PROTOCOL

Suggested guidelines for studying the combined effects of occupational exposure to noise and chemicals on hearing

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The present document, which describes recommended standardized procedures, aims to assist individual investigators plan a study on the effects of industrial chemicals on the auditory system, collect and analyze environmental and hearing sensitivity data that are accurate and comparable to data acquired by others. This draft document is currently being reviewed by the *NoiseChem* Research Group. In this peer review stage we are currently accepting critiques and suggestions to this proposal.

Investigations on the aforementioned topic are necessary since there is strong evidence that occupational hearing loss may be caused not only by noise but also by exposure to certain chemicals in the work environment. Since some industrial chemicals are known to be ototoxic, it is plausible to expect that if these chemicals occurred in high enough concentrations in the workplace they could affect hearing. Laboratory studies have yielded a finding not expected, namely that when simultaneous exposure to noise and chemicals occur, the hearing loss observed was greater than the expected hearing loss from noise added to the expected hearing loss from the chemical. If this synergism is verified in humans, then changes will be required in the limits that are set for occupational hazards in order to prevent occupational hearing loss.

Study Objectives

The main objective of this document is to assist in the design of field studies that aim:
(1) To determine whether exposure to selected chemicals at levels commonly found in industry affects workers' hearing.
(2) To determine whether these chemicals interact with noise in a way that the resulting hearing losses are not equivalent to the expected hearing loss from the noise exposure added to the expected hearing loss from the chemical exposure.
(3) To investigate adequate means to assess and prevent hearing disorders that may occur due to the exposures to be studied.

The identification of the mechanisms underlying the lesions shall not be part of this effort since it can be better addressed by laboratory animal research.

Literature Review/Background

The combined effect of noise and chemicals on hearing

The approach to isolate or vary a single parameter to determine an effect is often utilized in the investigation of occupational hazards and results in hazards being studied as if they occurred in isolation in the work place. In fact, most work environments are complex, consisting of a myriad of physical and chemical agents that are potentially hazardous to health. The results of studies of isolated work place hazards often are used to develop occupational safety criteria that may not be adequate for protecting workers in environments where simultaneous or sequential exposures to a variety of agents occur.

Over the past two decades, research on the effects that simultaneous exposure to noise and chemicals might have on the auditory system has increased significantly (Barregård and Axelsson, 1984; Bergström and Nyström, 1986; Johnson et al., 1988; Morata, 1989; Lataye et al, 1997, 2000; Teixeira et al, 2002; Morioka et al., 2000; Sliwińska-Kowalska et al., 2001, Morata, 2002).

In a 20-year longitudinal study of hearing sensitivity in 319 employees from different sectors of industry, a remarkably large proportion of the workers in the chemical sector showed pronounced hearing loss (23%) as compared to groups from non-chemical environments (5-8%) (Bergström and Nyström, 1986). This effect was found despite the lower noise levels in the chemical sector (80-90 dBA) when compared to other divisions (95-100 dBA). The authors Bergström and Nyström (1986) were among the first to suggest that exposure to industrial solvents (not identified in the article) could be implicated as an additional causative factor for those hearing losses.

Clinical studies have suggested that exposure to certain industrial chemicals can have retrocochlear effects. The hearing and balance of workers exposed to mixtures of aliphatic and aromatic solvents for periods ranging from 9 to 40 years have been examined (Ödkvist et al, 1987). Their scores on speech audiometry were lower than would be predicted by the person's pure tone audiogram (38-64% incidence of abnormality) and their cortical responses to frequency glides were abnormal (50-64% incidence of abnormality); however no effects were observed on the auditory brainstem responses (0-9% incidence of abnormality). Therefore, it was concluded that the auditory system might be vulnerable at cortical levels, as indicated by the speech discrimination test and the cortical responses, two of the most sensitive tests available today in detecting central auditory lesions at the cortical levels.

