Hearing loss prevention and Ototoxicants in the workplace

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The findings and conclusions in this presentation are those of the author and do not necessarily represent the views of the National Institute for Occupational Safety and Health.
Acknowledgement

The review reported here was prepared for the Nordic Expert Group with Dr. Ann-Christin Johnson from the Karolinska Institute in Stockholm, Sweden.

www.nordicexpertgroup.org
Complexity, often used to characterize something with many parts in intricate arrangement.
Great appeal for the state, quality, or an instance of being simple; freedom from complexity, intricacy, or division into parts

Danger of simplism, making unrealistically simple judgments or analyses
Health Effects Research

Health research is characterized by the study of single agents as if they occurred alone.

95% of the resources in toxicology are committed to single chemical investigations, as well as with noise!
Synergism: occurs when both agents have an effect individually and a more than additive effect when together. \(1+1>2\)

Potentiation: is when one agent has an effect but the second does not but enhances the effect of the former agent on combined exposure. \(1+0>1\)

What about greater-than-additive scenarios???
Ototoxicity of therapeutic drugs

Antimalarial
Non-steroidal anti-inflammatory
Aminoglycosides
Antimicrobial
Loop diuretics
Antineoplastic
Chelating agents

Mostly:
✓ Vastly studied
✓ Effects restricted to cochlea
✓ Use monitored, i.e., knowledge of intake

Approaches:
✓ Substitution
✓ Antioxidants
Ototoxicity of environmental chemical exposures

Mostly:
- Relatively few studies
- Effects not restricted to the cochlea
- Use poorly monitored, i.e., poor knowledge of exposure history
- Confounded by noise

Approaches:
- Substitution/control of exposure
- Antioxidants
Before the 1980’s

No systematic research effort on auditory effects of environmental/occupational chemicals, but isolated reports:

- Poisoning: accidents or abuse
- Occupational exposures (painters, printers, metal, chemical, leather industry workers, etc.)
- Environmental exposures (air, food and water contamination)
During the 1980’s

The involvement of other groups: as the Swedish NIOH (later the NIWL), Johns Hopkins University, INRS, US NIOSH, etc., resulted in more evidence of auditory effects of chemicals and interactions.

Proposed Strategies for the Prevention of Leading Work-Related Diseases and Injuries, p.9 NIOSH, 1988:

• “Determine through investigations the degree of which noise interacts with other agents in the work environment (solvents, metals, prescription drugs, etc.) to affect hearing.”
Occupational hearing loss research
Endogenous & exogenous factors

Agent
- OHL
- Genetics
- Age
- Diet
- Lifestyle
- General health
- Socio-economic factors
- Education
- Gender
- Occupational exposures

Key minimum information to be gathered
Which chemicals have been evaluated and shown to be ototoxic?

Solvents, PCBs, asphyxiants, pesticides, metals

Recognition that hearing loss is caused by more than just noise (case reports, laboratory, clinical, epi studies).
Intoxication route

