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Approaches to managing ototoxicity in the workplace

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Abstract

Objective: Ototoxic chemicals in the workplace can pose a risk to hearing and balance functions. Our objective was to identify evidence-based practices for occupational health settings in managing ototoxicity. This resulted in the document, *Health Management of Workers Exposed to Ototoxic Chemicals*, created by the International Ototoxicity Management Group.

Design: To develop a practical approach for any workplace, we reviewed a variety of sources and used an international panel of interdisciplinary experts. Evidence included data from experimental,

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CRedit: **Thais C. Morata:** Conceptualization, Data curation, Investigation, Methodology, Project administration, Supervision, Visualization, Writing – original draft, Writing – review & editing; **Krystin Carlson:** Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Visualization, Writing – original draft, Writing – review & editing; **Gayla L. Poling:** Conceptualization, Writing – original draft.

Ethical clearance

This activity was reviewed by CDC, deemed not research, and was conducted consistent with applicable federal law and CDC policy. See 45 C.F.R. part 46.102(l)(2), 21 C.F.R. part 56; 42 U.S.C. §241(d); 5 U.S.C. §552a; 44 U.S.C. §3501 et seq.

Disclosure statement

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observational, and review studies. Thirty-two subject matter experts were invited to review the document; twenty-two completed the review and unanimously endorsed the ototoxicity management system as proposed.

Results: Six key action steps were proposed to: (1) identify workers exposed to ototoxic chemicals, (2) perform auditory and vestibular assessments, (3) follow-up after monitoring health, (4) document worker data, (5) maintain healthy safety culture, and (6) review ototoxicity management approach. These steps focus on the management of workers who are at-risk for workplace ototoxic chemical exposure at any level (with or without concurrent noise exposures).

Conclusions: Early identification strategies include self-report questionnaires; auditory testing; vestibular screening; referrals for diagnosis; management of cases; and monitoring of exposure scenarios to prevent further cases.

Keywords

Ototoxic; hearing; vestibular function; occupational; workplace exposures; solvents; ototoxicants

Introduction

The Global Burden of Disease (GBD) initiative examined population-representative surveys on hearing loss prevalence from 1990 to 2019 (Haile et al. 2021). It estimated that, in 2019, 1.57 billion people (95% CI 1.51 to 1.64) globally had hearing loss, which corresponds to one in five individuals (20.3%, 95% CI 19.5 to 21.1). Identifying risk factors (e.g., occupational exposures) that could potentially be modified at scale will aid in the development of strategies to address this global health challenge. In 2021, the World Health Organisation (WHO) published its first World Report on Hearing highlighting the individual and societal costs of hearing loss; this report discusses noise and ototoxic substances as key actionable occupational risk factors affecting large populations (WHO 2021). In a similar vein, the GBD study identified noise-reduction strategies as an urgently needed action to improve hearing health. The GBD study attributed differences in hearing loss prevalence between countries to the rates of occupational noise exposures and disparities in healthcare access and quality; by 2019, seven million years lived with disability (95% CI 4.76 to 10.1) were attributable to occupational noise exposure (Haile et al. 2021).

One major modifiable risk factor for hearing loss is exposure to ototoxic substances (WHO 2021). Ototoxicity occurs when exposure to toxic substances damages the normal functions of the auditory or vestibular system (WHO 2021). Symptoms include vertigo, dizziness, loss of hearing, tinnitus, and difficulty understanding speech. Many chemicals commonly used in workplaces are associated with ototoxicity. These include styrene, toluene, xylenes, mercury, lead, ethylbenzene, and carbon monoxide among others (Johnson and Morata 2010).

A systematic rapid review by Prasad and colleagues (2024) concluded that exposure to ototoxic medications was the greatest contributor to preventable disease-based cases of hearing loss, approaching 32.4 million cases annually. Exposures to ototoxic substances *at work*, however, were not included in the review. Estimates of the number of exposed workers can contribute to the burden estimate of hearing disorders. Beaver and Schneider (2023)

reported an estimate of 13.7 million workers, from 14 of 59 different industries, as having the highest risk of ototoxicant exposure. The 2023 US National Health Interview Survey indicated that 13% of the workers surveyed were exposed to ototoxic chemicals, 16% were exposed to noise, 7% were exposed to both and 11% of workers reported hearing difficulties (Masterson et al. 2025).

Data from European industries show that between 2005 and 2015 the percentages of workers exposed to chemicals from three different routes shifted; risks of exposures have increased for those “handling or being in skin contact with chemical products or substances” (14 to 17%), remained stable for those exposed to “vapours such as solvents and thinners” (11%), and decreased for those exposed to “smoke, fumes powder or dust” (19 to 15%) (Eurofound 2017).

Development of an ototoxicity management program in the workplace

Management of ototoxicity includes prevention, diagnosis, and treatment of dysfunction, in either the auditory or vestibular systems, that may result following exposure to certain agents. Despite the well-established physical, socio-economic, and psychological consequences of hearing and/or balance dysfunctions, few care-delivery models provide ototoxicity management.

