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Noise and neurotoxic chemical exposure relationship to workplace traumatic injuries: A review☆

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Abstract

Introduction—More than 5,000 fatalities and eight million injuries occurred in the workplace in 2007 at a cost of $6 billion and $186 billion, respectively. Neurotoxic chemicals are known to affect central nervous system functions among workers, which include balance and hearing disorders. However, it is not known if there is an association between exposure to noise and solvents and acute injuries.

Method—A thorough review was conducted of the literature on the relationship between noise or solvent exposures and hearing loss with various health outcomes.

Results—The search resulted in 41 studies. Health outcomes included: hearing loss, workplace injuries, absence from work due to sickness, fatalities, hospital admissions due to workplace accidents, traffic accidents, hypertension, balance, slip, trips, or falls, cognitive measures, or disability retirement. Important covariates in these studies were age of employee, type of industry or occupation, or length of employment.

Discussion—Most authors that evaluated noise exposure concluded that higher exposure to noise resulted in more of the chosen health effect but the relationship is not well understood. Studies that evaluated hearing loss found that hearing loss was related to occupational injury, disability retirement, or traffic accidents. Studies that assessed both noise exposure and hearing loss as risk factors for occupational injuries reported that hearing loss was related to occupational injuries as much or more than noise exposure. Evidence suggests that solvent exposure is likely to be related to accidents or other health consequences such balance disorders.

Conclusions—Many authors reported that noise exposures and hearing loss, respectively, are likely to be related to occupational accidents.

Practical applications—The potential significance of the study is that findings could be used by managers to reduce injuries and the costs associated with those injures.

☆Disclaimer: The findings and conclusions in this report are those of the author(s) and do not necessarily represent the views of the National Institute for Occupational Safety and Health.

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Keywords

Workplace; Accidents; Workers' compensation; Solvent exposure; Injury

1. Problem

More than 5,000 fatalities and eight million injuries occurred in the workplace in 2007 at a cost of $6 billion and $186 billion, respectively (Leigh, 2011). Approximately 22 million workers are exposed to hazardous noise in the United States (Tak, Davis, & Calvert, 2009). *Healthy People 2020* objectives include a 10% reduction in occupational injuries to 380 per 10,000 workers (HHS, 2010). One potential contributor to occupational injury is noise exposure (Girard et al., 2009; Kling, Demers, Alamgir, & Davies, 2012). Cohen (1973a) reported a higher number of accidents per worker among younger workers in high noise jobs (≥95 dBA) but he did not control for inherent risk of injury in jobs. Girard et al., (2009) reported that noise exposure (>90 dBA) increased the risk of workplace accidents (RR = 1.1 to 1.3) as did hearing loss (RR = 1.1 to 2.3) and both factors (RR = 1.2 to 2.8). Girard et al., (2009) recruited participants from six manufacturing industries, somewhat controlling for workplace risk. Workers were shown to have higher injuries among those newly exposed to noise and those with high job complexity (Melamed, Fried, & Froom, 2004). These significant associations may be due to hearing loss (Park, Bushnell, Bailer, Collins, & Stayner, 2009; Zwerling et al., 1996), high job complexity (Melamed et al., 2004), or communication abilities (Kling et al., 2012).

Solvents are commonly used in many industries and processes including: vapor degreasing, dry cleaning, painting, adhesives, dyes, agricultural products, aviation, and shoes and other textiles (Kelafant, Berg, & Schleenbaker, 1994; NIOSH, 1987). Over 30 million American workers are exposed to hazardous chemicals in their workplaces, and several of these can represent a risk to the hearing of the exposed worker (OSHA, 2004). An outdated, but best estimate is that there are as many as 9.8 million workers exposed to organic solvents (NIOSH, 1987). Organic solvents are volatile, relatively stable, liquid (at room temperature) mixtures or compounds in the following general classes: aliphatic hydrocarbons, cyclic hydrocarbons, aromatic hydrocarbons, halogenated hydrocarbons, ketones, amines, esters, alcohols, aldehydes, and ethers (NIOSH, 1987). Many industries with solvent exposures also have workers exposed to hazardous noise levels. Masterson et al. (2013) reported high prevalence of hearing loss among workers in mining, construction, and certain manufacturing industries. The workers in these industries are often also using solvents and other chemicals that could affect the central nervous system. High-level, acute exposures to solvents (e.g., abusers) cause central nervous system depressant effects. Moderate to high level chronic exposures to certain solvents (e.g., n-hexane and carbon disulfide) cause specific degenerative effects to the central and peripheral nervous system. However, the extent to which low-level chronic exposures can cause neurological damage is less clear (Klaassen, 2008). Animal studies of solvent exposure may underestimate the effects of exposure to workers because sedentary animals have lower pulmonary and cardiac requirements (American Conference of Governmental Industrial Hygienists, 1996). Schaper and Bisesi (2003) suggest occupational injuries can be related to overexposure to neurotoxic substances such as solvents, heavy metals, pesticides, and asphyxiates. Ototoxic chemicals are known to cause central nervous system (CNS) effects and hearing loss but little is known about the relationship with occupational injuries.

