NOISE INDUCED HEARING LOSS AND AUDIOMETRY

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1 December 2010

Accompanying documents to this report

Title	*Report number*
Noise Induced Hearing Loss and Audiometry	Research Brief No. 1210-004-R2B
Supercedes: Noise Induced Hearing Loss and Audiometry	Research Report No. 0810-004-R2D

Research Report No. 1210-004-R2 (Final)

A joint initiative of

NOISE INDUCED HEARING LOSS AND AUDIOMETRY

Introduction

Audiometric assessment of the auditory system is not pathology specific. Its main goals are to locate the site of a disruption in the system and to determine the severity of that disruption. The traditional categories of hearing loss are conductive, sensorineural, mixed and functional. The sensorineural component can be subcategorized into cochlear and retro-cochlear. The severity of a disruption in the auditory system can be viewed in several ways, including the degree of loss for specific tonal frequency, loss in speech intelligibility or, more generically, the amount of disruption to everyday activities as a result of communicative difficulty. Noise induced hearing loss (NIHL) is sensorineural hearing loss as noise damages the outer hair cells of the cochlea.

Hearing Loss

Hearing loss (HL) is often categorized as normal, mild, moderate, severe and profound. This description is based on the pure tone average (PTA), which is the average loss at 0.5, 1 and 2 kHz measured with the pure tone audiogram. These frequencies are chosen based on their contribution to the understanding of speech.

- Normal hearing is on average less than or equal to 20 dB HL; individuals with this degree of loss should not experience a great deal of difficulty in normal listening situations.

- Individuals with a mild loss have a pure tone average between 20 and 40 dB HL. These individuals typically will have only mild difficulty in most listening situations. They should be able to carry on a conversation in quiet at 3 ft. However, as distance or competing noise increases, their difficulty will become more apparent.

- Moderate hearing loss is a pure tone average ranging from 40 to 70 dB HL. Individuals with a moderate loss will experience difficulty in conversation at 3 ft in quiet and will rely on visual cues to help in communication.

- Severe loss is a pure tone average of 70 to 90 dB HL. Because conversational speech is generally in the 60- to 70-dB SPL range, a listener with a severe loss will miss most, if not

all, of conversational level speech even in quiet. Individuals with moderate and severe hearing losses typically benefit from the use of assistive listening devices and hearing aids.

- Profound hearing loss is a pure tone average of 90 dB HL or greater. Individuals with a profound loss may experience benefit from hearing aids but will often still have difficulty in oral communication situations. Frequency transposition aids and multichannel cochlear implants often provide significant levels of help (Sataloff 2006).

It must be noted that, though generalizations about daily function can be made based on the pure tone average, there is a great deal of individual variability. Some individuals with moderate hearing loss will experience significantly more difficulty than others with severe to profound hearing losses.

The expectation that audiometry as part of the broader assessment of NIHL injuries is to reliably diagnose and quantify that NIHL which has occurred as a result of a persons occupation. It is an evidential tool to provide important information about the nature and extent of the loss to assist health professionals and scheme operatives determine the appropriate level of compensation in accordance with the Accident Compensation Act.

Audiometry helps in establishing the nature of the hearing loss. For NIHL epidemiological studies have recognized that changes in the pattern of frequency loss correlates to damage of the aural structures caused by prolonged and excessive noise exposure (Nelson 2005). This is represented as a loss of hearing efficiency (db) at the frequencies from 3 kHz to 6 kHz and appears as a notch representing the loss on the audiogram. The frequencies affected broaden as the exposure to noise extends over longer periods ie 10 years.

All types of audiometry cannot discriminate between occupational and non-occupational noise exposure. However, it plays an important role in discriminating between other types of hearing loss caused by disease, congenital factors, age, ototoxicity etc.

Once it is established that the hearing loss, or part of, is caused by noise exposure then the audiogram must precisely quantify the db loss at the specific frequency intervals to calculate the percentage loss which is converted to a monetary sum.

To varying degrees audiometry is subject to the cooperation of the injured person or affected by activity leading up to or during the assessment. A method which is less able to be influenced by the actions or omissions of the injured person is a factor in determining the reliability of the results. In the event that an injured person is fully cooperating the audiometry must produce consistent and reliable results when applied by experience audiometrists and ENT specialists.

Pure-Tone Audiometry

The mainstay of audiometric measurement has been the pure-tone audiogram (PTA). PTA provides a method for separating conductive losses, located in the outer and middle ear, from sensorineural losses associated with problems in the cochlea and central nervous system. PTA is performed using both air conducted signals that pass through the outer and middle ears as well as bone conducted signals that are generated by an oscillator pressed against the mastoid or forehead. Bone conducted signals pass through the skull and bypass the outer and middle ear structures providing the signal directly to the cochlea. Typically, a problem in the outer or middle ear is suspected when the air conduction results are poorer than the bone conduction results. If lowered bone conduction scores are seen with the reduced air scores, a mixed loss is present indicating both an outer/middle ear problem and a simultaneous inner ear disorder.

The audiogram is obtained at octave intervals from 0.25 through 8 kHz. Signals are initially presented at 30 dB HL for 2 sec at the frequency being tested. Longer signals increase the probability of a false positive response. Signals shorter than 1 sec will not allow the proper rise and fall times of the signal. If signals have very short durations (less than 500 msec), there will be inadequate sensory integration leading to higher threshold levels. The signal is lowered by 10 dB HL until no response is given, followed by raising the signal in 5 dB HL steps until a response is given. The signal is then lowered by 10 dB HL and the steps repeated. Once the subject responds two out of three times, at the same level, on the ascending signal increments, threshold is obtained and the process repeated at a new frequency. Standard audiometric test frequencies are 0.25 to 8 kHz at octave intervals. Typically, the better hearing ear, by subject report, is measured first, commencing at 1 kHz. After all frequencies have been measured, the test is repeated at 1 kHz. The subject should have a threshold within 5 dB of the previous score for the measure to be

considered reliable. The hearing threshold levels are usually plotted on a graph, or audiogram, with sound intensity (dB) on the y axis and the frequency (Hz) along the x axis. Standard symbols are used to denote right and left ears.

The assessment of hearing disability using any system has its problems. There is a continuum of hearing disability that is measurable in most individuals at a hearing threshold of between 15 and 30 dB. There is not specific point at which hearing disability suddenly starts. Hearing disability progresses with increasing hearing loss in a sigmoidal fashion. It progresses slowly initially and then rapidly accelerates and slows again. Therefore the selection of a point at which hearing disability starts has obvious inherent problems. A number of different methods may be used for the selection of such a low fence. However, it is important to note that the speech frequencies selected for the assessment system are extremely important in setting a low fence. If more high frequencies are included, the low fence should be higher, and if more low frequencies are chosen, it should be lower. Regardless of the level at which the low fence is set, there is evidence to suggest that individuals with hearing threshold levels of 12 dB at 1 kHz, 2 kHz, and 3 kHz or 15 dB at 1 kHz, 2 kHz, and 4 kHz perform as well as normal hearing controls even in noisy conditions (Hone 2003).

Other audiometry tests

Within occupational health care determining someone's hearing disability will also involve other audiometry tests to get a complete picture of the hearing ability of a worker. These tests can involve for example speech in noise tests, sound localization tests, determining speech reception threshold (SRT) and testing of word recognition. All these tests are very helpful in giving a full profile of a person's hearing ability. In Europe much research in this area is happening and the experience so far is promising for future developments on this topic. In the assessment of NIHL for workers compensation purposes usually speech discrimination tests and also acoustic reflexes are included besides PTA.

For the purpose of diagnosing NIHL for workers compensation purposes the main focus is not only to establish the work relatedness but also to quantify the hearing loss. This means that audiometrists or ENT specialists needs to determine a frequency specific hearing threshold in order to provide guidance for the rehabilitation process, as well as to facilitate

recommendations and decisions regarding patient referrals. The work relatedness of the hearing loss can mainly be determined by a thorough work history, information on noise levels from all previous employers, and previous pure tone audiometry tests of the worker.

For this project we will focus on the diagnostic qualities of other more objective audiometry tests. Although, these objective electrophysiological tests are not yet standard procedure in determining NIHL in most countries, they can be very helpful in determining the severity of the hearing loss or in confirming exaggeration of hearing loss. For this project we have focussed on those tests that have been studied widely and are already sometimes used for this purpose. We have searched for evidence on their diagnostic qualities, especially regarding NIHL, and their practicality. We have had contact with experts in the field of audiology and have also contacted foreign contacts to enquire if these new tests are already used in medico-legal investigations of NIHL.

Methods

For our literature search we searched in PubMed from March 2010 until April 2010. We have not done a systematic review but tried to achieve a comprehensive overview of the existing literature on this topic. We combined the information from PubMed with several informative websites on audiometry, and information from our contacts in foreign countries.

1. Search PubMed, limit English Language:

- “Hearing Loss, Noise-Induced” [Mesh] AND “Audiometry” [Majr] →218 hits

- "Hearing Loss, Noise-Induced"[Majr] AND "Audiometry, Evoked Response"[Majr]

→ 20 hits

- "Hearing Loss, Noise-Induced"[Mesh] AND assr → 31 hits

- ("Audiometry"[Majr]) AND (Diagnosis/Narrow[filter]) →90 hits

- ("Audiometry"[Majr]) AND (Diagnosis/Narrow[filter]) AND "Hearing Loss, Noise-Induced"[Mesh] → 5 hits

We selected those articles that focussed on:

- NIHL for workers (or adults with sensorineural hearing loss),

- comparing pure tone audiometry (PTA) with other diagnostic audiometry tests; or studies comparing two objective tests with PTA.

- we preferred recent articles over the older ones.

We analysed the quality of the article based on the guidelines of critical appraisal as described by van Dijk et al.