A study of 190 workers was carried out with rotogravure printing workers where the hearing and balance functions of groups of printers exposed simultaneously to noise and toluene were compared with a group of printers exposed to noise alone, a group exposed to a solvent mixture and a group neither exposed to noise nor toluene (Morata et al., 1993). The adjusted relative risk estimates for hearing loss were 4 times greater (95% C.I., 1.4 to 12.2) for the noise group; 11 times greater (95% C.I., 4.1 to 28.9) for the noise and toluene group; and 5 times greater (95% C.I., 1.4 to 17.5) for the solvents group. The acoustic reflex measurements suggested that the hearing losses found in the group exposed to both agents might be due to lesions beyond the peripheral auditory system.

Another study on printing workers (n=124) failed to detect an interaction of toluene and noise, other than addictive (Morata et al., 1997). Forty-nine percent of the workers had hearing loss. From the numerous variables that were analyzed for their contribution to the development of hearing loss, age and hippuric acid (the biologic marker for toluene in urine) were the only variables found to be associated with the outcome. The odds ratio estimates for hearing loss were 1.07 times greater for each increment of 1 year of age [95% CI 1.03-1.11) and 1.76 times greater for each gram of hippuric acid per gram of creatinine (95% CI 1.00-2.98). The findings suggest that exposure to toluene has a toxic effect on the auditory system. Since the workers who participated in the study had relatively short noise exposure time, it is likely that they have not been exposed long enough to allow for the noise effects to be detectable.

The relationship between self-assessed hearing disorders and occupational exposure to solvent mixtures was investigated in a cross-sectional design with 3284 men (Jacobsen et al., 1993). Exposure to solvents for 5 years or more resulted in an adjusted relative risk for hearing impairment of 1.4 in men without occupational exposure to noise. A sub-sample of 51 men was examined with pure-tone audiometry and 20 of the 21 men who reported abnormal hearing also were found to have a hearing impairment. Occupational exposure to noise had an effect twice that of solvents; and in the case of combined exposures, the effects from noise dominated.

A more recent study conducted in Poland examined 517 subjects, who were divided into three groups of unexposed workers, workers exposed to organic solvents only, and workers exposed to both organic solvents and noise (Sliwińska-Kowalska et al., 2001). Hearing thresholds were significantly poorer in a wide range of frequencies (1-8 kHz) for both groups exposed to solvents, when compared with the reference group. The mean hearing thresholds at frequencies of 2-4 kHz were poorer for workers exposed to solvents plus noise than for the solvent-only group; this finding suggested an additional effect for noise. The results indicate that occupational organic solvent exposure at moderate concentrations increases the risk of hearing loss, and the ototoxic effects should be considered when the health effects of exposed workers are monitored.

Selection of chemicals to be prioritized
A literature search will indicate that the chemicals that can be considered as ototoxicants as numerous (for a literature review of the effects of chemicals on hearing, see Rybak, 1992). For the purpose of elaborating this protocol, these chemicals were divided into priority lists. The placement of a chemical in the high priority category took into consideration available evidence of ototoxicity, severity of the problem, accessibility and number of occupationally exposed workers. The following is the priority ranking of the elements discussed.

HIGH PRIORITY OTOTOXINS

- *Toluene*
- *Xylenes*
- *Styrene*
- *n-Hexane*
- *Mixtures containing the above*
- *Trichloroethylene*
- *Lead and derivates*
- *Carbon Monoxide*
- *Cyanide*

ADDITIONAL OTOTOXINS

- *Mercury and derivates*
- *Stoddard Solvent*
- *Arsenic*
- *Carbon Disulfide*
- *Benzene*
- *Manganese*

The present protocol focuses on the study of the high priority list chemicals, although some of the recommendations such as hearing assessment procedures, noise assessment and data analysis strategies can be used in studies of other agents.

Magnitude of the problem
Two of the most common hazards that occur simultaneously in many work environments are noise and chemicals. It has been estimated by NIOSH that 30 million people are estimated to work in potentially hazardous noise levels, an estimates that includes workers in manufacturing, construction, agriculture (Franks, Stephenson and Merry, 1996). Approximately 10 million workers are exposed to solvents in the manufacturing sector where frequently noise is also a potential exposure (Morata, Dunn and Sieber, 1994).