The goal of this paper is to review the literature of noise and solvent exposures and their relationships with traumatic injuries in the workplace.

2. Methods

A literature search was conducted for studies that evaluated the relationship between noise or solvent exposures, hearing loss, with various health outcomes. The health outcomes included: workplace fatalities or injuries, workplace absences, hearing loss, hypertension, memory loss, postural balance measures, or neurological symptoms. Additionally, a search was conducted for studies that evaluated noise *and* solvent exposures with injury or postural balance. Literature searches were conducted of PUBMED and CINAHL (Cumulative Index to Nursing and Allied Health Literature). All searches were limited to English language, humans, and publication since 1980. Articles were determined to be relevant after reviewing the abstract, if available, otherwise, the title.

For noise exposure or hearing loss, PUBMED and CINAHL searches used the following Medical Subject Headings (MESH) terms: (“accidents, occupational” OR “occupational injuries”) AND (“hearing loss, noise-induced” OR “noise, occupational”). For solvent exposure, PUBMED and CINAHL searches were conducted using the following Medical Subject Headings (MESH) terms: (“accidents, occupational” OR “occupational injuries” OR “postural balance”) AND “solvents.” For solvent *and* noise exposure, a review of the literature was conducted to identify research on a relationship between noise and chemical exposures with occupational accidents. A literature search of PUBMED was conducted using the following terms, “(noise or hearing) and (solvent or chemical) and (accident or injury or balance) and (work or occupational or job).”

To limit the introduction of bias through this process, after the first author selected studies for inclusion in this review, the three other authors indicated their agreement for inclusion.

3. Results

When searching PUBMED for articles on noise exposure or hearing loss that relate to injury outcomes, 38 articles were found. When searching CINAHL, seven additional articles were found that were relevant to noise exposure or hearing loss and accidents. Thereby 29 articles were determined to be relevant and provided a point estimate of effect. Tables 1 and 2 provide a summary of the articles for noise exposure and hearing loss, respectively. There were also three reviews articles (Jadhav, Achutan, Haynatzki, Rajaram, & Rautiainen, 2015; Palmer, Harris, & Coggon, 2008; Wilkins & Action, 1982). The studies reviewed in those articles were included here, if relevant. The goal of most studies was to evaluate the effect of noise exposure on accidents, injuries, sickness absence, or fatalities while the goal of a smaller group of studies was to evaluate the effect of hearing loss on accidents or injuries.

For articles on the relationship between solvent exposure and injury outcomes, 47 articles were found. After reviewing the abstracts for relevance, 17 were included in this review. Many of those not reviewed were case studies or reports about conditions in various industries. Most studies were reports of the effect of solvent exposure on balance, while other outcome measures included cognitive measures, slip, trips, and falls, or hypertension.

When searching for articles evaluating exposures to solvents and noise as they relate to injury outcomes, 55 records were found. However, most titles were broad descriptors of noise, chemicals and accidents or described possible hazards of an occupation; the titles did not indicate results relating noise and chemical exposure to occupational accidents. Three reports were retrieved (Hodgkinson & Prasher, 2006; Nies, 2012; Prasher, Al-Hajjaj, Aylott, & Aksentijevic, 2005) for possible relevance to this topic. Fig. 1 shows a relationship between chemical and physical occupational exposures, those factors on the causal pathway, and occupational accidents.