- Was the diagnostic test compared with a reference test that is considered as the ‘gold’ standard for this diagnostic research?

- Was the group of patients that took part in the study representative of patients in our practice?
- Was the reference test applied without the researchers having knowledge about the result of the diagnostic test?
- Was the test applied again on a second independent group of patients?

2. Search for back ground literature on audiometry in recent books or narrative reviews available via medical databases to provide a good basis overview what the different audiometry tools involve.

3. We checked the references of the retrieved articles to find more relevant information (snow ball) and used separate search terms such as ‘NIHL’, ‘CERA’ or ‘ASSR’ in four audiology journals. These journals were selected based on their impact factor (over the last 5 years) according to the ISI Web of Knowledge and there relevance to audiology:

- Hearing Research .

- Audiol Neuro-Otol,

- Ear Hearing

- International Journal of Audiology

4. Asked our foreign contacts what other audiometry tests are used in measuring NIHL for workers compensation?

What other audiometric diagnostic tools are nowadays available?

Otoacoustic Emissions

In 1977, Kemp discovered that the cochlea was capable of producing sound emissions (Kemp 1977). OAEs are mechanical auditory phenomena. In response to acoustic stimulus, the olivocochlear bundle activates the efferent nerves to the outer hair cells. Stimulation of the outer hair cells causes them to vibrate the basilar membrane. These vibrations are driven through the cochlea, through the ossicular chain, to produce sound at the tympanic membrane. In theory, the outer hair cells act as the cochlear amplifier as their vibrations enhance the tuning of the travelling wave. OAEs are thought to be a by-product of this cochlear amplifier. There are four categories of OAEs: spontaneous, evoked, stimulus frequency, and distortion product. Evoked OAEs and Distortion product OAEs are used in clinical practice.

- Transiently evoked OAEs can be seen as an echo in response to a single sound stimulus. In noise induced hearing loss, ototoxicity and hereditary hearing loss there will be consistent pathologic patterns produced by the emissions from the outer hair cells. These emissions are generally absent in hearing loss of more than 30 dB. The screening of newborns has perhaps the highest volume of clinical application of OAEs

- Distortion product otoacoustic emissions (DPOAE) are generated in response to paired pure tones, F1 and F2 and are more frequency specific. The emission is called a distortion product because it originates from the cochlea at a frequency not present in either of the stimulus tones. Several distortion products are produced in response F1 and F2, but the largest is found at their cubic-difference of 2F1 2 F2. As the primary frequencies are incremented from 500 to 8000 Hz, a distortion product audiogram can be generated similar to a pure-tone audiogram. DPOAE's can accurately assess boundaries between normal and abnormal hearing with losses up to 50 dB. This category of OAEs may be clinically useful in monitoring changes in the cochlea due to hereditary hearing loss, progressive disease, and ototoxic agents. DPOAEs are the only OAEs that are readily detectable in virtually all normal-hearing ears and are present for hearing thresholds up to 40–60 dB HL. DPOAEs are the acoustic products that occur as intermodulation responses to two simultaneous pure tones of different frequencies, f1 being lower than f2. The most

prominent distortion response (the recorded DPOAE level) at frequency 2f1–f2 serves as a marker frequency and indicates that the region of the basilar membrane corresponding to the overlap of f1 and f2 is functioning (Kimberley et al, 1997).

The evoked responses are recorded serially by a probe microphone in the external canal. The recorded signals are then amplified, averaged, and processed by fast Fourier transform. A frequency spectrum of the OAEs is produced. The quality of the OAEs can be affected by poor stimulus delivery as well as internal and ambient noise. These factors can be minimized with proper equipment controls, noise floor thresholds, and patient cooperation. OAE testing can also be affected by pathologic conditions involving the external and middle ear. Inflammation of the external ear canal can prevent comfortable placement of the stimulus and microphone probes. Middle ear effusion or ossicular discontinuity can prevent passage of the stimulus or production of the emission.

OAEs are sensitive to sensorineural hearing loss and can augment traditional audiometric diagnosis. The presence of transient OAEs indicates a hearing threshold of 30 dB or better for the frequency range in their spectrum. Distortion product OAEs reveal amplitude decreases at hearing thresholds of more than 15 dB, and are generally absent at thresholds of more than 50 dB.

A useful role for OAEs is monitoring for dynamic changes in cochlear function and ototoxicity. Noise trauma and ototoxic agents have been shown to affect outer hair cell function in animals. Distortion product OAEs have been shown to correlate well with the typical 4000-Hz notch pattern associated with noise-induced hearing loss. OAEs also have been shown to be an early and sensitive indicator of the ototoxic effects of cis-platinum and aminoglycosides. Serial monitoring of OAEs in workers in noisy environments or patients receiving ototoxic agents may provide a simple and objective measure of hearing loss. Additionally, some researchers have suggested that cochlear changes resulting from excessive sound exposure may be detectable by otoacoustic emission measurement before these changes become apparent on the pure-tone audiogram.

It is impossible for a patient with compensable hearing loss to have normal OAEs- and OAE testing is therefore advocated as a quick and objective means of confirming hearing status in suspected cases of pseudohypacusis. 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 2004).

Auditory Evoked Potentials

Classification of auditory evoked potentials (AEPs) is usually done based on the response latency (time between stimulus and response) as short (early or fast), middle or late latency response.

Short latency response

These potentials are measured in response to sound stimuli after **5 ms** and originate in the cochlea and distal portions of auditory nerve. They are also grouped together in clinical use as electrocochleogram. The value of the electrocochleogram lies in its usefulness for assessing the hearing of young children; and in the fact that these potentials are not altered by anaesthesia. The electrocochleogram provides information on inner ear function, in conditions such as tinnitus, Meniere's disease and sudden hearing loss. Its disadvantages are that low frequency function is almost impossible to assess, and the surgical procedures required for transtympanic placement make the electrocochleogram invasive (Abramovitch 1990)

Brainstem Evoked Response Audiometry (BERA or ABR)

Brainstem evoked responses occur within the first **10 ms**, and they are unaffected by behaviour, attention, drugs, or level of consciousness. In fact, they can be measured under general anaesthesia or during deep coma. The test measures electrical peaks generated in the brainstem along the auditory pathways. The most widely used stimulus is a broadband click, because of its rapid onset and broad frequency content, which stimulates a large portion of the basilar membrane to give a reasonable indication of hearing thresholds between 2000 and 4000 Hz. ABR can predict auditory sensitivity within 5-20 dB of behavioural thresholds. Tone bursts are more frequency specific than clicks, but the resulting stimulus does not elicit a clear ABR and therefore, an abrupt stimulus onset is necessary to improve the quality of the response. This needs the use of masking

techniques to eliminate the effects of unwanted high frequency energy. Stapells et al. have obtained good agreement between ABR and behavioural thresholds by using tone burst stimuli embedded in notched noise (Stapells 1990, de Koker 2004). Unfortunately, the time needed to obtain a single ABR threshold for each ear exceeds 30 minutes, making a full audiogram not practical. An advantage of ABR is that the latencies of the various waves are quite stable within and among patients. In addition, time intervals between peaks are prolonged by auditory disorders central to the cochlea, making ABR useful in differentiating cochlear and retrocochlear pathology (Xu 1998).

A disadvantage of ABR is that the interpretation of wave forms is subjective, and the interpretation of tone bursts requires considerable expertise and experience (Swanepoel 2001). The ABR is also time consuming, and the instrumentation and software that is needed is expensive.

Middle Latency Responses

There are also middle latency responses that occur somewhere between **10 and 80 ms** after an auditory stimulus. They can be used clinically for electrophysiological determination of hearing thresholds at lower frequencies, for the assessments of cochlear implants and auditory pathway functions. However, its clinical use is limited because there are too many disadvantages. These are first of all a lack of facilities where these procedures could be tested, the need for the patient to be awake, co-operative and alert. The need for highly specialised equipment, and reports that these potentials can be contaminated by muscle potentials from the neck or peri-auricular (de Koker 2004)

Cortical Evoked Response Audiometry (CERA)

Late latency responses are mostly described as cortical evoked responses as it refers to the electrical activity at the cerebral–cortex level. CERA allows measurement not only of auditory signals but also of other brain wave variations that are associated with the perception of sound. Therefore, CERA is a valuable tool in evaluating thresholds and also whether or not a sound actually reaches a level of perception in the brain. Cortical evoked responses occur at **200 ms** after the stimulus. A disadvantage of CERA is they can be affected volitionally. For example, responses are better if a patient concentrates on an auditory signal than if he/she attempts to ignore it. Cortical evoked responses may also be

altered substantially by drugs and state of consciousness. On the other hand, for diagnosing NIHL when there is a suspicion of malingering this could also be seen as an advantage.

In summary, all AEPs need special equipment, a skilled tester, they are expensive, time-consuming and may have a subjective interpretation of the results. CERA testing has the advantage that it is frequency specific (especially at the lower frequencies) and also measures the perception of sound. It has a good correlation within 5-10 dB with behavioural thresholds. BERA or ABR testing has the advantage that it is not state dependent and can also be used for differential diagnostic purposes.

Auditory Steady State Responses (ASSR)

These are periodic scalp potentials that arise in response to regularly varying auditory stimuli such as sinusoidal amplitude (AM) and/or frequency modulated (FM) tones. The response is evoked when stimuli is presented at a sufficiently high repetition rate to cause overlapping of the responses to successive stimuli.