At least one million workers in manufacturing have sustained job-related hearing impairment (defined as greater than a 25-dB average threshold hearing level at 1,2 & 3 kHz), and about half a million of these have moderate to severe hearing impairment (defined as greater than or equal to 40-dB average threshold hearing level at 1, 2 & 3 kHz (OSHA, 1981). The cost of workers compensation claims for hearing losses

Table 1. Power as a function of sample size and exposure

SAMPLE SIZE	EXPOSURE CONDITION Noise	Chemical	Both
180	0.62	0.63	0.70
190	0.64	0.65	0.73
200	0.66	0.68	0.75
210	0.68	0.70	0.78
220	0.70	0.72	0.80
230	0.72	0.73	0.82
240	0.74	0.75	0.84
250	0.75	0.77	0.86
260	0.77	0.78	0.88
270	0.78	0.80	0.89
280	0.80	0.81	0.90
290	0.81	0.83	0.92
300	0.82	0.84	0.93
Odds Ratio	2.02	2.14	4.11
R	0.57	0.62	0.61

Odds ratio and multiple correlation coefficients are calculated from the data of Morata et al, (1993). Calculations methods were based on Hsieh (1989).

thought to result from occupational noise exposure for the period of 1977-1987 has been estimated at 800 million dollars (Ginnold, 1979).

Regulatory Background

In 1983, the Occupational Safety and Health Administration (OSHA, 1983) promulgated the Hearing Conservation Amendment to the Occupational Noise Standard of 1971, which specified the components of a hearing conservation program. It requires that such a program be started if workers have an exposure of 85 dBA TWA or greater. A hearing conservation program must include an assessment of noise exposure, audiometric tests of exposed workers, noise abatement and/or administrative controls, maintenance of records on noise and hearing data, availability of hearing protectors and employment training and education.

In the United States as in many other countries, the only agent that is considered to be ototraumatic is high intensity noise. Therefore, there may be a large number of workers with unmet needs concerning hearing conservation. Currently, there are no regulations requiring monitoring of a worker's hearing due to occupational exposure to potentially ototoxic chemicals, but agencies as NIOSH and ACGIH have recommended that chemical exposure be taken into consideration when planning for hearing loss prevention measures (Franks, Stephenson and Merry, 1996; ACGIH, 2000).

Hitherto, despite the large number of workers exposed to these chemicals in the presence of background noise, few will be required to have regular hearing tests because the noise exposure may not exceed the regulatory guidelines. In addition, controlling chemical exposures is not seen as a necessary preventive measure, and it is not regarded for hearing conservation. Since there is strong evidence that exposure to these chemicals alone or in combination with noise can produce a hearing loss, it is very possible that current hearing conservation practices are not adequate for this population of workers. Some of the other issues these findings raise include the adequacy of pure tone audiometry testing in screening solvent-exposed workers, the appropriateness of the current threshold limits when certain hazards occur simultaneously in the work place, and finally, the role of hearing assessment as applied to the early identification of those most susceptible to neurotoxic disorders.

Research Methods

Study Design

Occupational hearing losses have a gradual onset and require neither reporting nor hospitalization, which makes it difficult to obtain incidence rates. However, prevalence rates are easier to obtain. Since there is neither recovery nor death from hearing loss, its prevalence rate is less biased than prevalence measures for other chronic conditions such as diabetes or heart disease. So, because of the nature of occupational hearing loss, a cross-sectional design is suggested, following the recommendations of several researchers (Elliot, 1978; Erdreich and Erdreich, 1982; Morata and Lemasters, 1995).

Populations to be studied

Groups of workers with various degrees of chemical exposure should be studied, in comparison with workers not exposed to chemicals. Noise exposure should be accounted for.