The International Ototoxicity Management Group (IOMG) was formed in response to a critical healthcare gap worldwide in ototoxicity management practices (<https://www.ncrar.research.va.gov/ClinicianResources/IOMG.asp>). The IOMG is a global consortium of experts from professional societies, government agencies, universities, task forces, health foundations, and health care users. It provides operational awareness of ototoxicity management across a variety of contexts, as well as expertise in relevant clinical, population health, and implementation research. IOMG’s documents are written by its members and approved by the chairs of different focus areas. IOMG documents include input from non-hearing research and/or clinical specialists involved in the care of persons who suffer from ototoxicity. These may include individuals specialising in toxicology, pharmacology, oncology, infectious disease, and pulmonary medicine.

In February 2021 the IOMG Environmental and Occupational Focus Area was established to address the gap in ototoxicity management and practice for non-clinical settings. Management of ototoxicity in workers includes prioritising preventive measures that stop potentially hazardous exposures from occurring (OSHA and NIOSH 2018). Steps may also include monitoring workers already diagnosed or demonstrating auditory or vestibular dysfunction (OSHA and NIOSH 2018).

Due to concerns about workplace exposures to ototoxic chemicals and to clarify options to address possible risks, the IOMG created the document *Health Management of Workers Exposed to Ototoxic Chemicals*. It is an abbreviated version of this article and can be found at [https://en.wikiversity.org/wiki/International_Ototoxicity_Management_Group_\(IOMG\)/Protocols#Environmental_and_occupational](https://en.wikiversity.org/wiki/International_Ototoxicity_Management_Group_(IOMG)/Protocols#Environmental_and_occupational). Three companion pieces are included at the link above and with this article as supplementary materials: (1) a graphic summary (Supplementary file I), (2) citations used to inform the document (Supplementary

file II), and (3) a bibliography covering auditory and balance functional assessments (Supplementary file III).

Previous information on ototoxicity monitoring in the workplace comes from several entities (ACGIH 2024; Beaver and Schneider 2023; Department of Defense 2023; EU OSHA 2009; Johnson and Morata 2010; OSHA and NIOSH 2018; Sliwinska-Kowalska et al. 2007). These documents highlight the need for considering ototoxicity when conducting occupational hygiene assessments to determine eligibility for enrolment in hearing conservation programs and steps to expand their scope. In 2015 and 2023, the US Army and the US Air Force, respectively, established hearing conservation program enrollment requirements when exposure to at least one ototoxic chemical exceeded 50% of the occupational exposure limit (Department of the Army 2019; Department of the Air Force 2024).

In 2018, for ototoxic substances designated by their OTO notation, the American Conference of Governmental Industrial Hygienists (ACGIH) started to “highly recommend” annual audiograms for workers whose exposures to ototoxicants occur at 20 percent or more of the ACGIH threshold limit value. In 2024, ACGIH listed four solvents with the OTO notation: ethyl benzene, styrene, toluene, and xylene (ACGIH, 2024). These notations specify exposure levels that trigger employee monitoring for these four chemicals. However, ACGIH does not provide best practices to implement an ototoxicity management plan for workers exposed to these solvents, or any of the other chemicals associated with ototoxicity. The OTO notation indicates that keeping workers’ exposures below the recommended exposure limit is not always sufficient to protect workers against hearing/auditory or vestibular insults. Solvents which received the OTO notation from ACGIH are only a few of the chemicals identified as having ototoxic properties. Other ototoxicants include several organic solvent mixtures, metals, and asphyxiants (see Zarus et al. 2024 and OSHA and NIOSH 2018).

Ototoxicity is something occupational health practitioners are newly broaching. Two main challenges exist across countries: (1) technical and administrative barriers to preventing risks from exposure to ototoxic chemicals and (2) lack of guidance and structured approaches to manage ototoxic risks. In occupational settings, safety and health professionals are often well-positioned to prevent or mitigate the ototoxic effects of workplace chemicals. Yet, there are no standard protocols for the ototoxicity management of individuals exposed to hazardous chemicals at work. The goal of the present work was to identify evidence-based actions applicable to occupational settings. Actions include identification of exposed workers, screening for auditory and vestibular problems, referral practices for clinical evaluation, and management of occupational exposures to prevent further cases. Our efforts may serve as a basis for updating occupational health processes, informing future research, and advancing clinical audiology practices.

Methods

IOMG Environmental and occupational focus group

In 2021, IOMG invited an all-volunteer panel to join its Environmental and Occupational Focus Area. This group held regular meetings to develop and implement a working plan toward improving ototoxicity management in situations where environmental or occupational exposure occur. Activities included holding 3–4 meetings a year (a total of 15 meetings at the time this manuscript was prepared), discussing research, conducting literature reviews, and contributing to other IOMG activities. Attendance in virtual meetings fluctuated from 9 to 30 participants.

Translation of evidence-based findings into a cohesive realistic approach took input from professionals who manage hearing conservation programs in workplaces. Indicators such as the number of publications, citation records, professional experience, service records, contributions, honours, and roles in conferences/journals were used to identify additional experts.

Base of evidence

The approaches described in this document were informed by literature and expert opinion from the focus area members. Focus Area chairs continuously monitored the ototoxicity literature for relevant publications.