ASSR was previously referred to as SSEP (Steady State Evoked Potential) and/or AMFR (Amplitude Modulation Following Response). ASSR is similar to the Auditory Brainstem Response (ABR) in some respects. The ABR is a transient response to a single transient stimulus, and ABR testing measures the neural responses of the VIII nerve and lower brainstem over a time frame of about 10 milliseconds (ms). The ABR response stops after each stimulus presentation, and does not begin again until the next stimulus presentation. Stimulus repetition rate (per second) assesses the length of the response time-frame (100 ms), and thus cannot exceed 1 second. Repeated stimulation and computerized signal averaging improve the signal-to-noise ratio of the ABR, making it visible from the rest of the brain's activity (i.e., activity unrelated to sound stimulus). ASSR on the other hand is a continuous, ongoing neural response because its waveform follows the waveform of the continuous ongoing stimulus. Such a true sustained, steady-state response is phase-locked to the stimulus; it occurs slightly later in time than the stimulus, but faithfully follows the continuous temporal waveform envelope of the stimulus (Venema 2004). Most audiologists see ASSR as a complement to ABR testing.

Another difference with ABR is that rather than depending on amplitude and latency, ASSR uses amplitudes and phases in the spectral (frequency) domain. ASSR depends on peak detection across a spectrum, rather than peak detection across a time versus amplitude waveform. ASSR is evoked using repeated sound stimuli presented at a high repetition rate, whereas ABR is evoked using brief sounds presented at a relatively low repetition rate. A big advantage of ASSR over ABR measurement is that ASSR uses an objective, sophisticated, statistics-based mathematical detection algorithm to detect and define hearing thresholds. While ABR measurements are dependent on the examiner who will subjectively review the waveforms and decide whether a response is present.

ABR protocols typically use clicks or tone-bursts in one ear at a time. ASSR can be used binaurally, while evaluating broad bands of four frequencies (0.5 kHz, 1 kHz, 2 kHz, and 4 kHz) simultaneously.

ABR is useful in estimating hearing thresholds essentially from 1 kHz to 4 kHz, in typical (non-ski-slope) mild-moderate-severe hearing losses. ASSR can also estimate hearing thresholds across the same range as the ABR, but ASSR offers more spectral information more quickly, and can estimate and differentiate hearing within the severe-to-profound hearing loss ranges (Lin 2009).

ASSR can be used to estimate hearing thresholds for those who cannot or will not participate in traditional behavioural measures. Therefore, primary candidates for ASSR are: newborn infants for screenings and follow-up diagnostic assessments, babies in the neonatal intensive care unit (NICU), unresponsive and/or comatose patients, people who are suspect due to the nature of their visit (i.e., workers' compensation, legal matters, insurance claims, etc), ototoxicity monitoring, and others. (ref: Research and Technology Auditory Steady-State Response (ASSR): A Beginner's Guide by Douglas L. Beck, AuD; David P. Speidel, MS; and Michelle Petrak, PhD)

There are different types of ASSR such single or multiple stimuli ASSR and there are different results when 40 Hz or 80 Hz stimulus are used. The multiple-stimulus ASSR appears to be advantageous over single-stimulus ASSR in that it enables evaluation of at least four frequencies for both ears simultaneously, resulting in faster threshold estimation compared to single-stimulus ASSR (Dimitrijevic et al, 2002, van Maanen 2005)

Table audiometry

Audiometric measurement	Pure tone audiometry (PTA)	Transient Oto-acoustic Emissions (TOAEs)	Distortion product Oto-acoustic Emissions (DPOAEs)	Cortical Evoked Response Audiometry (CERA)	Brainstem Evoked Response Audiometry (BERA or ABR)	Auditory Steady State Responses (ASSR)
How does it work	Consists of air-conduction, pure-tone, hearing threshold measures at octave intervals from 0.25- 8 kHz	These emissions occur in response to brief acoustic stimuli such as a click or a tone burst.	They are single-frequency emissions produced in response to two simultaneous tones; it originates from the cochlea at a frequency not present in either of the stimulus tones.	It measures electrical activity at the cerebral-cortex level 200 ms after acoustic stimuli.	It measures electrical activity in response to clicks or tones that occur within 10-15ms after stimulus.	These are periodic scalp potentials that arise in response to regularly varying auditory stimuli such as AM and/or FM tones. The response is evoked when stimuli is presented at a sufficiently high repetition rate to cause overlapping of the responses to successive stimuli.*
Positive points	Is considered gold standard in audiometric measurement	- Time efficient - objective - no cooperation necessary - may be more sensitive to outer hair cell damage than PTA	- Time efficient - objective - no cooperation necessary - may be more sensitive to outer hair cell damage than PTA - DPOAEs may be more accurate in frequency specific threshold detection than TOAEs?	- Valuable because it not only evaluates thresholds, but also whether or not a sound actually reaches a level of perception in the brain. - Highly specific over speech frequency range 500-4000Hz	- accurate only to moderate hearing loss degree - good for differential diagnostic purposes; such as differentiating between cochlear and retro-cochlear pathology - can be performed in restless and awake persons (children)	- accurate from moderate to profound hearing loss - can be used for all frequencies of audiometric range
Negative points	Requires full patient cooperation	- The quality of OAEs can be affected by poor stimulus delivery as well as internal and ambient noise. - does not provide a frequency	- The quality of OAEs can be affected by poor stimulus delivery as well as internal and ambient noise. - does not provide a frequency specific threshold	- Threshold testing can be effected volitionally - needs an experienced tester	- click ABR provides little frequency specific information - tone burst ABR threshold testing frequency by frequency takes very long time	- time consuming - needs an experienced tester - not much evidence regarding its use for NIHL diagnosis

		specific threshold - OAEs cannot distinguish hearing loss over 40dB - Presence of OAEs does not guarantee transmission of neural signals to the central auditory pathways.	- OAEs cannot distinguish hearing loss over 40dB -- Presence of OAEs does not guarantee transmission of neural signals to the central auditory pathways.		- potentially ABR results are more variable at lower frequencies - needs an experienced tester	- may overestimate thresholds when patient is not sedated
Is it used in NIHL assessments?	Yes, this is the gold standard.	Rarely used in the Netherlands for difficult cases.	Is suggested to use for medico legal purpose in Hong Kong.	Is used in UK, British Columbia and in Victoria (Australia) for medico-legal assessments	- may be used in Taiwan	- not yet used in medico-legal assessments; good results for assessment in children, and mostly in combination with ABR

What are the diagnostic qualities of these objective auditory measurements specifically for noise induced hearing loss?

Oto acoustic Emissions

- What is the diagnostic value of transient evoked otoacoustic emissions in comparison with PTA for people with NIHL?

- What is the diagnostic value of distortion product otoacoustic emissions in comparison with PTA for people with NIHL?

The majority (n=10) of studies combined evaluating DPOAEs and TOAEs with PTA. We found 7 studies only looking at DPOAEs and 1 study focussing on TEOAEs.

Various cross-sectional studies showed diminished OAEs in subjects with NIHL, and lower levels of OAEs in association with hazardous noise- exposed populations even when PT audiograms were within normal limits (Dessi 1999, Attias 1995, Plinkert 1999, Sutton 1994, Lucertine 1995).

For example, Sisto et al. measured the correlation between TOAE signal to noise ratio and DPOAE with audiometric thresholds in young workers (between 18 and 35 years) exposed to different levels of industrial noise. Their results showed that if both OAE data and audiometric data are averaged over a sufficiently large bandwidth, the correlation between DPOAE levels and audiometric hearing threshold is sufficient to design OAE-based diagnostic tests with good sensitivity and specificity also in a very mild hearing loss range (1-3 kHz), between 10 and 20 dB (Sisto 2007). The researchers found that the inclusion of the information from TEOAEs added no predictive power to the test.

Another study by Attias et al. also explored the application of the TOAEs and DPOAEs in the diagnosis and detection of NIHL in 283 noise-exposed subjects and 176 subjects with a history of noise exposure but with a normal audiogram. Findings were also compared with those in 310 young military recruits with no reported history of noise exposure and normal bilateral audiogram. They found that in general, the features of the TOAEs and DPOAEs closely resembled the behavioural NIHL parameters: both were bilateral and

both affected primarily the high frequencies, with a "notch" at around 3 kHz in the DPOAEs. On average, TOAEs were recorded up to 2 kHz, indicating that up to this frequency range (speech area), cochlear functioning is intact and the hearing threshold s better than 25 dBHL. A clear association between the OAEs and the severity of the NIHL was noted. As the severity of NIHL increased, the emissions range became narrower and the amplitude smaller. OAEs were found to be more sensitive to noise damage than behavioural audiometry. Lower DPOAEs and TOAEs were found in subjects with normal audiograms but with a history of noise exposure. The authors concluded that OAEs may sometimes provide indispensable information in medico-legal cases, in which the configuration of the audiometric threshold is needed to obtain an accurate diagnosis of NIHL and compensation is proportional to the severity of NIHL. Furthermore, OAE testing between ears with and without NIHL revealed a high sensitivity (79 - 95%) and specificity (84 - 87%). This study showed that OAEs provide objectivity and greater accuracy, complementing the behavioural audiogram in the diagnosis and monitoring of the cochlear status following noise exposure (Attias 2001).