Sample size calculations were performed using data from Morata et al., 1993. The results of power calculations based on Hsieh (1989) are shown in Table 1. Morata et al. used logistic regression analysis and found significant exposure effects with 190 subjects. However, in order to get adequate power (.80) in all the exposure groups it is recommended that at least 280 subjects be used in a study of the mentioned topic.

Methods for Estimating Noise Exposure

Area surveys should be performed to estimate noise exposure. In an area survey, one measures environmental noise levels, using a sound level meter to identify work areas where workers' exposures are above or below hazardous levels, and where more through exposure monitoring may be needed. The result may be plotted in the form of a "noise map," showing noise level measurements for the different areas of the workplace. Dosimetry involves the use of body-worn instruments (dosimeters) to monitor an employee's noise exposure over the work-shift. Monitoring results for one employee can also represent the exposures of other workers in the area whose noise exposures are similar. It may also be possible to use task-based exposure methods to represent the exposures of other workers in different areas whose exposures result from having performed the same task (Franks, Stephenson and Merry, 1996).

When available, retrospective noise measurements should also be used to characterize noise exposure. For detailed procedures on noise measurements see Berger, et al., 2000.

Methods for Estimating Chemical Exposure

Until the chemicals to be studied are identified, the specific methods cannot be determined. However, for the case of the chemicals classified as High Priority, air sampling of the chemical should be conducted and, when possible, some form of biological monitoring.

Whenever reliable retrospective exposure records exist, they should be used for estimating past exposure. However, any attempt to quantify the worker's exposure will give only an estimate or approximation of the actual total work exposure.

Table 2. Biological monitoring tests for selected chemicals

Workplace exposure	Biological specimen	Substance analyzed
Toluene	Urine	Hippuric acid
Xylene	Urine	Methyl hippuric acid
Styrene	Urine	Mandelic acid Phenylglyoxylic acid
n-Hexane	Urine	2-Hexanol 2,5-Hexadione

Air-Sampling Methods for the Selected Chemicals

Personal air sampling is the preferred method of evaluating individuals' exposure to air contaminants (for detailed description see Plog, 1988). As with noise, exposure to chemicals should be determined with task-based measurements. It involves the collection of an air-sample by a small device worn by the subject. The sampling device is positioned as close as possible to the subject's breathing zone so data collected closely approximate the concentration inhaled. Active monitoring, with the use of air sampling pumps, should also will be considered.

Analytical procedures specify the collection media, sample volume, and chemical analysis. They can be found, for an extensive number of compounds, in the NIOSH Manual of Analytical Methods (1994). The first stage should be a direct-reading qualitative exposure assessment to ascertain all potential exposures (chemical phases) and ranges. The second stage involves quantitative exposure assessment of specific entities identified in the first stage. Since it is possible for dermal exposure to aromatics to yield higher doses than air samples, patch samplers should also be considered.

Biological Monitoring

Biological Monitoring involves the measurement of changes in the composition of blood fluid, tissues, or expired air to determine absorption of a potentially hazardous material. Biological monitoring should not be performed as a replacement of personal monitoring but may be used to complement it (Plog, 1988). Table 2 summarizes the biological monitoring tests for selected substances (for detailed procedures, see ACGIH, 2000-2001, Lauwerys and Hoet, 1993).

Interviews

An important element of most epidemiologic studies that investigate occupational illnesses is the development of a quality survey instrument. Questionnaire development information can be found in Morata and Lemasters, 1995.

Subjects should be interviewed with regard to health history, work history, chemical and noise exposure, including previous and non-occupational. A complete questionnaire should include demographic data, health history (focusing on hearing) and a work history that includes a job and work environment description and exposure to hazards history. A suggested protocol can be found in Appendix A. Major portions were extracted from a National Institute for Occupational Safety and Health, 1996 Questionnaire (Franks et al, 1996), combined with items from various clinical questionnaires.

Since the exposure to the selected chemicals has been associated with neurobehavioral and balance disorders (Ödkvist et al., 1980; Baker, Smith and Landrigan, 1985), the inclusion of portions in the questionnaire that investigate these functions is recommended (for sample questionnaires see Hogsted et al, 1984; Johnson, 1987).