Two recent reviews by IOMG members and collaborators evaluated the strength of relevant evidence. In 2023, a mixed methods review examined audiological tests used in the detection of ototoxicity from occupational chemicals; it, in part, informed the development of the present document (Roggia et al. 2023). The hearing tests most effective at detecting ototoxicity from this review on solvents were assumed to be applicable to all ototoxic chemicals studied so far as similar neurotoxic mechanisms have been observed. A 2024 study examined toxicological and epidemiological evidence of ototoxicity as documented in toxicological profiles by the Agency for Toxic Substances and Disease Registry (ATSDR) (Zarus et al. 2024). Overall, 26 profiles reported strong evidence for one or more of these outcomes: hearing loss; vestibular effects; cochlear lesions; tonal alterations; cellular damage; and ototoxicity-related outcomes (neurological, nephrotoxic, hepatic, and developmental effects).

Towards developing the present proposal, the IOMG Environmental and Occupational Focus Area also examined experimental and non-experimental (quasi-experimental, observational) evidence, expert opinion, authoritative documents, and historical records of common practices when developing the present approaches for the management of ototoxicity at work. The extended bibliography is listed in Supplementary file II.

Document development

The IOMG Environmental and Occupational Focus Area followed an informal consensus-based strategy, using comprehensive literature searches. Members of the group primarily communicated by sharing information through emails, document sharing, and in-person or

virtual discussions to resolve differences in the recommendations. Documents were further vetted through the IOMG and an opportunity to submit comments was provided.

Group chairs generated an outline of current procedures, protocols and actions to be implemented across countries. The outline was used to identify a framework and specific strategies to protect the hearing and balance functions of those exposed to ototoxicants at work. From 2023 to 2025 extensive discussions on draft versions took place through email and virtual meetings.

Twelve authors and 32 subject matter experts were invited to review the approaches provided in this document; 22 completed it and unanimously endorsed the document. Invitational emails failed to reach 7 experts, and 3 were unavailable to review it. Subject matter experts were associated with academic, military, and industrial institutions. Participants also reflected perspectives from France, Italy, Poland, Canada, Brazil, and the USA (see Acknowledgments below for peer reviewers).

Given the diverse perspectives involved in developing our IOMG occupational ototoxicity management approach and the wide range of workplaces where it may be applied, we built flexibility into the approach to accommodate a variety of needs. The proposed six action steps can be tailored to meet different scenarios and adjusted based on feasibility or resources available. The two-pronged approach using both self-report questionnaires and auditory testing is proposed with the knowledge that current standard pure-tone audiometric monitoring protocols alone are insufficient for early detection of ototoxicity (WHO 2021). When minimal material and personnel resources are available, steps can be eliminated (such as choosing to perform either an auditory test or a self-report questionnaire), and the frequency of testing can be adjusted (annually or biannually is recommended here).

Results

IOMG approaches for the health management of workers exposed to ototoxic chemicals

Below is the IOMG approach for the management of workers exposed to workplace chemicals that pose a risk to hearing and balance functions. Our template focuses on actions to be conducted in work settings, not in clinical settings (otolaryngology, otology or audiology clinic).

Theoretical frameworks

This strategy was influenced by the public health model of interventions (Tetrick and Quick 2003) as well as international guidance on risk management and occupational health (ISO 31000:2018; ISO 45001:2018). The progression through these steps informs the selection of actions to prevent health effects from ototoxic exposures. Example activities and their corresponding level of prevention from the public health model of intervention are shown in Figure 1. A summary of the action steps is shown in Figure 2, which highlights the importance of revisiting a chosen ototoxicity management plan repeatedly for continual improvement.

Six key action steps

The IOMG six key action steps are described below as well as in a graphical summary and flowcharts (Supplementary file I). This risk management strategy is intended as a template to be adjusted for the best fit of each individual workplace.

1) Determine workers for inclusion in ototoxicity management: Obtaining occupational (industrial) hygiene information about noise and chemical exposures is the best way to identify groups exposed to potential ototoxic chemicals. Information on exposure to ototoxicants (at any level with or without concurrent noise exposures) will inform which workers may be considered for inclusion in action steps 2–4.

Few chemicals have been tested for ototoxicity. Analysis and assessment of chemicals with unknown ototoxicity should trigger further information gathering on any findings of associated listening difficulties in exposed populations. When auditory or vestibular research is absent, information on an agent's general neurotoxicity or nephrotoxicity potential can be used as a guide (since many of the chemicals that affect the auditory system are potentially neurotoxic and/or nephrotoxic) (OSHA and NIOSH 2018; Zarus et al. 2024). Information on potential exposure by target organ system can be obtained from databases like one from the Wisconsin Department of Health Services (2025) that show chemicals known to cause 'nervous system disturbances'; if ototoxicity data is absent, then chemicals demonstrating damage to neurological systems can be assumed to also be ototoxic until more specific data is available. Experts experienced in risk assessment may be necessary as consultants to determine the need for employee auditory and vestibular monitoring in uncertain cases (Morata 2003; Zarus et al. 2024).

2) Perform health assessments: We have outlined approaches using both (1) a self-report and (2) a functional assessment. It is important to provide information on both exposures to noise and ototoxic chemicals to those performing health assessments and to those reviewing the questionnaires identified below.

Ototoxic symptoms can manifest in either the auditory or vestibular systems. Occupational health managers need to identify the workers eligible to participate in these health assessments (see action step 1); they also need to choose whether, according to the resources and needs of their workplace, doing both self-report and functional testing is feasible. Baseline testing of workers offers valuable information but is not needed to capture early warning signs. A list of references for hearing and balance surveys mentioned in this document are provided in Supplementary file III.