4. Discussion

4.1. Noise exposure relationship with injury, absence, or symptom

To evaluate if noise exposure is related to occupational injury, the following outcome measures were used from the reviewed studies: workplace injuries, sickness absence, fatalities, hospital admissions due to workplace accidents, traffic accidents, and hypertension. Tables 1 & 2 include columns that provide the factors that were adjusted in the analyses. The inherent safety hazards associated with each job are difficult to discern. d’Errico and Costa (2012) asked workers about the inherent physical risk when performing their job. Although there are disadvantages to this method, use of the method did address the possible association. The result considers the inherent risk of accidents associated with the job regardless of noise level. Cantley et al. (2015) used company records of physical job demands as a surrogate for degree of job hazard. In the study by Zwerling gender and education level were removed from analysis after adding occupation (Zwerling, Whitten, Davis, & Sprince, 1997). Age is a covariate with accidents in these studies as younger people who are also less experienced are more likely to be injured. Most studies were adjusted for age. Melamed (2004) conducted a study with 6,000 workers and adjusted for risk of physical injury, age, years of experience, occupation, body mass index (BMI), and education level; an odds ratio (OR) of 5.96 for an accident with one lost workday was reported for workers with noise exposure greater than 80 dBA. Three studies that included odds ratios as an effect measure showed a 36% increase in sickness absence (d’Errico & Costa, 2012), a 52% increase in workplace injuries (Amjad-Sardrudi, Dormohammadi, Golmohammadi, & Poorolajal, 2012), and 495% increase in accidents with one lost work day (Melamed et al., 2004). Cantley et al. (2015) reported a relative risk (RR) of 1.61 for jobs with noise exposure of 88 dBA or more compared to those with noise exposure less than 82 dBA. Clausen, Christensen, Lund, and Kristiansen (2009) described a cohort of Danish workers and found those who self-reported their noise exposure as “rarely” or “half time” had a hazard ratio (using Cox proportional hazard model) for sickness absence of 1.43, and 1.37, respectively, while those who reported exposure of “¾ time” had a hazard ratio of 0.87. In this study, the authors suggested that actual measurements would have been more useful because some workers perceive noise differently (e.g., teachers with lower exposures than industrial workers may consider noise more of a problem). Authors of all other studies reported increased accidents, sickness, or fatalities associated with higher levels of noise exposure or longer duration of noise exposure.

Researchers performing cohort studies often merged multiple databases to analyze for the health risk of noise exposure. Many of the cross-sectional studies and some of the case–control studies were conducted at one or two manufacturing facilities. Only one study was found that included data at the company level rather than the individual level. Yoon, Hong, Roh, Kim, and Won (2015) conducted analyses of 1790 workplaces in Korea and combined those data with injury compensation records on a company level but did not adjust for the level of physical risk at the workplace. Noise exposure is likely to be related to acute injury. Authors of all studies except Lees, Romeril, and Wetherall (1980) concluded that higher exposure to noise increased the risk of the chosen health effect (e.g., accidents, injuries, hospitalizations, absences, or hypertension). However, limitations existed in these studies. The overall relationship is not well understood because these results were confined to a few industrial sectors (Amjad-Sardrudi et al., 2012; Barreto, Swerdlow, Smith, & Higgins, 1997; Cantley et al., 2015; Cohen, 1973b; Lees et al., 1980; Moll van Charante & Mulder, 1990; Picard, Girard, Simard, et al., 2008; Sbihi, Davies, & Demers, 2008), relied on worker's opinion or recall (Clausen et al., 2009; d'Errico & Costa, 2012; Dias & Cordeiro, 2007, 2008; Melamed, Luz, & Green, 1992), or were not adjusted for age or experience (Barreto et al., 1997; Dias & Cordeiro, 2008; Melamed et al., 1992; Moll van Charante & Mulder, 1990) or occupation or safety hazard (Amjad-Sardrudi et al., 2012; Girard et al., 2009; Kling et al., 2012; Lees et al., 1980; Melamed et al., 1992; Moll van Charante & Mulder, 1990; Picard, Girard, Courteau, et al., 2008; Picard, Girard, Simard, et al., 2008; Sbihi et al., 2008; Yoon et al., 2015).