Blood burden: $C_{\text{art}}$ TOL

- Inhalation

- Cochlear arteries

- Stria vascularis

23-4 April 2012

Pierre Campo, 2012
### Animal studies

<table>
<thead>
<tr>
<th>NOAEL</th>
<th>LOAEL</th>
<th>Exposure duration</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Styrene - only</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-</td>
<td>250 ppm – 500 ppm</td>
<td>Gavage or Inhalation 3 w – 4 w</td>
<td>Chen et al., 2007; Lataye et al., 2005</td>
</tr>
<tr>
<td>300</td>
<td>600</td>
<td>Inhalation 4 w</td>
<td>Mäkitie, et al 2002</td>
</tr>
<tr>
<td>-combined with noise (N)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-</td>
<td>400 + 85 dB Leq8h</td>
<td>Inhalation and N 4 w</td>
<td>Lataye et al., 2005</td>
</tr>
<tr>
<td>300+ 100-105 dB SPL</td>
<td>600 + 100-105 dB SPL</td>
<td>Inhalation and N 4 w</td>
<td>Mäkitie et al., 2003</td>
</tr>
<tr>
<td><strong>Toluene - only</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-</td>
<td>900 -1000</td>
<td>Inhalation 14 h/d, 14 w or 6 h/d, 2-4 w</td>
<td>Pryor et al 1983a; Johnson et al 1988</td>
</tr>
<tr>
<td>700</td>
<td>1 000</td>
<td>Inhalation 14 h/d,16 w</td>
<td>Pryor et al 1984b</td>
</tr>
<tr>
<td>-combined with noise (N)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>500 + 87 dB Leq8h</td>
<td>-</td>
<td>Inhalation and N 90 d</td>
<td>Lund and Kristiansen 2008</td>
</tr>
<tr>
<td>500+90 dB Leq8h</td>
<td>1 000 + 90–100 dB Leq8h</td>
<td>Inhalation and N 10 d</td>
<td>Brandt-Lassen et al 2000</td>
</tr>
<tr>
<td><strong>Xylene - only</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>450 p-XYL</td>
<td>900 p-XYL</td>
<td>Inhalation 13 w</td>
<td>Gagnaire et al 2001</td>
</tr>
<tr>
<td>-combined with noise (N)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No data</td>
<td></td>
<td></td>
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<tr>
<td><strong>Trichloroethylene - only</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-</td>
<td>2 000</td>
<td>Inhalation 3 w</td>
<td>Rebert et al 1991</td>
</tr>
<tr>
<td>800</td>
<td>2 500</td>
<td>Inhalation 13 w</td>
<td>Albee at al 2006</td>
</tr>
<tr>
<td>-combined with noise (N)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-</td>
<td>3 000 + 95 dB SPL</td>
<td>Inhalation and N: 18 h/d, 3 w</td>
<td>Muijser et al 2000</td>
</tr>
</tbody>
</table>
## Human studies – Styrene OEL 20-

<table>
<thead>
<tr>
<th>Exposure levels</th>
<th>Styrene groups</th>
<th>Evidence of HL shown</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>S= Styrene, N= Noise</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>S:</strong> Mean 3.5 ppm</td>
<td>65, S 89, S and N; 81 controls</td>
<td>++</td>
<td>Morata <em>et al</em>, 2002, Johnson <em>et al</em>, 2007</td>
</tr>
<tr>
<td><strong>N:</strong> S+N mean 89 dBA</td>
<td>32 S 60 controls (age matched)</td>
<td>++</td>
<td>Mascagni <em>et al</em>, 2007</td>
</tr>
<tr>
<td><strong>S:</strong> Mean ca 5 ppm (biol. monit)</td>
<td>44, S; 49 S in mixt 33 controls</td>
<td>++</td>
<td>Morioka <em>et al.</em>, 1999</td>
</tr>
<tr>
<td><strong>N:</strong> 73 dBA</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>S:</strong> Mean 8 ppm</td>
<td>220 S 70 S and N 157 controls</td>
<td>+++</td>
<td>Sliwinska-Kowalska <em>et al</em>, 2003</td>
</tr>
<tr>
<td><strong>N:</strong> &lt; 85 dB</td>
<td>16 S 16 controls</td>
<td>-</td>
<td>Hoffman <em>et al</em>, 2006</td>
</tr>
<tr>
<td><strong>S:</strong> Mean ca 22 ppm (biol. monit)</td>
<td>170 dir exp 86 indir exp 43 controls</td>
<td>-</td>
<td>Sass-Kortsak <em>et al</em>, 1995</td>
</tr>
<tr>
<td><strong>N:</strong> not given</td>
<td>18 S Comp to reference pop.</td>
<td>+</td>
<td>Möller <em>et al</em>, 1990</td>
</tr>
<tr>
<td><strong>S:</strong> &lt; 25 ppm.</td>
<td></td>
<td>++ Bal</td>
<td></td>
</tr>
<tr>
<td><strong>N:</strong> not given</td>
<td>23 S and N 12 controls</td>
<td>++</td>
<td>Morioka <em>et al</em>, 2000</td>
</tr>
<tr>
<td><strong>S:</strong> &lt; 30 ppm</td>
<td>59 S 94 controls</td>
<td>+</td>
<td>Muijser <em>et al</em>, 1988</td>
</tr>
<tr>
<td><strong>N:</strong> S+N =76 dBA</td>
<td>20 S</td>
<td>-</td>
<td>Calabrese <em>et al</em>, 1996</td>
</tr>
<tr>
<td><strong>S:</strong> &lt; 35 ppm.</td>
<td></td>
<td>++ Bal</td>
<td></td>
</tr>
<tr>
<td><strong>N:</strong> &lt; 85 dBA</td>
<td>20 S</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Solvents - Possible Mechanisms