2a) Administering validated self-report questionnaires. Self-report questionnaires can cover listening performance and balance functions. Health and safety professionals in occupational health programs or hearing conservation programs would likely be responsible for collecting and managing these records. The use of self-report tools facilitates screening for early dysfunctions having an impact on activities and social participation. These tools can be used to inform the decision on when to refer a worker for audiological and/or vestibular diagnostic evaluation. Before selecting a self-assessment questionnaire, review the background publications related to the administration, scoring, and interpretation associated

with that specific tool. Validated self-report questionnaires about listening performance and vestibular functions can detect when a person is not answering questions in a reliable or consistent manner. An option is to administer these instruments annually or bi-annually to workers exposed to ototoxic chemicals.

2ai) Collect self-report hearing data. The World Report on Hearing highlights that “[w]hile audiometric descriptors ... provide a useful summary of an individual’s hearing thresholds, they should not be used as the sole determinant in the assessment of disability or the provision of intervention(s)” (p.38 WHO 2021). Use of a questionnaire assessing difficulty with speech discrimination, or other listening difficulties has been shown to help reveal additional effects of the chemical and/or noise exposure(s) on the auditory system. Studies on validated instruments that explore exposure history or auditory and balance functions in daily-life activities are listed in Supplementary file III.

The Amsterdam Inventory for Auditory Disability and Handicap (AIADH) (Kramer et al. 1995) (available in Dutch, English, Spanish, Cantonese, Chinese, Polish, Portuguese, and Turkish) has been the most commonly used instrument with groups exposed to ototoxic chemicals in the workplace (Roggia et al. 2023). It has detected performance differences between workers exposed to solvents and/or jet fuel and unexposed workers, even when pure-tone thresholds are within normal ranges (Dreisbach et al. 2022; Fuente and McPherson 2007). The Speech, Spatial and Qualities of Hearing Scale (SSQ) has also detected listening difficulties among workers exposed to various chemicals (Gedik Tokar and Kuru 2024).

Two other instruments are also worth considering in targeting hearing difficulties that might be missed when using pure-tone audiometry (PTA) testing. The Hearing Handicap Inventory for Adults (HHIA) and the Tinnitus Functional Index (TFI) are designed to identify auditory dysfunction. Both tinnitus and self-perceived hearing handicap were detected using the HHIA and TFI in an investigation of hearing outcomes among firefighters (Jamesdaniel et al. 2019).

2aii) Collect self-report vestibular function data. Researchers have found an association between occupational chemical exposures (even at low exposure levels) and workers’ vestibular function when using screening tools or more sophisticated diagnostic procedures (Park et al. 2009; Prasher et al. 2005). Most industrial ototoxicants have acute neurodepressive properties that could cause immediate symptoms of imbalance or dizziness (Zarus et al. 2024).

Distinguishing acute effects from any chronic impairments of vestibular structures would be beneficial. Asking workers whether symptoms persist after work and during the weekend can provide relevant information. Different instruments assessing overall health have been shown to be efficient in assessing symptoms more commonly associated with vestibular dysfunction and balance function in real-world settings (Stewart et al. 2018).

The Activities-Specific Balance Confidence (ABC) Scale (Fong et al. 2015) can monitor chronic, progressive neurologic conditions (available in Arabic, Brazilian Portuguese,

Chinese, German, Hindi, Hungarian, Icelandic and Sepedi) and was validated as a screening tool for vestibular disorders (Karapolat et al. 2010; Montilla-Ibanez et al. 2017; Moore et al. 2018). The ABC Scale evaluates an individual's confidence in performing various ambulatory activities (such as walking around the house and reaching for a can on a shelf at eye level) without falling or feeling unsteady. Unlike other questionnaires, it has been shown to demonstrate good responsiveness to change in working-age adults (Fong et al. 2015). The Vertigo Symptom Scale may also be appropriate but is less well studied (Yardley et al. 1992).

2b) Conduct health testing on workers: Additional testing can be done alongside review of self-report questionnaires to give a more complete perspective of a worker's health. The tests mentioned below often miss dimensions in auditory or balance performance, which is why self-report is given as a first option. Workers who are exposed to ototoxic substances should undergo a selection of tests periodically. The most robust ototoxicity risk management system would take multiple lines of evidence into account when screening workers for symptom development.

2bi) Conducting hearing/auditory testing. Hearing/auditory screening is particularly important for workers exposed to ototoxicants. Reducing risk involves informing workers of test results and the need for further examination or treatment. Exchanging information about exposures of concern with any worker who is referred for further audiological testing is likely to lead to a more accurate diagnosis, as it can influence the clinician's decision of which tests to use (Roggia et al. 2023). In case country-specific requirements for audiometric monitoring for the identification of threshold shifts does not exist, occupational safety and health professionals may consider international recommendations, such as those from the National Institute for Occupational Safety and Health (NIOSH) (1998).

A variety of tests can be considered to evaluate the performance of a worker's auditory system. The tests highlighted below were selected based on criteria *specifically* suited to the context of workplace health programmes rather than hospital or clinical settings. Tests that are considered key components of ototoxicity management of patients undergoing treatments with ototoxic medications (such as extended high frequencies and otoacoustic emissions) while potentially valuable could be impractical to implement in occupational settings.