4.2. Hearing loss relationship to injury, absence, or symptom

Table 2 provides summaries of studies about hearing loss and the risk of occupational injury. Most studies were performed by evaluating hearing loss by audiometry. The other studies used interview techniques. Outcome measures for these studies included occupational injury, ill-health retirement, or traffic accidents. Authors of the studies that were performed by adjusting for occupation and providing odds ratios reported that impaired hearing resulted in 60%, 69%, and 55% more injuries, respectively, than among individuals without hearing loss (Moll van Charante & Mulder, 1990; Zwerling et al., 1996, 1997). Authors of one study reported a RR of 1.21 for workers with a hearing threshold shift level of ≥25 dB compared to those with normal hearing (<10 dB) (Cantley et al., 2015). As shown in Table 2, every study included evidence that hearing loss was related to occupational injury, ill-health retirement, or traffic accidents.

When studying an association between noise exposure and the risk of occupational injury, hearing loss is on a causal pathway between noise exposure and accidents. Hearing loss could be considered an intermediate outcome because it is principally caused by noise exposure and can, without continuing noise exposure, be related to workplace accidents.

Results from studies of both noise and hearing loss as risk factors for occupational injuries (Tables 1 & 2) show that hearing loss was related to occupational injuries to a similar or greater degree than noise-exposure. Amjad-Sardrudi et al. (2012) reported an OR of 1.52 for workplace injuries resulting from noise exposure compared to an OR of 1.72 to 7.87 resulting from partial to mild hearing loss. Picard reported a 6.2% attributable fraction (AF) to noise exposure for resulting workers' compensation accidents, 7% to hearing loss, and 12% to both (Picard, Girard, Simard, et al., 2008). Moll van Charante et al. (1990) reported that participants with a hearing loss of 20 dB had a significantly higher odds ratio of a workplace accident, and those with high noise exposure also had a significantly higher odds ratio of developing a workplace accident. However, those with hearing loss and noise exposure did not have an odds ratio significantly different from one. The authors suggested that hearing is not as important for avoiding accidents in situations with high noise levels as it is in quieter environments. Taken together these results suggest the possibility that there could be an additive effect of noise and hearing loss on the risk of occupational injury.

4.3. Solvent exposure relationship with injury, absence, or symptom

Table 3 shows a summary of outcome statistics from the articles that included point estimates for relationships between the studied variables. Seven investigators evaluated the relationship between occupational solvent exposure and workers' balancing abilities (Herpin et al., 2008; Iwata, Mori, Dakeishi, Onozaki, & Murata, 2005; Kilburn, Warshaw, & Thornton, 1987; Kuo, Bhattacharya, Succop, & Linz, 1996; Park, Lee, Lee, & Lim, 2009; Zamyslowska-Szmytke, Politanski, & Sliwinska-Kowalska, 2011; Zamyslowska-Szmytke & Sliwinska-Kowalska, 2011). All of these studies involved groups of workers with low-level solvent exposure; the highest exposure level (Zamyslowska-Szmytke et al., 2011) studied was styrene at 37 mg/m^3 (~9 ppm). Postural balance was typically assessed with static posturography quantifying sway area and sway length. A force platform was used to determine the *x* and *y* coordinates of a participant's center of pressure. Sway area and length are the area within and the distanced traversed by the participant's center of pressure, respectively, during the observation period (Smith et al., 1997). Results from these seven studies show that those workers exposed to solvents at low levels in their work areas had larger sway area or sway length than non-exposed workers.

Among elderly populations, research shows that force platform data may have predictive value for subsequent falls (Maki, Holliday, & Topper, 1994; Piirtola & Era, 2006). A majority of the investigators adjusted for age in the final model, as shown in the right column of Table 3. Loss of balancing abilities is clearly related to risk of falls among the elderly (Doheny et al., 2012; Maki et al., 1994; Piirtola & Era, 2006).