Avan et al. analysed DPOAE and TOAEs with PTA in a sample of 36 ears from 27 patients with NIHL. Ears with NIHL split into two subgroups, one (n = 25) with a notch in the DP-gram such that its lower boundary matched the lower limit of the audiometric notch (linear regression with a slope of 0.91, $r2 = 0.644$, $p < 0.001$). Likewise, when it existed, its upper boundary matched its upper counterpart on the audiogram (linear regression with a slope of 0.96, $r2 = 0.89$, $p < 0.001$). In this respect, DP-grams performed better than transient-evoked OAE spectra, which exhibited poor correlations with audiogram patterns. The second subgroup (n = 11) exhibited normal DPOAEs at all frequencies despite audiometric losses similar to those of the first subgroup. In all cases, DPOAE levels were poor predictors of the degree of hearing losses. It is hypothesized that NIHL in the second subgroup involves inner hair cells or auditory neurons, instead of outer hair cells in the first subgroup. Provided NIHL affected outer hair cells, DP-grams provided a comparatively accurate predictor of the spectral extent of hearing loss. (Avan 2005)

Jansen et al. studied a group of normal hearing musicians in a cross sectional study. They found large inter-individual differences in both TEOAEs and DPOAEs and no relation to individual audiometric patterns could be determined. On group level however, they found

clear differences between the average OAE responses of different audiometric subgroups: in general, more intense OAEs were found for groups with better average pure-tone thresholds. The OAEs of the normal hearing musicians were clearly distinguishable from the OAEs of the musicians in the other audiometric categories, suggesting a signalling function for early detection of NIHL. The authors concluded that firm statement on this issue can, however, only be made on the basis of a longitudinal study. The dissociation between audiometric thresholds and OAE outcome measures can be a complication in the application of OAEs for screening purposes on an individual level. As long as experimental evidence about the predictive value is not strong enough, the pure-tone audiogram should remain the gold standard for the assessment of NIHL (Jansen 2009).

Chan et al. investigated DPOAE as a potential screening procedure for occupational hearing loss screening in Hong Kong. In order to identify an optimal criterion or set of criteria for DPOAE screening, DPOAE and PTA measurements were obtained from successful and rejected occupational deafness compensation applicants. Various criteria that could effectively identify compensation applicants meeting and not meeting the occupational hearing loss requirements of 40 dB HL hearing loss across 1000, 2000 and 3000 Hz were examined (Chan 2004). The authors concluded that the results of their study were encouraging with regard to the use of DPOAE as a screening tool to identify applicants for occupational deafness compensation. However, DPOAE cannot replace PTA as a measure of hearing sensitivity. DPOAE is an almost direct measure of outer hair cell function integrity, with middle ear function as an influential factor, while PTA is dependent on the status of the middle ear, cochlea, eighth nerve, central auditory system, and auditory perceptual abilities. Thus, PTA offers a more comprehensive evaluation of hearing sensitivity. Moreover, abnormal DPOAE recordings may infrequently be recorded in individuals with normal audiograms, and, conversely, normal DPOAEs may be recorded in subjects with abnormal audiograms. Therefore, DPOAE screening should be used only as an adjunct to PTA, which is still the gold standard in determining actual hearing sensitivity in cooperative applicants for occupational hearing loss compensation.

Korres et al. evaluated DPOAEs in a group of 105 industrial workers in conjunction with PTA, and the results were compared with 34 subjects not exposed to noise. Results showed significant lower DPOAEs in the noise- exposed group. They also found lower

DPOAEs at 4 and 6 kHz, and a maximum response at 2 kHz. Pure tone audiograms also showed higher thresholds in the group exposed to noise, but could not find a particular main effect in a certain frequency. Thus DPOAEs levels were selectively affected at the higher frequencies, whereas pure tone thresholds were affected at all frequencies. Another measurement showed that more ears were affected in PTA at 4 kHz, and more ears were affected with lower DPOAEs at the lower frequencies. The authors concluded that both methods are sensitive in detecting NIHL, with DPOAEs tending to be more sensitive at lower frequencies (Korres 2009).

Good levels of DPOAE sensitivity, specificity and predictive efficiency were also found by Kim et al with up to maximum levels of 86%, 85% and 85% respectively at 4000 Hz. However, these percentages were obtained with regard to detection of hearing loss of more than 23dB (Kim 1996).

Hamdan et al. analysed whether TEOAEs measured in a group of normal hearing professional singers, who were frequently exposed to high-level sound during rehearsals and performances, differed from those measured in age and gender-matched normal-hearing non-singers, who were at minimal risk of hearing loss resulting from excessive sound exposure or other risk factors. For this they used twenty-three normal-hearing singers, 23 normal-hearing controls, and 9 hearing impaired singers. Pure-tone audiometry confirmed normal-hearing thresholds (>15 dB HL) at 0.5, 1.0, 2.0, 3.0, 4.0, 6.0, and 8.0 kHz in normal hearing singers and controls, and confirmed mild, high frequency, sensorineural hearing loss in the hearing impaired group. TEOAEs were measured twice in all ears. TEOAE signal to noise ratio (S/N) and reproducibility were examined for the whole wave response, and for frequency bands centred at 1.0, 1.4, 2.0, 2.8, and 4.0 kHz.

Results showed that TEOAE responses were measurable in all singers with normal audiometric thresholds, but responses were less robust than those of normal hearing controls. The findings suggest that subtle cochlear dysfunction can be detected with TEOAE measurement in a subset of normal-hearing professional singers. The authors concluded that TEOAE measurements may be useful as tool to identify musicians at risk for NIHL.

We found 5 prospective controlled studies evaluating the value of OAEs and NIHL.

Seixas et al. conducted a baseline audiometry and DPOAE evaluation on a cohort of 328 construction industry apprentices and followed them annually for 3 consecutive years. In parallel to these measures, noise exposure and hearing protection device (HPD) use were extensively monitored during construction work tasks. Recreational/non-occupational exposures also were queried and monitored in subgroups of subjects. Trade specific mean exposure Leq levels, with and without accounting for the variable use of hearing protection in each trade, were calculated and used to group subjects by trade specific exposure level. Mixed effects models were used to estimate the change in hearing outcomes over time for each exposure group. Results showed small but significant exposure related changes in DPOAEs over time were observed, especially at 4 kHz with stimulus levels (L1) between 50 and 75 dB, with less clear but similar patterns observed at 3 kHz. After controlling for covariates, the high exposure group had annual changes in 4 kHz emissions of about 0.5 dB per year. Pure tone audiometric thresholds displayed only slight trends towards increased threshold levels with increasing exposure groups. Some unexpected results were observed, including an apparent increase in DPOAEs among controls over time, and improvement in behavioural thresholds among controls at 6 kHz only. The authors concluded that results indicated that construction apprentices in their first three years of work, with average noise exposures under 90 dBA, have measurable losses of hearing function. Despite numerous challenges in using DPOAEs for hearing surveillance in an industrial setting, they appear somewhat more sensitive to these early changes than is evident with standard PTA (Seixas 2005).

Another longitudinal study by Lapsley Miller et al. with 338 volunteers, measured audiometric thresholds and otoacoustic emissions before and after 6 months of noise exposure on an aircraft carrier. While the average amplitudes of the otoacoustic emissions decreased significantly, the average audiometric thresholds did not change. Furthermore, there were no significant correlations between changes in audiometric thresholds and changes in otoacoustic emissions. Changes in transient-evoked otoacoustic emissions and distortion-product otoacoustic emissions were moderately correlated. Eighteen ears acquired permanent audiometric threshold shifts. Only one-third of those ears showed significant otoacoustic emission shifts that mirrored their permanent threshold shifts. A Bayesian analysis indicated that permanent threshold shift status following a deployment was predicted by baseline low-level or absent otoacoustic emissions. The best predictor

was transient-evoked otoacoustic emission amplitude in the 4-kHz half-octave frequency band, with risk increasing more than sixfold from approximately 3% to 20% as the emission amplitude decreased. It is possible that the otoacoustic emissions indicated noise-induced changes in the inner ear, undetected by audiometric tests. Otoacoustic emissions may therefore be a diagnostic predictor for noise-induced-hearing-loss risk.

Job et al. performed a 3- year follow up study in a population of pilots between 20-40 years (n=521). They measured tonal audiograms and performed DPOAE measurements during those 3 years. The objective of their study was to analyse if low DPOAEs in normal hearing ears are risk markers for subsequent early hearing loss when subjects are exposed to noise. With the DPOAEs they calculated an index of abnormality. There results showed that in adults with a normal audiogram, ear vulnerability to noise could be elicited by the use of objective DPOAE measurements. A high index of abnormality measured with the DPOAE (that corresponded to reduced DPOAE levels) represented a risk for early hearing loss. This study emphasised the interest of DPOAE measurements in public health and occupational noise prevention policies. The index of abnormality calculation with DPOAE may also be interesting for clinicians because no DPOAE index of abnormality is currently available.

Shupak et al. also followed changes in TEOAEs and DPOAEs in relation to PTA during the first 2 years of noise exposure. They used a prospective controlled cohort study design with 135 ship engine room recruits and a control group of 100 subjects with no noise exposure. In contrast to previous results, they reported that DPOAEs were not significantly correlated with PTA results and cannot be used as an objective measure of pure- tone thresholds in early NIHL. Medial olivocochlear reflex strength before the beginning of chronic exposure to occupational noise has no relation to individual vulnerability to NIHL. Although TEOAEs changes after 1 year showed high sensitivity in predicting NIHL after 2 years of exposure, they cannot be recommended as an efficient screening tool due to high false-positive rates (Shupak 2007).

Helleman et al. assessed the hearing status of workers (N = 233) in a printing office twice within 17 months by pure-tone audiometry and otoacoustic emissions (OAEs) in a longitudinal study design. The objective of this study was not so much in evaluating the diagnostic quality of OAEs but more so if OAEs are useful in monitoring hearing in a

hearing conservation program. The authors wanted to know how a quality criterion of OAE-measurements based on a minimum signal-to-noise-ratio (SNR) would affect the applicability on the entire population. Secondly, effects of noise exposure were investigated in overall changes in audiogram and OAE-measurements. For TEOAEs in the frequency band of 4 kHz, only 55% of the data points met the SNR-inclusion criterion. For DPOAEs (distortion product OAEs) around 6 kHz approximately 80% of the data points satisfied the criterion. Thus OAEs have a limited applicability for monitoring the hearing status of this entire population.