Air-conduction PTA is a commonly used test which could be used to assess hearing thresholds of workers exposed to any level of ototoxic chemicals, regardless of their noise exposure levels. Hearing thresholds shifts have been observed following exposures to ototoxicants in a range of test frequencies, not restricted to the 4–6 kHz notch (Johnson and Morata 2010). Testing a larger number of frequencies (particularly those above 6 kHz) provides information that can aid the decision process on other needed action steps. Ideally, audiometric testing would follow an otoscopic screening (to check for ear canal blockage or other outer/middle ear conditions).

If performing PTA, testing should follow, at a minimum, country-specific requirements established for noise-exposed workers. Recommendations for air-conduction PTA includes

testing at 0.5, 1, 2, 3, 4, 6 and 8 kHz (NIOSH 1998). Comparing PTA hearing thresholds to baseline values allows for the determination of whether a threshold shift has occurred. Different metrics have been examined in the evaluation of shifts (Blair et al. 2022). Note that poorer PTA behavioural hearing thresholds have been observed in the 1–3 kHz frequency range among workers exposed to ototoxic chemicals when compared with non-exposed or noise-exposed groups (Blair et al. 2021, 2022; Hormozi et al. 2017; Morata et al. 2011; Schaal et al. 2017, 2018; Śliwińska-Kowalska et al. 2007). Age correction for hearing thresholds of individual monitoring audiograms is not recommended for prevention efforts because it delays the early identification of hearing shifts (NIOSH 1998). Technology today allows for “boothless” hearing testing (Meinke et al. 2017) which has been used and validated in the field (Sheffield et al. 2023).

An evaluation of central auditory nervous system (CANS) functions helps with the early identification of the effects of ototoxic chemicals. Several auditory processing dysfunctions related to ototoxicity can be missed when using PTA. Speech tests have detected the damaging effects on hearing of several ototoxicants, including metals (Castellanos and Fuente 2016; Johnson and Morata 2010). In particular, dichotic listening tests were shown to be effective in detecting the effects of solvent exposure on the CANS (Roggia et al. 2023).

Dichotic listening tests are also sensitive to the effects of other, if not all, ototoxicants that damage hearing and balance through similar biomolecular mechanisms as solvents. The Dichotic Digits Test (Musiek et al. 1991) is a convenient choice as it does not require sophisticated equipment. The test consists of simultaneous unpredictable presentation of digits to the two ears in groups of one, two, or three pairs of items. Its interpretation does not require a comparison with baseline results, a desired feature since it allows for earlier detection and intervention. The Dichotic Digits Test is quick to administer, and results are simple for those with training to interpret. It is available in multiple languages (Cantonese, English, French, Malay, Persian, Polish, Portuguese and Spanish).

Other central auditory tests with similar features can be used, as several have been shown to be sensitive in detecting central auditory signs associated with exposure to ototoxic chemicals (Fuente et al. 2011). Tests that are language-independent and do not require expensive equipment or a baseline include:

- Random Gap Detection Test (Keith 2000). This test asks individuals to detect brief gaps between two stimuli. The stimuli used in each presentation can be either pure tones or clicks, and the test measures the shortest silent interval that a person can perceive between these sounds.
- Gaps-in-Noise Test (Musiek et al. 2005). Individuals must report how many silent gaps they perceive in each presentation.

2bii) Screening for vestibular dysfunction. Trained occupational safety and health professionals can perform vestibular screening (baseline and periodically) of workers exposed to ototoxic chemicals, particularly those who report symptoms of imbalance or dizziness (Zamysłowska-Szmytke et al. 2015). Several functional assessments for vestibular screening that are not time-intensive and require minimal equipment are available to use

in work settings. Some common vestibular screening tests include as described by Cohen (2019):

- The Romberg test: a simple test of how long a person can maintain his/her balance while standing with eyes closed. Extensive training is not needed for examiners, but they must maintain close proximity with the worker because of the risk of falls.
- The Fukuda stepping test: a test of path integration and spatial orientation that evaluates how much and in what direction an individual rotates when they walk in place with their eyes closed.
- Dix-Hallpike manoeuvre: a widely accepted screening assessment of the Vestibular Ocular Reflex (VOR). A person seated on a table with the head turned 45 degrees to the side is quickly moved from the sitting position to a supine position with the head hanging slightly over the edge of the table, still turned 45 degrees. The examiner observes for nystagmus, which is typically a torsional upbeating nystagmus.
- Dynamic visual acuity: a behavioural measure of VOR function and gaze stability in which changes in a worker's visual acuity is evaluated. The Dynamic visual acuity test is typically measured by having a patient read letters or symbols on a chart while they are in motion, either through head movement or while walking. The results are compared to static visual acuity, which is the ability to see details while stationary.

3) Follow-up: Consider reviewing worker health assessment data not only individually, but also collectively. Individually, workers need to be referred when auditory or vestibular dysfunction is detected. When multiple workers are observed to report health problems, consider analysing worker data together for possible trends in tasks, chemical exposures, or noise levels. These types of collective analyses can generate awareness of additional ototoxic risks that may have been missed in the ototoxicity management plan.