Zamyslowska-Szmytke and Sliwinska-Kowalska (2011) reported on a study of a group of non-symptomatic workers exposed to solvents to evaluate their vestibular system and balance. Sixty-four percent of the exposed workers showed some disturbances in these vestibular tests. Park (Park, Bushnell, et al., 2009; Park, Lee, et al., 2009) evaluated 41 exposed and 90 non-exposed workers from four plants in South Korea to assess neurotoxic effects from exposure to solvent mixtures using biological monitoring. Monitoring results were a mean of 47% for exposed workers when compared to the American Conference of

Governmental Industrial Hygienists (ACGIH) Biological Exposure Indices (BEI), showing that exposure was about half of exposure guidelines. Statistically significant differences were found in sway area ($p = 0.001$) with the exposed group having higher areas indicating an association between occupational solvent exposure and sub-clinical balancing abilities of workers. A couple of case studies were performed among occupational groups whose authors concluded that an individual's intrinsic balance capability was a factor in falls at the same level (Derosier, Leclercq, Rabardel, & Langa, 2008; Gauchard, Chau, Mur, & Perrin, 2001).

Only three studies were found that included assessment of the effect of solvent exposures on occupational accidents. A longitudinal study of the relationship between solvent exposure and slips, trips, and falls (STF) was conducted by collecting weekly surveys from members of a painters union (Hunting, Matanoski, Larson, & Wolford, 1991). STFs increased for those workers with low solvent exposure compared to those with no solvent exposure. Workers with moderate to high levels of solvent exposure did not have a statistically greater number of STFs. A cross-sectional survey of 1,000 workers was conducted in the Thailand wood furniture industry (Tuntiseranee & Chongsuvivatwong, 1998). The authors found that many workers had chemical exposures and injury rates that were higher than other industries in Thailand. Other authors did not find factors predictive of WC claims in a cross-sectional study of companies where workers were exposed to lead (Seligman, Halperin, Mullan, & Frazier, 1986). The latter two studies are not included in Table 3 because no statistical analyses were made to quantify a relationship between exposure and accidents.

Results of three studies described a relationship with solvent exposures and memory or cognition. Decreased memory or cognition was related to worker solvent exposure (Kilburn et al., 1987) in one study. Another author reported increased relative risk of having a cognition test score in the lowest 25th percentile among workers exposed to solvents (Sabbath et al., 2012). A group of workers that had been accidentally poisoned to solvents were compared to their non-exposed peers and had reduced performance on memory tasks (Stollery & Flindt, 1988).

Collectively, these research results show that solvents may be related to accidents or other health consequences. Many studies compared exposures to loss of balancing abilities; loss of balancing abilities could be an intermediate result leading to accidents in the workplace.

4.4. Solvents and noise exposure

The Nordic Expert Group (Johnson & Morata, 2010) published a comprehensive review of occupational exposure to chemicals and hearing loss summarizing the literature on this topic from 1950 to November 2007. The chemicals were chosen based on the extensive evidence on their ototoxicity. The review included pharmaceuticals, organic solvents, metals, asphyxiants, pesticides, and polychlorinated biphenyls. Exposures near or below the existing occupational exposure limits (OEL) resulted in auditory effects for the following chemicals: styrene, toluene, carbon disulfide, lead, mercury and carbon monoxide. They also reported animal evidence showing that exposure to p-xylene, ethylbenzene, and hydrogen cyanide (at or below the OEL) are related to hearing loss but there is a lack of human data. Another review of animal and human literature of ototoxic substances through 2009 was conducted and findings showed that "lead, styrene, toluene and trichloroethylene are ototoxic and ethyl benzene, n-hexane and p-xylene are possibly ototoxic at concentrations that are relevant to the occupational setting" (Vyskocil et al., 2012). The authors also noted that carbon monoxide possibly interacts and toluene does interact with noise exposure to exacerbate hearing loss.

Hodgkinson and Prasher (2006) reviewed the literature on the effects of industrial solvents on both hearing and balance and concluded that noise can lead to hearing loss and solvent exposure can result in vestibular disturbances but further research was needed. Prasher et al. (2005) conducted a study of aircraft maintenance workers with groups exposed to noise and noise plus solvents and observed effects on the audio-vestibular system from noise plus solvent exposure. Postural sway abnormalities were reported in about one third of workers exposed to noise and solvents. These studies were primarily concerned with ototoxic chemicals causing hearing loss and not the combined effect of noise and solvents on balance. No literature was found that describes the combined effect of noise and solvent exposure on occupational accidents.