Audiological Testing

A test battery should include pure tone audiometry (air conduction) and tests to complement it. Performing only pure tone audiometry will probably not be enough to meet the objectives of the investigation of chemical effects on the auditory system. The rationale for recommending complementary audiologic tests is that not only prevalence data but also descriptions of the pathologies should be sought. In addition, these minimum complementary tests may enable the research team to differentiate the effects of noise from the effects of chemicals. This information will probably lead to the generation of new hypothesis related to the lesions underlying mechanisms. Some alternative tests and procedures are described in Appendix B.

Data Analysis

The American Conference of Governmental Industrial Hygienists (ACGIH, 2000) alluded to the complexity of investigating industrial chemicals effects, by recommending careful review of audiometric data. The hearing loss from industrial chemicals can be very similar to the hearing loss from ototoxic drugs such as aminoglycosides and cisplatin, as well as to the hearing loss from noise. General descriptors of these disorders are very similar: bilaterally symmetrical, irreversible, high frequency (3 to 6 kHz) sensorineural hearing loss with damage mainly to cochlear hair cells. Comparison of these descriptors reveals how difficult it may be to make a differential diagnosis and to determine causation of hearing loss among workers. For a discussion on some of the alternatives available to researchers in addressing these challenges, see Morata and Lemasters (1995).

Mean audiometric thresholds should be obtained, but hearing outcome could also be treated as a binary outcome variable (normal hearing vs. hearing loss) when examining the relationship between the combined exposure to noise and chemicals and hearing. The prevalence of hearing loss between groups with different exposure conditions should be examined even if audiometric thresholds, by themselves, do not allow for easy identification of the effect of chemicals on hearing, and especially when pure-tone audiometry is the only available test.

The use of Statistical Analysis System (SAS) or other appropriate computer software is suggested for data analysis. Analysis of Variance (ANOVA) or regression analysis can be used for threshold data. Logistic regression can be used for binary outcomes. Confounding variables such as age, length of exposure, gender, previous and non-occupational exposures to the studied agents, use of ototoxic medications, smoking and drinking habits, should be controlled for.

Concluding Remarks

This draft document was submitted to the NoiseChem Research Group for review. This group consists of research institutions from seven different countries. One of NoiseChem's objectives is to examine study designs, hearing assessment alternatives, and strategies for the analysis of combined effects of noise and chemical exposures. Moreover, on the basis of agreed protocols, NoiseChem's goal is to conduct epidemiological studies on factory workers in Sweden, Finland, Poland, and the United Kingdom. In this peer review stage we are currently accepting critiques and suggestions to this proposal, which can be sent directly to the authors.

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APPENDIX A: SUGGESTED QUESTIONNAIRE

NoiseChem Questionnaire

Date:

PERSONNAL

Please leave blank any questions you do not understand or do not know the answer to. A researcher will go through your questionnaire with you

Name:

Age: yrs Weight: Kgs Height: cms

Please circle as appropriate

Sex: Male / Female

Eye Colour: Blue / Green / Brown / Other

Hair Colour: Blonde / Auburn / Black / Brown

Ethnic Origin: Caucasian / Asian / African / Caribbean

Left or right handed ? Left / Right

Do you sun tan easily? Yes / No / Unknown

Do you smoke?Yes / No
If Yes:
How many a day? day; For how many years? yrs
Have you ever smoked? Yes / No
If Yes:
How many a day? day; For how many years? yrs

Do you drink alcohol? Yes / No
If Yes:
How many units per week? Less than 5 units per week / More than 5 units per week

Have you been in the
Military / Air Force / Navy? Yes / No
If Yes:
For how many years? yrs

Did you use hearing protection? Aways / Often / Seldom / Never

Was your hearing affected by
the service? Yes / No / Unknown

Do you participate in any of the following ?