Audiometry showed significant deteriorations at 6 and 8 kHz. TEOAEs showed a significant decline at all frequency bands (1-4 kHz), DPOAEs between 4 and 8 kHz and less pronounced between 1 and 2 kHz. On group level, OAEs showed a decline in a larger frequency region than the audiogram, suggesting an increased sensitivity of OAEs compared to audiometry. The authors noted that OAEs can only be used as a monitoring tool for a subset of the population investigated in this study. The use of an inclusion criterion based on the signal-to-noise ratio of the emission resulted in a large amount of subjects for whom the emission in the high-frequency area cannot be tracked in time. This means that pure-tone audiometry is indispensable when there is a pre-existing hearing loss and/or when the OAEs at start are too low. Occupational Health Officers should be made aware of this limitation before OAEs are considered as a replacement for conventional audiometry in hearing conservation programs. Monitoring is only possible when there is room for deterioration! (Helleman 2010)

Summary

No systematic review of the diagnostic validity of OAEs compared to PTA was found in the literature.

We did find a high amount (n=18) of single studies analysing the diagnostic quality of TOAEs and DPOAEs compared to PTAs in relation to NIHL. The number of participants in these studies ranged from 27 to 521. All studies focussed on the ability of OAEs to diagnose NIHL not to quantify the hearing loss.

We found 7 studies with a cross-sectional design with 6 studies reporting positive diagnostic validity for both TOAEs and DPOAEs in comparison to PTA. One study

reported that TOAE and DPOAE had a strong correlation with each other and on group level they both correlated well with PTA. However, on individual level no good correlations were found for either TOAEs or DPOAEs.

We found 2 cross-sectional studies with better results for DPOAE compared to TEOAE for diagnosing NIHL. There were 3 cross-sectional studies that analysed only DPOAE and found good results for diagnosing NIHL in comparison to PTA. The best results were found around 4kHz.

1 cross-sectional study analysed the diagnostic validity of TOEAs and found that it could be a good tool to use for screening those with higher risk for developing NIHL. This is explained that both TOAEs and DPOAEs measure the quality of the outer hair cells which may be affected by noise before increased thresholds can be measured with the PTAs.

We found 5 longitudinal studies, with 4 studies analysing the diagnostic quality of DPOAEs. Three out of these four found positive results for using DPOAEs as a screening tool, and one study reported that using DPOAEs is not good as screening tool because of the high amounts of false positive results. One longitudinal study looked at both DPOAEs and TOAEs and found on group level that both tools could be used as screening measurement because of the increased sensitivity. However, the authors warned that both OAE tools should only be used as screening tool for those workers who start without any NIHL, otherwise PTA should be used.

Auditory Evoked Potentials

- What is the diagnostic value of cortical evoked potentials (CERA) in comparison with pure tone audiometry (PTA) for people with NIHL?

- What is the diagnostic value of brainstem evoked potentials (BERA) in comparison with PTA for people with NIHL?

Five papers were identified which addressed CERA versus PTA. Only three particularly focussed on NIHL.

One older study by Coles et al. focussed on analysing the value of CERA in medico-legal investigations. They conducted CERA in 118 medico legal cases and compared results with PTA. They found that for true organic hearing loss cases only 4.4 % showed a difference between PTA and CERA of more than 7.5 dB. For the pseudohypacusis cases 35.1% showed a difference of more than 7.5 dB. The authors also mentioned that a flattening of the dip in the audiogram is suspect for pseudohypacusis (Coles 1984).

A large study with 1154 participants compared CERA testing in the assessment of NIHL with PTA. They assessed The participants were between 20-85 years, with average of 41 year; 673 underwent CERA and all underwent PTA. Pure tone averages were calculated using 500 Hz, 1kHz, 2kHz and 4 kHz. A PTA of > 20dB was considered significant for hearing disability (Irish hearing disability assessment system). PTA were also calculated at 3 kHz according to AMA system, with > 25dB being considered as hearing disability. Exaggerated hearing thresholds were considered to be present when the average threshold results obtained by CERA were > 10dB better than the PTA over 500 Hz, 1kHz, 2 kHz and 4 kHz. Results showed that approximately 25% had exaggerated hearing threshold levels (Hone 2003).

Tsui et al. analysed differences in thresholds estimated by CERA and by PTA. Results from 204 claimants (408 ears) with reliable PTA and CERA records showed mean discrepancy values between PTA and CERAT of less than 5 dB at high frequencies. Over 83.2% of claimants had a CERA and PTA threshold discrepancy within 10 dB. Results suggested that although CERA threshold measurement could not accurately predict PTA

in all cases, it could still be used as an objective guideline to rule out the presence of a non-organic component in hearing disability compensation claimants (Tsui 2002).

Two other studies focused more on comparing CERA with PTA for adults in general. One small study by Lightfoot et al. analysed the accuracy and efficiency of CERA in 24 volunteer subjects compared to PTA. Establishing the 6 threshold estimates took an average 20.6 minutes. The mean error in the CERA threshold estimate was 6.5 dB, with no significant effect of frequency. After correcting for this bias, 94% of individual threshold estimates were within 15 dB of the behavioural threshold and 80% were within 10 dB. The authors concluded that CERA has a performance that is as good as or better than BERA for threshold estimation in adults and that sophisticated stimulation techniques do not appear to be required. An efficient test protocol that automates many laborious tasks reduces the test time to less than half that previously reported in the literature for this response (Ligtfoot 2006). Another small study by Wong et al. found good test results for CERA compared to PTA and Cantonese hearing in noise test (CHINT). They tested 30 adults with normal hearing to profound sensorineural hearing loss. Speech thresholds were measured using the CHINT in four conditions: quiet, noise from the front, noise from the right, and noise from the left. CERA thresholds were measured at 0.5, 1, 2, and 4 kHz in both ears. Results showed that most participants had speech thresholds in quiet within +/-10 dB of pure-tone averages, and had CERA thresholds within +/-15 dB of pure-tone thresholds. Speech and CERA thresholds were highly correlated ($p<0.01$) with pure-tone behavioural thresholds (Wong 2008)

There were only a few studies focussing on NIHL and ABR in comparison to PTA. The majority of studies concerned animal tests, or children. We looked at three studies. Noorhassim 1996 et al. analysed the correspondence between ABR and PTA. For their study they used 22 participants with diagnosed NIHL and found that abnormal wave patterns were found in 72% of the ears. There conclusion was that ABR could be useful in diagnosing NIHL but larger sample sizes would be necessary. Another study by Xu et al. focused on the differences between ABR and TOAE for different age groups and with different levels of NIHL. They looked at 22 patients with NIHL and compared them to 21 controls. Based upon the hearing loss at 4, 3, 2 and 1 kHz on the pure-tone audiogram,

they were classified into four groups NIHL. With increasing hearing losses and extension of the involvement from 4 to 1 kHz in pure-tone audiometry, the objective TEOAE figures (presence of TEOAE, TEOAE-noise, percentage reproducibility and SNR) became lower and the objective ABR data (presence of wave I and I/V amplitude ratios) showed lower figures. (Xu 1998)

Another study by Beattie et al. focussed on an older group of participants (mean age 68 years) to compare ABR with PTA. They found that ABR was more accurate in the higher frequencies with differences between 25dB and 15dB with PTA results. (Beattie 1988)

Summary:

We found 5 studies evaluating the diagnostic value of CERA in people with NIHL in comparison to PTA. All studies had a cross-sectional design and showed good results (majority within 10 dB) for threshold testing. One large study (Hone 2003) particularly mentioned that CERA gives good results when exaggerated hearing thresholds can be found of more than 25dB at 500Hz. We hardly found any study focusing on ABR and NIHL. Of the three studies discussed reasonable results were found for ABR, however they were both very small cross-sectional studies. All other studies focussed on ABR in children or animals.

Auditory Steady State Response (ASSR)

- What is the diagnostic value of auditory steady state response (ASSR) in comparison with PTA for people with NIHL?

- What is the diagnostic value of auditory steady state response (ASSR) in comparison with CERA or BERA for people with NIHL?

We found one systematic review that addressed the first question. This review by Thlumak et al. looked at 56 studies regarding use of ASSRs for children from 6 years and older and adults. It did not particularly focus on NIHL, although some of the included studies did. Their main findings were:

(1) 80-Hz ASSR is a reasonably reliable method for estimating hearing sensitivity in the mid-to-upper conventional audiometric frequencies in both the normally hearing and in the hearing impaired population;

(2) accuracy of threshold estimation via 80-Hz ASSR-ERA suffers toward the lower audiometric extreme;

(3) more accurate threshold estimations via 80-Hz ASSR-ERA are obtained as carrier frequency increases in the hearing impaired population;

(4) electrode position (vis-a`-vis commonly used montages for recording ASSRs evoked at modulation rates at/above 80 Hz) is not related to MTDs at any carrier frequency in the normally hearing and in the hearing-impaired population;

(5) assuming validity of comparisons across ASSR-ERA studies using 80 vs. 40 Hz (vis-a`-vis methodological differences, etc.), threshold estimates follow results of ERA using conventional short- versus middle-latency transient-evoked responses, namely improved accuracy of threshold estimation using 40 Hz when testing at lower carrier frequencies (e.g. 0.5 kHz).

Other findings were (these were more contrasted by other studies in the literature)

(6) more accurate threshold estimates via 80-Hz ASSR-ERA might be obtained with the use of AM tones than MM tones in the hearing-impaired population;

(7) there appear to be practical limits of the number of sweeps in signal averaging of the 80-Hz ASSR (at least in the hearing-impaired population); and

(8) there are differences between 80-Hz ASSR MTDs found between stimulus conditions MMF and BMF (at least in the hearing-impaired population).

We looked at three more studies to address the first question regarding ASSR that were not included in the review.