5. Summary

This review of identified literature shows that many physical and chemical hazards are related or may be related to accidents in the workplace. Noise and hearing loss studies support a possible relationship between noise exposure and hearing loss, respectively, and occupational accidents. Noise exposure is known to cause hearing loss. Hearing loss may be included in the causal pathway between noise exposure and accidents. Studies of solvent exposure (without noise exposure) and its relationship to occupational accidents were not found, instead investigators showed that postural balance was affected by solvent exposure. A reduced ability to maintain postural balance could be a risk factor for occupational accidents but was not reviewed here. Exposure to ototoxic substances is also related to hearing loss, an element in the causal pathway to occupational accidents.

Biographies

Cheryl F. Estill, Ph.D., P.E. is a Captain in the US Public Health Service (PHS). CAPT Estill received her Ph.D. in Environmental Health from the University of Cincinnati, and engineering degrees from Virginia Tech and Purdue University. She is an Industrial Hygiene Supervisor at the National Institute for Occupational Safety and Health (NIOSH). Besides the research presented here, Dr. Estill is conducting research on exposure assessment to flame retardants in during installation of polyurethane spray foam insulation. Previously, she conducted studies on environmental sampling for *b. Anthracis*, engineering controls for the prevention of musculoskeletal disorders (MSDs) in the construction and agriculture industries, noise exposures in manufacturing, chemical exposures in nail salons, MSDs in appliance manufacturing, and chemical exposures at furniture stripping shops.

Carol H. Rice, PhD, CIH is Professor Emerita, Department of Environmental Health, University of Cincinnati College of Medicine. Current research interests include worker exposure to fibers (natural and man-made) and beryllium, and the uniform collection of worker and environmental exposure data following emergencies/disasters. Dr. Rice continues as director of the NIEHS-funded Midwest Consortium for Hazardous Waste Worker Training.

Thais C. Morata earned a doctoral degree in Communication Sciences and Disorders from the University of Cincinnati in 1990. Currently she is a Research Audiologist at the National Institute for Occupational Safety and Health (NIOSH, Cincinnati) and the Coordinator of the National Occupational Research Agenda Manufacturing Sector Council, a network of partners and stakeholders who collaborate through activities encompassing the entire research continuum. Dr. Morata created and directs the Safe-in-Sound Excellence in Hearing Loss Prevention Awards™. She is a Founding Associate Editor for the International Journal of Audiology (from the International Society of Audiology), and a Founding Editor of the Cochrane Work (Occupational Safety and Health) Group. Her pioneering work in the area of noise interactions in the workplace has influenced not only NIOSH priorities and policy, but has affected national and international occupational safety and health policies. More recently, she is devoting time to the goals of improving the communication of science to the public through new media, and promoting the adoption of evidence-based health practices.

Amit Bhattacharya, PhD is a Professor of Environmental Health, Biomedical and Mechanical Engineering at the University of Cincinnati. His areas of research interest include ergonomics, biomechanics, postural balance and gait mechanics and non-invasive detection of pre-clinical detection of bone fragility and neurodegenerative disorders associated with low level exposures to environmental and occupational toxins.

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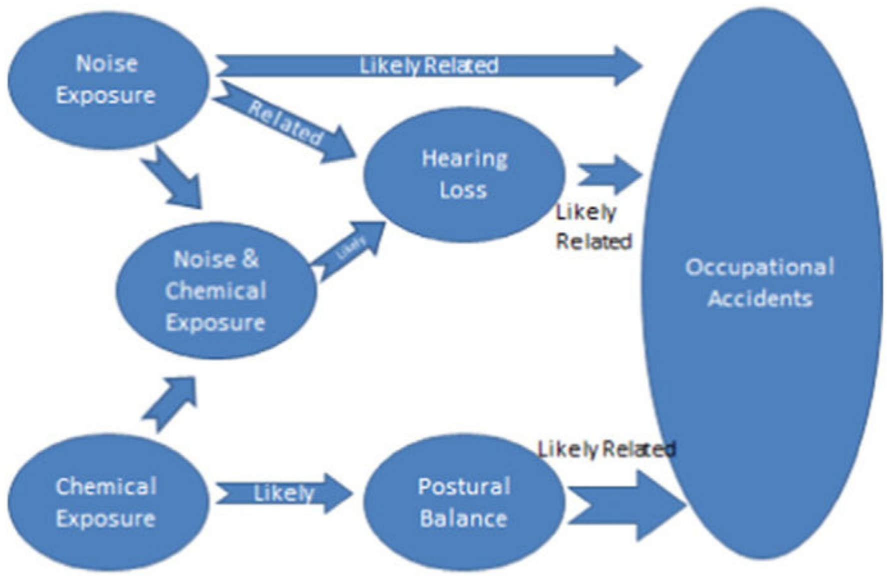