3a) Refer cases to clinical care. Auditory and vestibular screenings offer the opportunity to raise awareness of risks and prevention measures and educate workers about rehabilitative options available (e.g. environmental modifications, auditory training, amplification, vestibular physical therapy, etc.). Knowledge of existing options may increase the likelihood that an individual will pursue follow-up services. Whenever possible, referrals are to include information about potential risk factors (noise and chemical exposures).

Either screening alone, self-report information alone, or both screening and self-report data together can be used to suggest the need for referral to a licenced physician, audiologist, or physical therapist. When taken together, these results are stronger, especially if a worker reports hearing difficulties that are greater than expected based on the audiometric results. A referral to an ENT specialist or clinical audiologist allows for a complete evaluation for ototoxicity and auditory processing disorders, and a vestibular examination. Auditory and vestibular health treatment regimens and corrective measures (such as hearing aids) can

be determined through the audiological diagnostic process by the professionals to which workers are referred.

3b) Take actions to prevent further health effects. After a specialist confirms auditory or balance dysfunction, take steps to prevent further harm and support those affected by ototoxic outcomes. Management of confirmed cases of ototoxicity in the workplace involves communication between the worker and occupational health staff about any needed rehabilitation or accommodations. Consider workplace accommodations or compensation to be filed as allowed within specific jurisdictions. We encourage the occupational health staff to evaluate exposures and needed controls for groups of similarly exposed workers.

4) Document worker health and exposure data: Keeping track of worker health assessments and exposure histories allows occupational health professionals to adapt ototoxicity risk management approaches over time. There may be certain locations, job titles, or exposure categories that show similar trends in health outcomes. Contrast of current reports with baseline records, comparison of self-reports to testing or screening data, and monitoring changes in health outcomes over time can only be done when quality records are maintained.

5) Maintain healthy safety culture: To ensure worker health is protected, an ototoxicity risk management plan works best when embedded within a culture where worker hearing is valued, and health risks are taken seriously. Clear communication to workers regarding risks and required safety practices is a key piece in protecting worker health.

Further information is available in Supplementary file I on strategies for the prevention of ototoxicity in workplaces. Preventive measures that stop potentially hazardous exposures from occurring include, in order of priority, the removal (or reduction of the use) of known ototoxic substances, the implementation of better ventilation, the wearing of respiratory protection and/or hearing protection in case of noise co-exposure.

Communication with workers who develop ototoxicity is also important. Accommodating any rehabilitation or intervention necessary to restore or improve symptoms in the worker should be guided by clinical professional (not covered in the present document), and supported, when possible, in the workplace.

Workers may be unaware of the risk of ototoxicity in their workplace, whether they have symptoms or not. Teaching new employees and those with symptoms how to manage exposure risks can help prevent further hearing or balance issues. Educational initiatives may be an effective approach. Training may include noise in the workplace; loud music or other recreational noise exposures; ototoxic chemicals; controlling exposures at their source; personal protective equipment; limiting hand/skin or dermal exposures; handwashing to avoid contamination or hand-to-mouth exposures; and fit-testing for respiratory protection and hearing protection.

6) Review ototoxicity management approach: The goal of ototoxicity management plans is to prevent ototoxicity in workers completely, especially through chemical and noise

exposure controls. Continual monitoring and planning are needed to keep the ototoxicity management approach updated. For example, new ototoxicity guidance or research could create the need to adjust worker inclusion determinations, or new questionnaires or auditory tests focused on ototoxicity symptoms may be developed. The occupational health program manager and/or employer are the responsible parties for making informed decisions and for verifying that they are carried out. If exposure controls to noise and chemicals are implemented and shown to be effective, the frequency of testing and screening in action step 2 can be adjusted. Alternatively, if workers are found to develop health issues that could be due to occupational exposures to ototoxic chemicals, consider actions to monitor worker exposures more closely and perform health screenings and testing more frequently.

Discussion

This paper focused on the management of ototoxicity in the workplace. Ototoxicity researchers and practitioners in occupational health assembled practical approaches towards that goal.

No previous publications proposed specific approaches for the management of worker populations at risk of ototoxicity as compiled here. The six key action steps given here arose from a consensus between a wide variety of international experts. The extensive body of evidence that was drawn from is found in Supplementary file II. Supplementary file III includes a listing of studies on ototoxic risk, screening, audiological tests, and questionnaires for early identification of ototoxicity symptoms. Together the IOMG experts critically evaluated the literature and proposed preventive approaches in a realistically achievable manner. The preceding strategies for ototoxicity management in the workplace have accounted for: (1) common technical and administrative barriers to implementing an ototoxicity prevention program; and (2) flexibility and feasibility of implementation.

Strengths and limitations

The major strength of this work is the two frameworks that it is situated within (the public health intervention model and a risk management framework). The public health model framework (Tetrick and Quick 2003) allows for flexibility in meeting workplace needs to prevent the effects of exposure to ototoxicants among workers. Our approach identified preventive actions encompassing primary, secondary, and tertiary levels. These stages of prevention are not independent, but compatible strategies that can be simultaneously applied. Using multiple assessment strategies for both auditory and vestibular health allows confidence in identifying workers once a problem is occurring. Workers with early or late auditory or vestibular problems could be considered as signals to review strategies to manage the risk of ototoxicity preventing future workers from developing similar issues.