• **Synergistic** interaction with noise in animal model

• **Effect on isolated OHC**
  – Dose-response shortening of OHC, more pronounced in apical end of cochlea
  – Free intracellular Ca$^{2+}$ increased

• **Intoxication Route via Organ of Corti**
  – Toluene/Styrene concentrations highest in stria vascularis
  – Lower concentrations in supporting cells near to Organ of Corti

• **Inhibit the auditory efferent system**
  – modifying the response of the protective acoustic reflexes

• **ROS formation**
  – apoptotic cell death
Human studies on occupational exposure to Styrene

- 12 studies - 10 different groups of workers
- Different designs and outcome measures used
- Majority of studies showed effects on hearing
  - PTA not the best indicator AND Central effects also present

Conclusion: LOAEL is inconclusive but suggested to be below 20 ppm (current exposure and low noise level at time of studies).
### Human studies – Toluene OEL 50-100 ppm

<table>
<thead>
<tr>
<th>Exposure levels</th>
<th>Toluene groups</th>
<th>Evidence of HL shown</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Current exposures</strong></td>
<td><strong>T= Toluene, N= Noise</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>T</strong>: low 3 ppm</td>
<td>152 low T</td>
<td>-</td>
<td>Schäper et al., 2003</td>
</tr>
<tr>
<td><strong>T</strong>: high 26 ppm</td>
<td>181 high T</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>N</strong>: Not given</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| **T**: 20 ppm | 49 TOL | (+) | Vrca et al., 1996 |
| **N**: Not given | 59 controls | | |

| **T**: ~ 97 ppm | 40 T | (+) | Abate et al., 1993 |
| **N**: Not given | 40 controls | | |

| **T + N**: 9-37 ppm | 50 T+N | ++ with N | Bernardi, 2000 |
| **N**: 88-98 dBA | 50 N | 40 controls | |

| **T + N**: ≤50 ppm (in 109 workers; biol. monit.) | 124 T (in mixture)+N | + with N | Morata et al., 1997 |
| **N**: 71-93 dBA | | | |

| **Cumulative expo index** | | | |
| **T + N**: 176-2 265 year-ppm | 58 TOL+N | ++ with N | Chang et al., 2006 |
| **N**: 79-87 dBA | 58 N | 58 controls | |

| **T + N**: 100-365 ppm | 50 N | +++ with N | Morata et al., 1993 |
| **N**: 88-98 dBA | 51 T+N | 50 controls | |
Human studies on occupational exposure to Toluene

- 7 studies
- Different designs and outcome measures used
- Majority of studies showed effects on hearing
  - PTA not the best indicator, since central effects also present
- Toluene exposure levels in studies were moderate to high

Conclusion: LOAEL is approximately 50-100 ppm (current exposure and low noise level at time of studies).

- Noise was always present (above or below 85 dBA).
Other solvents – Human studies

Mixtures (Toluene & Xylene often included)

- In animal studies additive effects have been shown for solvent pairs in high doses
- In humans many studies with solvent mixtures have shown HL at low current exposure levels
  - Due to differences in exposure content and levels evidence available is not sufficient for the identification of the NOAELs and LOAELs in humans.
Other solvents – with human studies

CS$_2$
- Central auditory effects shown in rats
  - NOAEL 200 ppm (5 w) or 400 ppm (11 w)
  - LOAEL 800 ppm
- Central auditory effects and hearing loss shown in workers after chronic exposure
  - LOAEL above 14 ppm current exposure
Metals

Mercury
- neurotoxicity and sensorineural hearing deficits
- excitatory effects on central auditory structures
- potassium channels may be targets

Lead
- dysfunction of the eighth cranial nerve in rats
- cochlear effects were reported in studies with monkeys
- central auditory effects in humans

Organotins - trimethyltin
- hair cell damage and vascular damage in the cochlea
- disrupts function at the synapse between the inner hair cell and the Type 1 spiral ganglion cell
Study finds Beethoven died of lead poisoning

By Rick Weiss
Washington Post

By focusing the most powerful X-ray beam in the Western Hemisphere on six of Ludwig van Beethoven’s which evidence now suggests occurred over many years. Among the possibilities are his liberal indulgence in wine consumed from lead cups or perhaps a lifetime of medical treatments, which in the 19th century—
# Metals – Animal studies