Hsu 2003 et al. evaluated in a small cross-sectional design study the difference between steady-state evoked potential (SSEP) and PTA in 11 patients with noise-induced hearing loss (NIHL). The results showed that SSEP thresholds predicted pure-tone thresholds with correlation coefficients (r) of 0.86, 0.92, 0.94 and 0.95 at 500, 1000, 2000 and 4000 Hz respectively. Typically, the SSEP thresholds overestimated the pure-tone thresholds by 10-20 dB, but they closely reflected the configuration of the audiogram. The strength of the relationship between SSEP and pure-tone thresholds increased with increasing frequency and increasing degree of hearing loss. The authors concluded that SSEP can be used as a reliable and objective tool to assess auditory thresholds in patients with noise-induced hearing loss with high-frequency dips.

Lin et al. compared multi-channel ASSR with PTA in 142 adults with sensorineural hearing loss. They found a difference of less than 15 dB in 71 % of patients, while a difference of less than 20 dB was found in 83 %. Correlation between ASSR thresholds and pure tone thresholds, expressed as the correlation coefficient (r), was 0.89, 0.95, 0.96 and 0.97 at 500, 1000, 2000 and 4000 Hz, respectively. The strength of the relationship between ASSR thresholds and pure tone thresholds increased with increasing frequency and increasing degree of hearing loss. The prediction of pure tone thresholds based on the ASSR regression lines were all within 10 dB of the actual recorded pure tone thresholds. The average multi-channel ASSR test duration was 42 minutes per patient. Similar results were found in a smaller study by Herdman et al. who compared multiple ASSR test results with PTA in 31 adults with NIHL. They found that ASSR thresholds were on average less than 20dB above the PTA thresholds, with better results for the higher frequencies. For

those people with steep sloping audiograms the multiple ASSRs did not underestimate PTA thresholds.

Canale et al. analysed ASSR results in comparison with PTA in a very small group of 11 subjects, 6 with normal hearing and 5 with hearing loss. They found that the mean threshold difference between PTA and ASSR was 28 dB (SD 14.2) and the Pearsons correlation test value at 0.5, 1, 2 and 4 kHz was 0.71 (p=0.00012).

These differences were significantly smaller for the hearing-impaired separately (11.7 dB). The authors concluded that that ASSR is an accurate predictor of the behavioural audiogram in patients with sensory-neural hearing impairments and can be used as a valid support for behavioural evaluations. However, they also agreed that the relatively elevated difference between the two thresholds in normal hearing does not permit the utilization of the test for medico–legal reasons in which an objective determination of the true hearing threshold is necessary. The ASSR could be used to confirm the PTA threshold for compromised frequency, but should not be used to distinguish the hearing-impaired people from those that simulate.

ASSR compared to other diagnostic tools

We looked at two studies that compared ASSR with ABR:

This same study by Lin et al. also measured whether ASSR was a better testing method than ABR in adults with sensorineural hearing loss. The researchers used the same 142 subjects with varying degrees of sensorineural hearing loss, and evaluated the loss at 500, 1000, 2000, 4000 Hz. All subjects received PTA, multi-channel ASSR, and ABR tests for threshold measurement. Between multi-channel ASSR and pure tone thresholds, a difference of less than 15 dB was found in 71% while a difference of less than 25 dB was found in 89% of patients. The correlation coefficient (r) of multi-channel ASSR and pure tone thresholds were similar as stated previously. On the other hand, between ABR and pure-tone thresholds, a difference of less than 15 dB was found in 31%; a difference of less than 25 dB was found in 62% of patients. The r correlation value for ABR and pure tone thresholds was 0.83. The authors concluded that ASSR is a more reliable test for the accurate prediction of auditory thresholds than ABR (Lin 2009).

Johnson et al. evaluated (ABR) thresholds in comparison with ASSR and PTA in a group of 14 adults with normal hearing, 10 adults with flat, sensorineural hearing losses, and 10 adults with steeply sloping, high-frequency, sensorineural hearing losses. Evoked-potential thresholds were recorded at 1, 1.5, and 2 kHz and were compared with PTA thresholds. The predictive accuracy of two ABR protocols was evaluated: Blackman-gated tone bursts and linear-gated tone bursts presented in a background of notched noise. Two ASSR stimulation protocols also were evaluated: 100% amplitude-modulated (AM) sinusoids and 100% AM plus 25% frequency-modulated (FM) sinusoids. The results suggested there was no difference in the accuracy with which either ABR protocol predicted behavioural threshold, nor was there any difference in the predictive accuracy of the two ASSR protocols. On average, ABR thresholds were recorded 3 dB closer to behavioural threshold than ASSR thresholds. However, in the subjects with the most steeply sloping hearing losses, ABR thresholds were recorded as much as 25 dB below behavioural threshold, whereas ASSR thresholds were never recorded more than 5 dB below behavioural threshold, which may reflect more spread of excitation for the ABR than for the ASSR. In contrast, the ASSR overestimated behavioural threshold in two subjects with normal hearing, where the ABR provided a more accurate prediction of behavioural threshold (Johnson 2005).

The authors concluded that both the ABR and the ASSR provided reasonably accurate predictions of behavioural threshold across the three subject groups. There was no evidence that the predictive accuracy of the ABR evoked using Blackman-gated tone bursts differed from the predictive accuracy observed when linear-gated tone bursts were presented in conjunction with notched noise. Similarly, there was no evidence that the predictive accuracy of the AM ASSR differed from the AM/FM ASSR. In general, ABR thresholds were recorded at levels closer to behavioural threshold than the ASSR. For certain individuals with steeply sloping hearing losses, the ASSR may be a more accurate predictor of behavioural thresholds; however, the ABR may be a more appropriate choice when predicting behavioural thresholds in a population where the incidence of normal hearing is expected to be high.

Four studies compared ASSR with CERA; one study looked at differences between normal hearing and those with sensorineural hearing loss. The other three studies measured the hearing in either healthy subjects or different degrees of hearing loss.

Tomlin et al. measured evoked potential thresholds using the 40Hz auditory steady-state response (ASSR) and CERA at 500Hz and 4000Hz test frequencies in 36 subjects with normal hearing, and 30 subjects with sensorineural hearing loss. ASSR threshold sensation levels (SLs) were lower in ears with greater degrees of hearing loss, and for the 500Hz stimulus. Mean SLs (maximum duration of a single recording: 89 seconds) were as follows at 500Hz and 4000Hz respectively: normal hearing group, 16.9±10.3dB and 42.4±14.4dB; mild-moderate group, 10.6±8.8dB and 23.8±8.1dB; severe-profound group, 10.0±13.2dB and 21.5±18.9dB. CERA SLs showed no change with hearing level and CAEP/behavioural differences were similar at each test frequency. Mean SLs for CERA threshold (single recording duration: 84 seconds) at 500Hz and 4000Hz respectively were: normal hearing group, 10.3±6.4dB and 11.5±3.8dB; mild-moderate group, 8.4±7.4dB and 13.2±12.4dB; severe-profound group, 11.0±6.6dB and 15.9±16.4dB. The results of this study suggested that while both 40Hz ASSR and CERA can reflect the behavioural audiogram, CERAs may provide a more reliable estimate of hearing in awake adults. (Tomlin 2006)

Yeung et al. compared ASSR and CERA thresholds with PTA thresholds in 63 ears. For ASSR testing, 100% AM and 10% FM tone stimuli at a modulation frequency of 40Hz were used. Behavioural thresholds were closer to CERA thresholds than ASSR thresholds. ASSR and CERA thresholds were closer to behavioural thresholds at higher frequencies than at lower frequencies. Although predictions based on CERA thresholds are slightly more accurate than ASSR thresholds, the differences may not be clinically significant, particularly when the degree of individual variations is considered. Prediction of hearing thresholds became more accurate when hearing loss increased. Due to variations in prediction across participants, a single correction factor cannot be used. Other factors must be considered in selecting whether to use CERA or ASSR in predicting behavioural thresholds (Yeung 2007).

We looked at one study that compared two types of ASSR in both normal and hearing-impaired subjects (Wouters 2005). They compared a monaural single-frequency technique with a detection method based on phase coherence (AUDERA), and a binaural multiple-frequency technique using the F-test (MASTER). ASSR thresholds at four frequencies were assessed with both methods in both ears of ten normal hearing and ten hearing-impaired adult subjects, within test duration of one hour. The test-retest reliability and the influence of prolonging the test duration were assessed. For the total subject group the multiple-frequency technique outperformed the single-frequency technique. In hearing-impaired subjects, however, both techniques performed equally well. Hearing thresholds could be estimated with a standard error of the estimate between 7 and 12 dB dependent on frequency. About 55% of the estimates were within 5 dB of the behavioural hearing threshold, and 94% within 15 dB. Prolonging the test duration improved the performance of both techniques.

Summary:

We found one comprehensive systematic review that evaluated the value of ASSR in comparison with PTA when diagnosing hearing loss in adults and children. The review had looked at 56 studies and found that ASSR shows good test results mainly when there is a higher degree of hearing loss and for the higher frequencies.

In addition we evaluated 8 recent studies that focussed on the ability of ASSR to diagnose hearing loss thresholds compared to PTA in adults.

Three studies compared ASSR with PTA and found that there is a discrepancy between the thresholds measured with ASSR and with pure tone thresholds. However, the difference is within 20dB and becomes smaller with increasing degree of hearing loss and or higher frequencies.

Five studies measured ASSR hearing thresholds and CERA or ABR thresholds in relation to pure tone thresholds. Compared to CERA the ASSR was not considered superior in 2 out of the 4 studies. Compared to ABR, one study concluded that ASSR was superior. The other study (Johnson et al.) measured better accuracy for ABR than for ASSR except for those with steeply sloping hearing losses. However, ASSR overestimated behavioural threshold in two subjects with normal hearing.