The versatility of the IOMG approach is a strength of our work. A workplace could choose to adopt protocols which blanket all workers in regular auditory and balance testing as a primary intervention. Other primary interventions such as making sure workers have quiet break times and clean spaces improve health of all workers, not just those at risk. Resources are given to identify the ototoxic chemicals of greatest concern; using these resources allows a workplace to narrow efforts to the workers at the highest risk. This defines the

scope of secondary interventions determined to be of most benefit to a given workforce. Finally, tertiary interventions are also held within the IOMG approach; recommendations to refer workers who have ototoxicity symptoms for treatment and rehabilitation options are included. Identifying ototoxicity early is essential to minimise the worsening of symptoms and prevent significant impacts on a worker's quality of life.

Prevention strategies are also stronger when held in the context of workplace culture (see step 5). Developing the IOMG approach to align with international risk management standards (ISO 2018) has provided a broader perspective to enhance prevention of ototoxicity. This standard includes safety culture, risk communication, reporting, and process review activities incorporated within our voluntary six step model. Our flexible approach allows occupational health professionals to tailor a plan specific to the needs of their workers and workplace. A number of examples are offered within the template to help occupational safety and health professionals adapt these steps as needed.

Another key strength of the IOMG approach is an emphasis on self-report questionnaire metrics in conjunction with auditory and vestibular testing. Multi-pronged testing approaches have been shown to identify emerging ototoxicity symptoms more effectively (Fuente et al. 2011). While no specific auditory or vestibular test can unequivocally determine all damage related to ototoxicant exposures, self-report data of experienced difficulties captures symptoms that are often missed by other testing strategies. This more sensitive type of instrument allows for earlier awareness and remediation for auditory and vestibular dysfunctions.

Research gaps in workplace ototoxicity prevention have limited the development of evidence-based practices for managing risks to workers exposed to ototoxic chemicals. Currently, there is no best method to determine whether damage to either the auditory or vestibular systems has occurred. In contrast to the existing guidelines for audiological assessments for drug induced hearing loss, the proposed approach identified actions appropriate to work settings. We recommend future research continue to examine a variety of auditory and vestibular tests applicable to occupational scenarios to more readily recognise pathological symptoms of ototoxicity.

Finally, limitations may exist in the broad scope and language used in this approach for the people responsible for carrying out each of the six action steps. Across the globe, countries have a variety of requirements for guiding risk management strategies in workplaces and policies on hearing conservation. Where legal guidance is lacking, alternative expertise on ototoxicity may be found in academia, hospitals, or professional associations. Professional associations that provide specific training and certification in occupational hearing conservation (one example is the Council for Accreditation in Occupational Hearing Conservation [CAOHC]) and aim to educate, inform, and guide the successful implementation of occupational hearing conservation programs should consider broadening their efforts beyond occupational noise alone and include ototoxicity. The limited coverage of public health content in audiology curricula has likely impacted the state of the art in occupational hearing health. However, audiologists not only have the responsibility, but also have the tools, opportunities, and strategic positions for major

impacts in public health. They are best suited to advocate for healthy hearing practices and facilitate hearing loss prevention, even when doing so from a clinical setting.

Conclusions

Health surveillance of workers exposed to ototoxicants is usually only required when noise exposure limits are exceeded. For occupational professionals who wish to go beyond occupational and health legal requirements and prevent or address ototoxic symptoms, structured key action steps are now available.

The IOMG approaches for ototoxicity management of workers exposed to ototoxicants were developed as practical strategies to address a critical need for the expansion of hearing loss prevention activities in the workplace. This framework is intended to be customised to meet specific needs. It identifies novel technologies and metrics that can guide ototoxicity prevention into the future.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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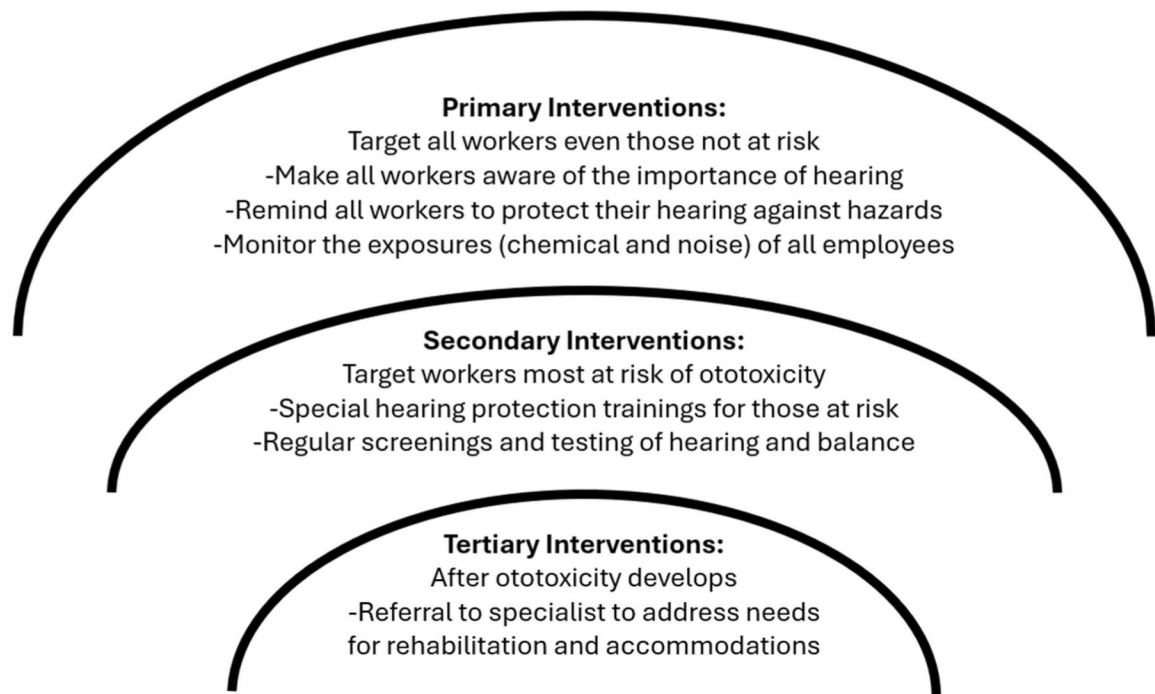