<table>
<thead>
<tr>
<th></th>
<th>NOAEL</th>
<th>LOAEL</th>
<th>Exposure duration</th>
<th>Referenc-G</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Lead (blood lead level) - only</strong></td>
<td></td>
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<tr>
<td></td>
<td>-</td>
<td>30 μg/dl</td>
<td>In diet: birth to 13 years of age</td>
<td>Rice 1997</td>
</tr>
<tr>
<td></td>
<td>35 μg/dl</td>
<td>55 μg/dl</td>
<td>In diet: prenatal to ~10 years of age</td>
<td>Lilienthal and Winneke, 1996</td>
</tr>
<tr>
<td><strong>Mercury - only</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>-</td>
<td>0.4 mg/kg bw HgCl₂</td>
<td>Gavage: daily in 12 weeks (rats)</td>
<td>Fazakas et al 2005</td>
</tr>
<tr>
<td></td>
<td></td>
<td>10 μg/kg/d HgCH₃Cl</td>
<td>Orally: gestation to 4 y of age</td>
<td>Rice 1998</td>
</tr>
<tr>
<td></td>
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<td></td>
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<tr>
<td><strong>Trimethyltins - only</strong></td>
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</tr>
<tr>
<td></td>
<td>2 mg/kg bw</td>
<td>0.2 mg/kg bw</td>
<td>single i.p. injection</td>
<td>Liu and Fechter, 1994</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3 mg/kg bw</td>
<td>Guinea pigs</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>single i.p. injection</td>
<td>Crofton et al., 1990</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Rats OHC-loss</td>
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</tr>
</tbody>
</table>
Metals – Human studies

**Lead**
- NOAEL is not known
- LOAEL is blood lead concentrations of 12-64 μg/dl
- No interaction greater than additive between lead (57 μg/dl) and noise found
  - One study only
- Auditory effects begin to appear at blood lead levels found in the general population
  - Western Europe (37 μg/dl) and North America (17 μg/dl)

**Mercury**
- LOAELs; Concentration in air of 0.008 mg/m3 and mean blood mercury levels of 0.5 μg/l showed effects in central auditory tests

**Trimethylnitins**
- No human studies
Other chemicals

• Asphyxiants
  – Interfere with cell “breathing”
  – Not ototoxic alone (animal models) BUT potentiate other ototoxic agents and noise
    – Maybe by ROS formation

• Carbon monoxide - CO
  – Smoking

• Hydrogen cyanide
  – Other nitrils
Carbon monoxide – animal studies

<table>
<thead>
<tr>
<th>NOAEL</th>
<th>LOAEL</th>
<th>Exposure duration</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Carbon monoxide - only</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1500 ppm</td>
<td>500 ppm + 95 or 100 dB</td>
<td>Inhalation 3.5-9.5 h</td>
<td>Chen and Fechter 1999</td>
</tr>
<tr>
<td>-combined with noise (N)</td>
<td>500 ppm + 95 or 100 dB</td>
<td>Inhalation 3.5-9.5 h, 5 d</td>
<td>Chen and Fechter 2000; Fechter et al 2000</td>
</tr>
<tr>
<td>300 ppm + 95 or 100 dB</td>
<td>500 ppm + 95 or 100 dB</td>
<td>Inhalation 3.5-9.5 h, 5 d</td>
<td>Chen and Fechter 2000; Fechter et al 2000</td>
</tr>
<tr>
<td>300 ppm + 87 dB SPL Leq8h impulse noise</td>
<td>500 ppm + 87 dB SPL Leq8h impulse noise</td>
<td>Inhalation and N: 6 h/d, 10 d</td>
<td>Lund et al 2003</td>
</tr>
<tr>
<td><strong>Hydrogen cyanide - only</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>50 ppm</td>
<td></td>
<td>Inhalation: 3.5 h</td>
<td>Fechter et al 2002</td>
</tr>
<tr>
<td>-combined with noise (N)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10 ppm + 100 dB</td>
<td>30 ppm + 100 dB</td>
<td>Inhalation: 3.5 h, N: 2 h</td>
<td>Fechter et al 2002</td>
</tr>
</tbody>
</table>

Additional stressors make it worse -
Exposure to CO, noise AND Toluene caused even more HL than CO and noise alone (Lund, Kristiansen and Campo, 2008)
Carbon monoxide