Hunting, Shooting Yes / No
If Yes:
How many times a month? month; For how many years? yrs

Motorcycling Yes / No
If Yes:
How many times a month? month; For how many years? yrs

Use of power tools Yes / No
If Yes:
How many times a month? month; For how many years? yrs

Playing a musical instrument? Yes / No
If Yes:
How many times a month? month; For how many years? yrs

Attending concerts, discos or clubs? Yes / No
If Yes:
How many times a month? month; For how many years? yrs

Diving Yes / No
If Yes:
How many times a month? month; For how many years? yrs

Are you exposed to solvents?
(e.g. building models, car repairs,
boat building, printing, painting) Yes / No
If Yes:
How many times a month? month; For how many years? yrs

MEDICAL

Please indicate whether you have OR have ever had in the past any of the following:

High blood pressure Yes / No / Unknown
Do you now or have in the past
taken medication for this ? Yes / No / Unknown

High Cholesterol Yes / No / Unknown
Do you now or have in the past
taken medication for this ? Yes / No / Unknown

Asthma Yes / No / Unknown
Do you now or have in the past
taken medication for this ? Yes / No / Unknown

Eczema Yes / No / Unknown
Do you now or have in the past
taken medication for this ? Yes / No / Unknown

Allergies Yes / No / Unknown
Do you now or have in the past
taken medication for this ? Yes / No / Unknown

Migraine Yes / No / Unknown
Do you now or have in the past
taken medication for this ? Yes / No / Unknown

Tuberculosis Yes / No / Unknown
Do you now or have in the past
taken medication for this ? Yes / No / Unknown

Kidney problems Yes / No / Unknown
Do you now or have in the past
taken medication for this ? Yes / No / Unknown

Diabetes Yes / No / Unknown
Do you now or have in the past
taken medication for this ? Yes / No / Unknown

White fingers Yes / No / Unknown
Do you now or have in the past
taken medication for this ? Yes / No / Unknown

Mumps Yes / No / Unknown
Do you now or have in the past
taken medication for this ? Yes / No / Unknown

Measles Yes / No / Unknown
Do you now or have in the past
taken medication for this ? Yes / No / Unknown

Meningitis Yes / No / Unknown
Do you now or have in the past
taken medication for this ? Yes / No / Unknown

Jaundice Yes / No / Unknown
Do you now or have in the past
taken medication for this ? Yes / No / Unknown

Head Injury Yes / No
If Yes
Were you unconscious ? Yes / No
If Yes
For how long ? minutes / hours / days

Acute poisoning Yes / No
If Yes
What type of poisoning ?

Colour vision problems Yes / No / Unknown

Any balance problems Yes / No
If Yes
How long do the attacks last ? seconds / minutes / hours / days / all the time

Do you now or have in the past
taken medication for this ? Yes / No / Unknown

Are you on any other long term
medication ? Yes / No
If Yes
Which medication ?

Do you regularly take painkillers ? Yes / No
If Yes
How many a day ? day; For how many years yrs
Are these on prescription ? Yes / No

APPENDIX B: HEARING EVALUATION
Description of Audiological Tests

Pure Tone Audiometry
In the United States, workers who are exposed to noise levels above 85 dBA are required by the Hearing Conservation Amendment (48 FR. 9776, Mar.8, 1983) to the US Occupational Safety and Health Act of 1970 to have their hearing tested periodically, by means of pure-tone air-conduction audiometry. Pure-Tone Audiometry (PTA) is a clinical test used to determine a person's hearing sensitivity at specific frequencies. While it is safe to assume that an individual is unaware of the presence of these tones if they are made less intense than his threshold, it cannot be assumed the tones sound clear, tonal, or as loud for him as for a normal hearing individual when they exceed his threshold. Pure tones simply evaluate the individual's hearing sensitivity at various selected points along the frequency continuum. The reason pure tone thresholds form the core of the hearing test battery is that these tones are easily generated, calibrated, and controlled. Additionally, pure tone audiometry, if performed properly, has a very high intraclinic and interclinic reliability (Lovrinic, 1980).