We specifically focussed on studies that only included adults with sensorineural hearing loss or workers with NIHL. The majority of studies had a small sample size, and compared the test results in a cross-sectional design to PTA. In the majority of studies there was no mentioning of blinding the tester for the test results of the PTA. All studies described adequately the methods on how the test was performed. However, there are various methods for ASSR described and this makes it extra difficult to summarize the results. Also there is different equipment available that analyses ASSR such as the 'Audera' and the 'Master'. For the purpose of this review we decided not to analyse in more details the differences between these methods and equipment.

Comparison between countries and guidelines regarding the method of assessment

Country/ state	Time between noise exposure and PTA	Requirements of the audiometer	Who may perform test	What frequencies are tested	Other tests
UK	- preceded by more than 12 hrs since last exposure to noise (Incl. social noise)	- audiometer should be calibrated within the previous 12 months	- audiogram only by trained and qualified audiometrician -medical assessors are qualified to read audiograms	- Overall hearing loss measured by air conduction from 0.5 to 8kHz and up to 11kHz if necessary in order that the pattern of the audiogram can be seen. -If average loss is > 50dB for 1,2,3 kHz, then bone conduction is carried out.	CERA testing is recommended when: - the PTA is not confirmed as being precise and repeatable - there is a discrepancy between the PTA and the clinical findings of the Medical Adviser - in reassessment cases, there is apparent improvement in the level of hearing loss. -to calculate average sensorineural hearing loss over 1,2,3 kHz, bone conduction thresholds should be used if there is an appreciable conductive element in the hearing loss ie an air/bone gap of more than 10dB when averaged over 1,2 and 3 kHz
Taiwan		Audiometry must be performed in a certified hearing test booth (conducted within workplace) or in hospital with accredited facilities.	There is no strict staff qualification for the PTA performers, however, they are usually trained for some period of time or either they are technicians recognized by ENT specialists in that hospital.	0.5, 1, 2 kHz	ABR (auditory brain evoke potential recording) or sometimes OAE,SSEP were used to further verify or certify the severity or nature of the hearing loss
Hong Kong				1,2,3 kHz	The present protocol includes optional objective tests such as the acoustic reflex threshold (ART) test and distortion-product otoacoustic emission (DPOAE), which are frequently performed but have no official status to support PTA results.
Singapore	at least 14 hrs noise free	- the audiometric examination should be conducted in a proper acoustic environment by a trained person		Thresholds are measured for 1,2 and 3kHz	- Objective tests may be used as and when to help in the assessment of hearing loss.
British Columbia	at least 24-48 hours		- a medical officer, staff audiologist	0.5, 1, 2 kHz	- CERA testing is also included

			or adjudicator employed by the board make a preliminary evaluation		
Ontario	worker must be out of noise for at least 12 hours (occupational and recreational)	- WSIB doesn't lay out requirements for the hearing assessment but relies on the information provided by regulated treating practitioner, including audiologists and physicians		-0.5, 1,2, and 3 kHz	Assessment includes manual PTA, 25-word standard list speech recognition.
Washington	- preceded by at least 14 hrs without high levels of noise (occupational or non-occupational)	- performed in a sound-proofed room meeting current ANSI standards - obtained from equipment calibrated to current ANSI standards	- performed by a licensed audiologist, an otolaryngologist or other qualified physician or ARNP or by a certified technician responsible to one of the above,	- 0.5, 1,2, and 3 kHz	- none mentioned
Germany			Qualified are ENT physicians or specialists for occupational medicine.		Speech and Tone Audiometry are used. For further examinations also tympano scopy or stapedius reflex are used. Normally CERA, BERA; ASSR or OAS are not used. However for special questions they could be necessary.
France	- three days at least noise free	Tonal audiometry is performed in soundproofed rooms.		0.5, 1, 2, and 4 kHz	
The Netherlands				0.25, 0.5, 1,2,3,4,6 and 8 kHz	- speech audiometry, speech in noise, STI, and sometimes OAE
Finland		the equipment must be qualified: diagnostic level audiometry device and qualified sound proof room	schooled audiometrician	0.5,1,2,4 kHz	Always include PTA; in most cases speech audiometry is measured but it is not mandatory except when results PTA are considered unreliable or there exists any other complicating questions. BERA, middle ear impedance measures or OAE are rarely registered.
Guidelines					
The Australian Society of Otolaryngology, head and neck surgery (Victorian	- there must be an interval of no less than 16 hours between the last noise exposure and the audiogram		- The assessment should be carried out as set out in the Ministerial Directive Accident Compensation Act 1985 for a work related event.	- Based on the NAL report No 118 Jan 1988: .5,1 ,1.5,2, 3 and 4 kHz and may be extended to 6 and 8 kHz.	- impedance and speech audiometry - If there is uncertainty as to the accuracy of the audiogram, CERA testing plus a repeat audiogram are indicated; they should also included the 6 required frequencies

section) 2010 draft					
AMA 4th edition		audiometer calibrated according to ANSI standards S3.6-1996 reference levels		- 0.5, 1,2 and 3 kHz	
AMA 5th edition; with the modifications by WorkCover NSW: "Guides for the Evaluation of Permanent Impairment- second Edition"		audiometer calibrated according to ANSI standards S3.6-1996 reference levels	Assessment must be undertaken by ENT specialist and the assessment needs to be in accordance with Table 11-10 (AMA 5). Only medical specialists can sign medical reports.	0.5,1,2 and 3 kHz	
AMA 6th edition		audiometer calibrated according to ANSI standards S3.6-1996 reference levels		-0.25,0.5,1,2,3,4,6,8 kHz	"There are more sophisticated and specialized tests, such as BERA, electrocochleography, or oto-acoustic emission tests and middle ear impedance measurement. These tests along with other medical evaluation are used by otologists to help determine the nature and specific cause of hearing impairment in selected individuals".

What do foreign countries use as diagnostic tool in diagnosing noise induced hearing loss?

All countries contacted use PTA as the gold standard to diagnose noise induced hearing loss (NIHL). All countries have a protocol on how, by who and when the PTA can be done for claimants of NIHL. In a few countries the new more objective audiometry tests are used when there is any doubt on the accuracy of the PTA. No country uses these tests as a standard tool.

We found that the UK and British Columbia have CERA as alternative test. The UK has a clearly written protocol when this should be used:

UK (source: Occupational Deafness by Department for Work and Pensions Social Security Administration Act 1992)

The Advantages and Disadvantages of CERA

CERA is not a superior test to PTA in all respects, as is sometimes suggested. Both methods of testing have their benefits. PTA is a more sensitive means of identifying hearing thresholds than CERA, so it remains the method of choice in assessing the threshold of hearing loss. Towards the hearing threshold the CERA signal becomes submerged in background signals so that the tracing can only be read to within 20 to 30 dB of the threshold. Mathematical techniques are then used to give the definitive readings. CERA provides acceptable readings when readings are impossible to obtain by PTA. If the PTA is precise and repeatable then the PTA readings are likely to be more accurate than the CERA readings. Where the PTA is unreliable, due to the subject having difficulty in complying with the test, then CERA is the preferred test in that results can be obtained without the subject having to do anything other than lie still. CERA helps to clarify the true level of hearing threshold when there is ambiguity between PTA readings. CERA cannot discriminate as clearly as PTA between conductive and sensorineural hearing loss thresholds. If there is believed to be a conductive element to the hearing loss large enough to affect the diagnosis of PD A10, then a specialist's opinion may need to be obtained in order for the Decision Maker to have adequate evidence on which to base a decision.

Appropriate use of CERA

There are circumstances where those advising decision-makers require further information than is available from the current medical evidence. The Medical Adviser has to decide whether to use his/ her own expertise or if he/ she requires a specialist opinion. There are certain circumstances where CERA may provide the information that the decision maker requires.

CERA may be useful where:

- the PTA is not confirmed as being precise and repeatable
- there is a discrepancy between the PTA and the clinical findings of the Medical Adviser
- in reassessment cases, there is apparent improvement in the level of hearing loss.

CERA is unlikely to be useful where:

- the shape of the audiogram does not conform to the pattern for occupational deafness. However, this is discussed.
- PTA is not precise and repeatable: The audiometrician is expected to state how precise and repeatable the customer's audiometric responses were, and whether the audiogram was consistent with the audiometrician's informal observations. The Medical Adviser should not consider the case unless these sections have been completed, and should obtain a CERA if there is any doubt as to the reliability of the PTA.
- Inconsistency between audiogram and clinical findings: The clinical hearing tests are a useful means of confirming that the audiometric findings are reasonably consistent with the perceived level of hearing loss. If a person's hearing distance for a conversational voice (CV) is 1 metre, for example, their hearing loss should be about 60dB [approx 40% disablement]. If his hearing distance for a CV is 2 metres the loss should be about 50 dB [20% disablements]. These are approximate guides, and should not be treated as anything else, but Medical Advisers should carry them out in all cases and be prepared to question the validity of audiograms if they are not reasonably consistent with the clinical findings [e.g.. hearing loss 60dB on audiogram but hears conversational voice well over two metres away]. Where there

is substantial incompatibility the Medical Adviser's suspicions should be aroused. CERA can provide useful additional evidence on which to base advice.

- Reassessment Cases - Apparent improvement in hearing loss: When a Medical Adviser has to advise on the claim again and there is an apparent improvement in the hearing loss, the Medical Adviser should conduct a clinical examination of the claimant, and consider all the evidence carefully before deciding on further action. If the new audiogram is confirmed as being precise and repeatable, the shape of the audiogram fits the pattern of NIHL and clinical observations fit with the PTA findings, then the Medical Adviser would be expected to give advice based on the PTA readings.

If there is any ambiguity in the newer findings whether in the reliability or shape of the PTA, or on clinical observation, then the Medical Adviser will need to obtain further evidence on which to base his/ her advice as follows:

- If the first assessment was based on a consultant report then it is recommended that a further consultant report should be requested, authorising the consultant to obtain CERA.

