests, particularly AEPs, as a possible means of determining accurate hearing thresholds for pseudohypacusic mine workers. Nomenclature, selected definitions and the historic evolution of AEPs have also been discussed, and the value of various AEP methods for estimating hearing thresholds have been examined.

A summary of the disadvantages of currently used AEPs based on the above discussion, is set out in Table 3.1 below.

TABLE 3.1: DISADVANTAGES OF AEPs

Type of AEP	Special equipment	expensive	time consuming	age sensitive	influenced by neural dysfunction	state dependant	subjective interpretation	not frequency specific	sub cortical	invasive	skilled tester
ECochG	✗	✗	✗		✗		✗	✗	✗	✗	✗
ABR	✗	✗	✗	✗	✗		✗	✗	✗		✗
MLRs	✗	✗	✗	✗	✗	✗	✗		✗		✗
LLRs	✗	✗	✗	✗		✗	✗				✗

Although LLRs have been used internationally in medico-legal evaluations, an even better solution is still sought for. A recent development in the field of AEPs is auditory steady state responses (ASSRs), which is discussed comprehensively in the next chapter. Lins *et al.* (1995) have found that results obtained from ASSR testing can be presented as an audiogram, thereby providing information about the extent, nature and configuration of hearing loss. Most importantly, it has been reported that ASSR provides true objectivity, as thresholds are not determined subjectively, through a clinician's interpretation of wave forms, as is the case with ABR and LLRs, but are rather calculated objectively by a computer (ERA systems Pty. Ltd, 2000).

The latter crucial benefit motivated this researcher to investigate this type of AEP as a possible means for testing pseudohypacusic patients, particularly those with noise-induced hearing loss in the South African mining industry.