Since PTA is commonly used in industry, its use is recommended at the frequencies 0.5, 1, 2, 3, 4, 6, and 8 kHz. The subjects must be tested in a room that meets the background noise requirements of ANSI S3.1-1999 for audiometric testing environment. The equipment calibration records should be made recent and available, and biologic calibration checks should also be performed everyday immediately before testing the subjects.

Pure-tone audiometry could be extended to include the frequencies of 10, 12.5, 14 and 16 kHz.

The effects of ototoxic substances and/or noise may be initially detected at frequencies above 8 kHz. Thus, High-Frequency Audiometry (HFA) could be used as an early indicator for hearing loss prior to any shift being detected by conventional audiometry. There is a growing body of evidence that HFA can be used to predict hearing loss in the conventional frequencies (Fausti et al, 1981; Gauz et al, 1986; Morton et al, 1991; Ahmed et al, 2001). Additionally, while intersubject threshold variability has been a topic of contention, intrasubject thresholds have been found to be reliable and valid (Frank, 2001).

Immittance Audiometry
This is another routine clinical audiology test that should be considered for inclusion in a test battery. It consists of a physical volume test, tympanometry, static compliance, contra and ipsilateral acoustic reflex testing, and contralateral acoustic reflex decay testing. The main objective in performing immittance audiometry and middle ear compliance is to obtain information on the hearing loss site of lesion. The acoustic reflex tests are suggested because they can be performed within a few minutes. Their contribution to the differential diagnosis of conductive, sensory or neural hearing loss has been extensively studied and there is a consensus that they constitute a valuable and reliable source of information (Borg and Odman, 1979; Moller, 1984). The acoustic reflex decay test has been shown to have good correlation with retrocochlear pathology (Jerger and Jerger, 1977). We suggest that the acoustic reflex thresholds be determined at the frequencies of 0.5 and 1 kHz on both ipsi and contralateral pathways and that the acoustic reflex decay testing be determined at 0.5 and 1 kHz contralaterally.

Otoacoustic Emmissions
Otoacoustic emissions are spontaneous or evoked acoustical signals that are produced by the cochlea and travel laterally out through the middle ear. These signals provide important objective information about the functional health of cochlear outer hair cells, and can be analysed by placing a small microphone inside the ear canal (Kemp, 1986).

The inclusion of otoacoustic emissions in the test battery would facilitate the differentiation between sensory and neural hearing disorders. Additionally, because they are a sensitive measure of outer hair cell integrity, they may provide an indicator of cochlear damage before hearing loss is observed. Transient (click) evoked otoacoustic emissions (TEOAE) and distortion product otoacoustic emissions (DPOAE) would offer information on the status of the Cochlea. The former provides an overview of cochlear function, while the latter provides frequency-specific data, which is valuable in assessing noise-induced hearing loss. Contralateral suppression of the transient-evoked otoacoustic emissions (TEOAEs) could also be included in the test battery to evaluate the auditory efferent function (Maison et al., 2001).

Central Auditory Processing Tests

There are numerous auditory tests that can be used to assess central auditory function. These fall into two major categories: electrophysiologic and behavioural tests. Electrophysiologic tests, such as the Auditory Brainstem Response (ABR), Cortical Response Audiometry (CRA) or event-related P300 potential, have been used in clinical investigations of the effects of industrial chemicals (see Laukli and Hansen, 1995). These tests require the use of more specialized equipment, extensive set-up and test time, and technical expertise. For these reasons their use in occupational studies may be unfeasible by both time and cost constraints. In the face of such constraints, we suggest the use of behavioural tests.

Behavioral tests are generally broken down into four subcategories, including monaural low-redundancy speech tests, dichotic speech tests, temporal resolution or patterning tests, and binaural interaction tests. The Bruton Consensus Conference (Jerger and Musiek, 2000) recently proposed that an effective screening battery for auditory processing dysfunction be brief and include a free-recall dichotic digits test and a gap-detection test.