Figure 1.
Examples of different levels for interventions focused on preventing ototoxicity in the workplace within a public health framework.

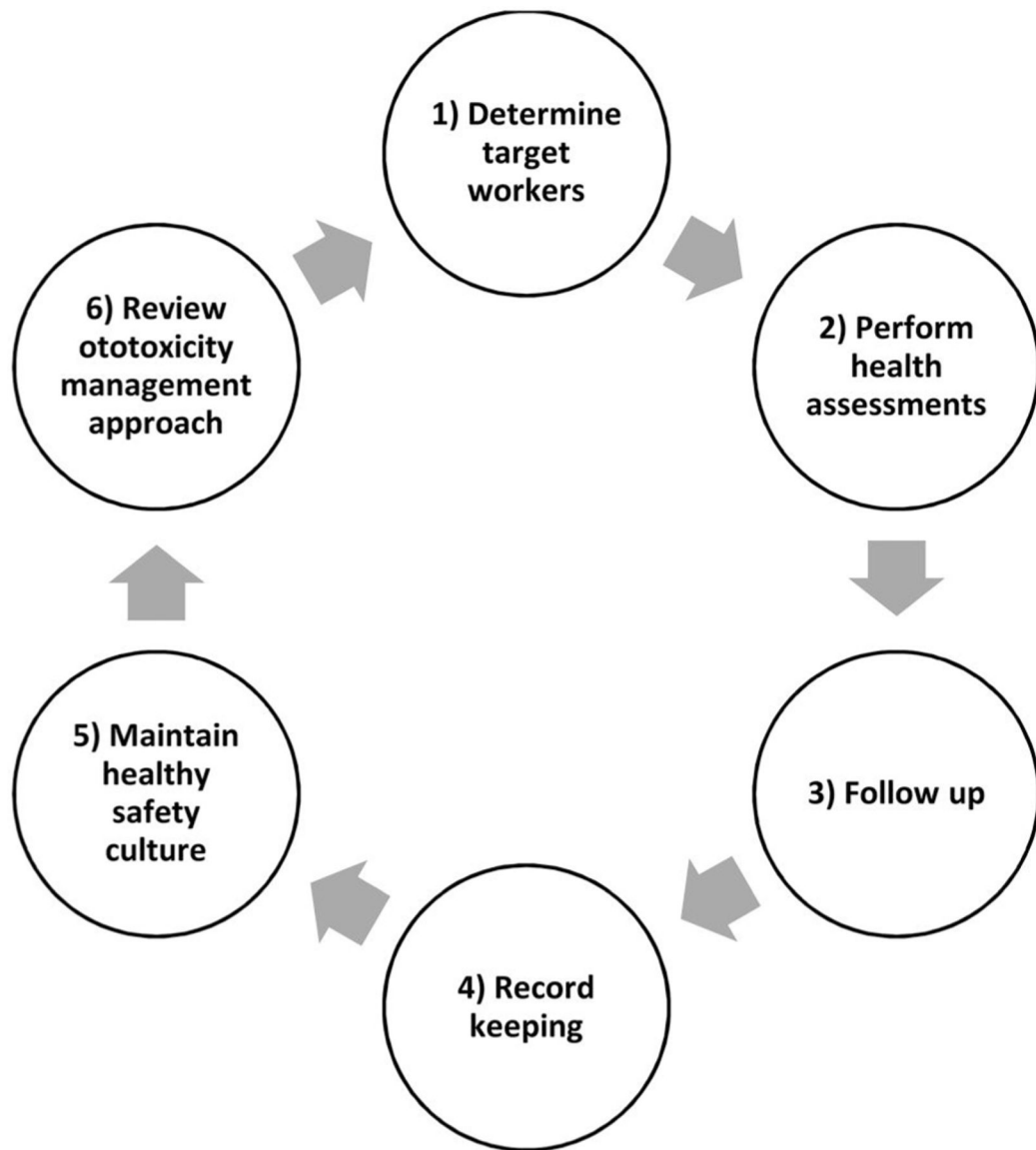


Figure 2.

Summary of six key action steps in the management of ototoxicity in the workplace.

Activities are each identified by a number (1–6) with the final step indicating that review of the entire process is also periodically needed.