• Animal studies/consider safety factor
  – Interaction and potentiation with noise shown
    • NOAEL without noise 1500 ppm
    • NOAEL with noise 300 ppm
    • LOAEL with noise 500 ppm

• Human studies
  – Few studies of auditory effects
  – Type of interaction between carbon monoxide and noise has not been established
  – The LOAEL is inconclusive,
    • One study suggested a LOAEL of ~ 20 ppm without excessive noise exposure
Other chemicals

• Pesticides
  – Many different substances
  – Limited evidence because of the heterogenicity

• PCBs
  – Only investigated in animal studies
  – Some PCBs give auditory effects in the offspring after dosage during gestation
    • NOAEL: 0.25 μg/kg body weight/day or 1mg/kg depending of PCB mixture
    • LOAEL: 1 μg/kg body weight/day (1 mg/kg body weight/day or 3 mg/kg depending of PCB mixture
Is there evidence for the ototoxicity of chemicals in occupational settings?

- Strongest evidence for
  - Styrene
  - Toluene
  - Mixtures of solvents
  - Lead
  - Carbon monoxide

- Dose - response relationship challenging in human studies

- Strong support from animal studies
  - Increased risk with more exposure factors
Threshold (dB HL)

Frequency (kHz)

Control
Noise
Styrene
Styrene & Noise

Best ear

Morata et al., 2002
TLVs® and BEIs®:

“Exposure to certain chemicals may also result in hearing loss. In settings in which there may be exposure to noise as well as toluene, lead,... ...periodic audiograms are advised and should be carefully reviewed.”
Position Papers


ACOEM Evidence-based Statement Noise-induced Hearing Loss, JOEM 2003, 2012:

“Clinicians evaluating cases of possible noise-induced hearing loss should keep in mind the following clinical concerns:...
Coexposure to ototoxic agents, such as solvents, heavy metals and tobacco smoke, may act in synergy with noise to cause hearing loss”.
US Army Regulation 1998-2016

Dept. of the Army Pamphlet 40-501 Hearing Conservation Program:
Requires consideration of ototoxic chemical exposures for program
inclusion, particularly when in combination with marginal noise (¶ 3-3).

Fact Sheet 51-002-0903 suggests Action Level for chemicals for
inclusion in Hearing Conservation Program.
Laws and Standards - Abroad

The European Community directive on noise (2003/10 EC noise) requires that the interaction between noise and work-related ototoxic substances, and noise and vibration be taken into account in the risk assessment of exposed populations.
(Article 4 of Section II)


Countries (Australia, New Zealand, Brazil) started to accept link between chemical exposure and hearing loss in compensation cases.

Occupational exposure to chemicals

- Ototoxic chemicals **DO** increase the risk for hearing loss

- OELs for chemicals do not account for ototoxicity

- New EU Noise directive
  - Acknowledge ototoxic substances in risk assessment

- Consideration ought to be given for the inclusion of workers exposed to ototoxic chemicals should in Hearing Loss Prevention Programs
Laws and Standards

Change in Toxicity label due to ototoxic effects

"I TOLD YOU WE SHOULD HAVE READ THE SOLVENT INSTRUCTIONS CAREFULLY!"
Combined exposure to noise and ototoxic substances

• Review of literature
• Strength of evidence
• Gaps in research and regulations and
• Perspectives considering individual countries, the Global Harmonised System and REACH

Information dissemination is very important

• Which chemicals are ototoxic?
• Acknowledge ototoxic substances in standards, but HOW??


http://www.av.se/dokument/inenglish/legislations/eng1118.pdf
The problem is complex, but... can the solution be simple?
What else can we all do?

Tell everybody about it!!!

Improve the exchange of information on evidence-based practices. Share your stories, so many avenues exist today for us to reach out to the general public and health community!
CLEAN IT UP and QUIET IT DOWN!

- Reduce hazardous exposures, thinking of the big picture
  - Engineering controls, Buy-Quiet, Design Quiet
  - Protective equipment (e.g. respirators, gloves)
- Education of the potentially affected population
Research, policy and practice

✓ Information to scientists
✓ Information to policy makers
  - Information to general public
✓ Publication of guidelines, best practices in different formats
✓ Regulation
✓ Awards and Incentives
Thank you! Any questions?

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