Random Gap Detection Test (RGDT)

This behavioural test of central auditory function is designed to measure an important aspect of audition called temporal resolution. Gap detection samples temporal processing, a key dimension of auditory processing (Jerger and Musiek, 2000). Normal temporal resolution is necessary for the processing of rapidly occurring information that is critically involved in the development and maintenance of language and speech. The ability to process basic acoustic parameters such as frequency and duration may predict speech intelligibility (Thompson and Abel, 1992). A random gap detection task is one in which a short silent gap (inter-pulse interval) is inserted between a pair of stimuli, and the listener reports whether the stimulus is heard as one or two. The Random Gap Detection Test (Keith, 2000) is an easily administered and efficient (approx. 10 minutes to administer and score) test for identifying temporal processing deficits. It also has the distinct advantage of being a non-linguistic measure, making linguistic background irrelevant in interpretation of results. The RGDT provides a gap detection threshold measured in milliseconds (msec) for each frequency 0.5, 1, 2, and 4 kHz. A normal gap detection threshold is considered to range between 2 and 20 msec.

Speech Tests

The ability to understand speech is a very important and complex function of the human auditory system, and is typically affected in varying degrees in people with cochlear and central auditory dysfunction. The most accurate assessment of this function is achieved with hearing tests that use speech material as stimuli. Speech tests, by evaluating speech discrimination, assist in the determination of site of lesion. They are accomplished through the use of standardized recorded speech materials.

Northwestern University Auditory Test no. 6

This test uses lists of phonemically balanced monosyllabic words for assessing speech discrimination.

The test result is expressed in percentage of words correctly identified, and reflects the relationship of understanding to changes in intensity (Tilman and Carhart, 1966).

Dichotic Digits Test

The use of dichotic speech tests has proven

Auditory Test	Differential Diagnosis	Ave. Time (min)	References
PTA	Auditory/cochlear sensitivity	11-15	Lovrinic, 1980 Yantis, 1985
HFA	Auditory/cochlear sensitivity	7-10	Frank, 2001
Immittance		6-10	
• **Tympanometry**	ME	1-2	Margolis et al., 1985
• **Acoustic Reflex**	ME/cochlear/retrocochlear/brainstem	4-6	Northern et al., 1985 Moller, 1984
• **Acoustic Reflex Decay**	Retrocochlear (CNVIII)	1-2	Northern et al., 1985
Otoacoustic Emissions	Cochlear sensitivity (OHC function)/ retrocochlear (CNVIII)	6-9	Kemp, 1986 Robinette and Glattke, 1997
• **TEOAE**		2-3	Maison et al, 2001
• **DPOAE**		4-6	
Speech Test NU-6	Cochlear/central	5	Tilman and Carhart, 1966 Penrod, 1985
Speech Test DDT	Central	5	Musiek, 1983 www.auditec.com
RGDT	Central	10	Keith, 2000 www.auditec.com
		Total Test Protocol Time: 50-60 min	

Abbreviations used in Table 3: PTA = Pure-Tone Audiometry, HFA = High Frequency Audiometry, ME = middle ear, CNVIII = 8th cranial nerve, TEOAE = Transient Evoked Otoacoustic Emissions, DPOAE = Distortion Product Otoacoustic Emissions, OHC = Outer Hair Cell, NU-6 = Northwestern University Auditory Test #6, DDT = Dichotic Digits Test, RGDT = Random Gap Detection Test

in the evaluation of central auditory dysfunction and only requires approximately
g (for a review, see Musiek and Lamb, five minutes to administer and score. Dichotic
ne of the more commonly used tests in digit materials are ideal for use with subjects
ory is the Dichotic Digits Test (Musiek, with hearing loss because digits (1) are relatively
his test consists of two digits presented immune to the effects of mild – to-moderate
ously in each ear at a comfortable cochlear hearing loss and (2) have high inter-test
level, utilizing a free-recall response reliability in both young and elderly adult
has a reported high sensitivity and listeners (Strouse and Wilson, 1999).
y for the detection of central auditory