If the first report was based on an audiometrician's report without a consultant opinion then the Medical Adviser may wish to request CERA itself to help identify which set of figures is more accurate. The Medical Adviser should always comment on the difference between the two assessments, and explain why the newer set of readings should be accepted or rejected.

- Irregular shape of audiogram: There is a recognised shape to the audiogram in sensorineural hearing loss due to exposure to noise. The audiogram should have readings at the 500Hz, 1kHz, 3kHz, 4kHz, 6kHz and 8kHz.

Features consistent with occupational hearing loss include:

- Maximum deficit in the 4kHz to 6kHz range
- Bilateral Symmetry

The typical audiogram of noise-induced hearing loss has a characteristic notch in the 4-6 kHz range. This notch may be obscured by the effects of presbycusis. If the maximum hearing deficit occurs in the 0.5-3.0 kHz range or if there is an apparent profound hearing loss across the hearing range then the Medical Adviser will need to seek further information. Our guidance is that a consultant's opinion should be sought on the nature of the hearing loss. The specialist may require a CERA, and this should be authorised at the time the request for a consultant report is made. If a Medical Adviser requests a CERA, and this confirms the PTA reading indicating an additional pathology, further delay will be incurred as a specialist opinion will then be required. Bilateral symmetry - The audiograms for both ears should be roughly symmetrical. If they are asymmetrical then the possibility of other pathology should be considered as a consultant report may be required, rather than relying on further requests for audiometry.

Conclusion

Medical Advisers have always adopted a logical approach in assessing claims for occupational deafness, basing their assessment on the PTA in most cases, but taking into account their observations of the subject's voice hearing ability, clinical findings, and features of the PTA, and being prepared to seek additional information or a specialist opinion where necessary. It is hoped that these guidance notes will clarify the usefulness of CERA, so that the Medical Adviser can decide whether to request further tests or to seek a specialist opinion on a more informed basis.

Hong Kong uses the acoustic reflex threshold in rare cases or the DPOAE. We found an article by Chan 2004 who described this as follows:

"The present hearing test protocol of the Occupational Deafness Medical Committee uses pure-tone audiometry (PTA) as the gold standard for measuring hearing sensitivity. The present protocol includes optional objective tests such as the acoustic reflex threshold (ART) test and distortion-product otoacoustic emission (DPOAE), which are frequently performed but have no official status to support PTA results. The present hearing test protocol requires the reliability of all hearing test results to be assessed by the Occupational Deafness Medical Committee. The inclusion of an objective screening tool

with validated criteria may assist in determining the reliability of individual results. Such a procedure may serve as an indicator of the likelihood of applicants meeting the hearing loss requirements, helping in the determination of full assessment appointment priorities.

The Netherlands

PTA is used as gold standard with the addition of some other audiology tools such as: Speech audiograms, speech in noise measurements, speech transmission index and direction hearing measurements. In rare cases otoacoustic emissions are measured. However, this rarely happens for workers with NIHL. In the Netherlands particular attention is focussed on the demands on hearing in the work situation. For example, working in construction could mean that the worker needs to be able to hear beep sounds coming from a truck that is entering the construction site. The occupational physician with assistance from specialists in audiology and/ or ENT specialists will make a profile of the hearing demands from the workplace and the hearing abilities of the worker. In agreement with all parties a plan is made how the particular worker can keep doing his job despite the hearing problems.

Our contacts from Germany, Singapore, France and Washington all reported that PTA is the gold standard for measuring hearing thresholds in workers with potential NIHL. Speech tests are usually also mentioned as extra options for testing hearing in workers. The described objective tests in this project are not (yet) used in these countries.

Conclusion and Recommendation

There are various more objective tools to measure hearing loss besides PTA. With regards to NIHL there are five new methods that could be used: DPOAE/TOAE, CERA/ABR and ASSR. None of these methods can differentiate between an occupational or non-occupational cause of hearing loss.

All five methods have their own advantages and disadvantages. See table 1.

Regarding oto-acoustic emissions (OAEs):

Based on 18 single studies only, and with a majority (n=13) having a cross-sectional design, evidence suggests that both types of OAEs have reasonable comparable results with pure tone audiometry (PTA) for diagnosing NIHL. However, the biggest disadvantage of OAEs compared to PTA is that they are not fully able to detect the degree of hearing loss. OAEs do not measure frequency specific thresholds; a response to a signal is either there or not there. This makes the use of OAEs less helpful for diagnosing NIHL for compensation purposes. Their biggest advantage may actually be their high sensitivity for noise damage to the outer hair cells and therefore have more potential to be used as a screening tool instead of diagnostic tool for compensation purposes. More research is necessary to confirm this potential use, as limitations have been mentioned (Helleman 2010).

At this stage we cannot say if distortion product OAEs (DPOAEs) should be preferred over transient OAEs (TOAEs), although it seems that DPOAEs may be more frequency specific than TOAEs according to two studies, which was not confirmed in any of the other studies (n=15). Only in the Netherlands it seems that OAEs are sometimes used for diagnosing hearing problems with adults, but this country does not have a similar system of compensation for NIHL as Australia. Other countries that were included in our questionnaire do not mention using this tool in diagnosing NIHL for compensation purposes.

Regarding cortical evoked response audiometry (CERA) and brainstem evoked response audiometry (BERA/ABR):

We found that CERA and BERA were evaluated to a lesser extent as a diagnostic tool than OAEs in relation to NIHL. There were 5 cross-sectional studies that evaluated CERA in comparison to PTA, and all found reasonable comparable results for CERA (within 10dB difference with PTA thresholds). CERA can measure frequency specific thresholds over the speech frequency range of 0.5 kHz - 4 kHz. This suggests that CERA could be a useful tool in diagnosing NIHL for compensation purposes. Its biggest problem is that the results can be influenced by the state of the patient; he/she needs to be awake and cooperative.

The UK and British Columbia use CERA when the PTA gives unclear results. The use of CERA is also recommended by the guidelines of the Australian ENT specialist organisation.

We found only 3 very small studies that evaluated the quality of BERA/ABR in diagnosing NIHL. All three studies had reasonable results compared to PTA. The biggest disadvantage of BERA/ABR is that only low amplitude responses can be measured and therefore any small movement of the patient may gives a lot of disturbance. The patient should actually be asleep to achieve the best results. Further issues are that click ABR is not frequency specific, and tone burst ABR can measure thresholds only in the higher frequency range of 2 kHz- 4kHz. It also takes a very long time to measure a frequency specific threshold with tone burst ABR. ABR/BERA have their biggest advantage in differential diagnostic purposes; such as differentiating between cochlear and retro-cochlear pathology. The majority of studies regarding ABR and hearing loss evaluation involved children or animals. Only Taiwan mentioned potential ABR use for NIHL claims.

Regarding ASSR:

For ASSR we found a systematic review that had included 57 single studies. These studies involved both children and adults with or without hearing loss. The conclusion of this review suggested that ASSR can be a reasonably reliable method for estimating hearing thresholds. However, as with ABR, the measured amplitude of the response is also relatively low and therefore there is a high variability in the responses to the stimuli. Results of the review showed that ASSR is more accurate in the higher frequencies and for higher amounts of hearing loss. The three extra single studies that were included in this

review confirmed the potential of ASSR in diagnosing NIHL. The advantage of ASSR is that the calculation of the thresholds is done mathematically. We found five studies that compared ASSR to CERA or BERA but the results of these studies could not show a clear advantage of ASSR over CERA or BERA. Because ASSR is a fairly new diagnostic tool it is not yet used for medico-legal decisions regarding NIHL in any of the countries.

Conclusion:

For the diagnosis of NIHL for compensation purpose the use of pure tone audiometry (PTA) is considered the most accurate diagnostic tool. Recent literature has not changed this view and all foreign countries asked for this project, agreed that PTA is the recommended choice for this purpose. Cortical evoked response audiometry (CERA) seems to be the best alternative to objectively measure the actual hearing threshold. Literature suggests that this method gives accurate and comparable results as PTA. It can measure hearing loss thresholds over a broad frequency range and is helpful in cases of exaggerated hearing loss.

Recommendation:

We recommend the use of pure tone air and bone audiogram for the accurate diagnosis of noise induced hearing loss for workers compensation purposes. The audiogram should include the 6 frequencies: 0.5, 1, 1.5, 2, 3 and 4 kHz as described in the ASOHNs guidelines (concept 2010). We recommend complying with the Australian standards for the calibration of the audiometer and the sound proof room. We recommend 16 hours as minimum time between noise exposure and assessment as described in the ASOHNs guidelines (concept 2010). In cases where there is suspicion that PTA may not be giving a valid measure of hearing loss we recommend use of cortical evoked response audiometry (CERA) plus a repeat pure tone audiogram (PTA). These should both include the 6 required frequencies.

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- for Washington state: answers to questionnaire

- for UK: answers to questionnaire and from Department for Work and Pensions Social Security Administration Act 1992 (issue Nov 2002)

- for France: answers to questionnaire

- for Taiwan: answers to questionnaire

- for Netherlands: answers to questionnaire

- for Germany: answers to questionnaire

- for Ontario: answers to questionnaire and Policy 16-01-04 Noise-Induced Hearing Loss, On/After January 2, 1990 http://www.wsib.on.ca/wsib/wopm.nsf/Public/160104

or

Policy 16-01-03 Occupational Noise-Induced Hearing Loss (applies to accidents before January 2, 1990) http://www.wsib.on.ca/wsib/wopm.nsf/Public/160103

- for Finland: answers to questionnaire

- for British Columbia: answers to questionnaire

Other information via telephone conference with Gary Rance, Associate Professor at the University of Melbourne