Fig. 1.
Relationships between noise and neurotoxic chemical exposures and accidents.

Table 1

Studies on noise exposure and risk of occupational injury, absence, or symptom. Table adapted from (Palmer et al., 2008).

Design first author	Definition of exposure*	Injury or health measure	Sample size	Effect measure**	Point estimate (CI)†	Factors considered‡
Amjad-Sardrudi et al. (2012)	≥85 dBA	Workplace injuries	1062	OR	1.52(1.10,2.11)	a, y
Barreto et al. (1997)	High ≥95 dBA	Fatality	177	OR	2.19(0.60, 8.04)	e
	Moderate				5.72 (1.63, 20.1)	
	Low <90 dBA				3.05(0.80,11.7)	
(Cohen, 1973b)	High >95 dBA	% with 15 accidents in	903	%	35%	a, o, e,
Boiler plant only	Low <80 dBA	5 year period			5%	
Cantley et al. (2015)	>88 dB	All injuries	9,220 workers	RR	1.61 (1.13–2.30)	a, li, o, ra, s, y
	85–87.9 dB				1.34 (1.07–1.70)	
	82–84.9 dB				1.15 (0.94–1.41)	
	<82 dB					
	>88 dB	Serious Injuries			2.29 (1.52–3.47)	
	85–87.9 dB				1.39 (1.05–1.85)	
	82–84.9 dB				1.26 (0.96–1.64)	
	<82 dB					
Clausen et al. (2009)	Self-report noise	Sickness absence	5186	HR		a, e, c, ch, b, al, sm, r
	exposure — men > ¾ time				0.87 (0.61, 1.23)	
	1/2 time				1.43 (1.10, 1.85)	
	Rarely				1.37 (1.07, 1.76)	
d'Errico and Costa (2012)	Noise & vibration, men	Sickness absence	60,000	OR	1.36 (1.05, 1.77)	r, a, e
Dias and Cordeiro (2007)	Workplace noise: High	Hospital admission for work-related injury	600	OR	2.294(1.513, 3.479)	e, a, o
	Medium				1.630(1.172, 2.268)	
	Low				1.331(0.938, 1.887)	
	All			AF	30.4%	
Dias and Cordeiro (2008)	Noise:	Work-related accident in past 90 d	432	RR		e, w, o, co, sh, ov
	Always				4.955(2.817, 8.716)	
	Sometimes				3.660 (1.817–7.370)	
Girard, Leroux, Verreault, et al. (2015)	Year of noise exposure	Death from CVD	5,524 workers	OR		a, o, n
	≥37 y		over 55 years		1.70 (1.10–2.62)	

Design first author	Definition of exposure*	Injury or health measure	Sample size	Effect measure**	Point estimate (CI)†	Factors considered‡
	27–36.4 y				0.76 (0.47–1.22)	
	<27 y				1.00	
Girard, Leroux, Courteau, et al. (2015)	Noise ≥100 dBA	Work-related hospital admission	46,550	HR	2.36 (2.01 to 2.77)	a, y
	Noise 80–89 dBA					
Girard et al. (2009)	Noise ≥90 dBA	Acute accident #	52,982	RR		a
		1			1.08 (1.02, 1.14)	
		2			1.21 (1.12, 1.31)	
		3			1.15 (1.03, 1.28)	
		4			1.28 (1.15, 1.43)	
Kling et al. (2012)	Noise >85 dBA, duration:	Hospitalized for workplace injury	5000	RR		a, ra, yr
	5+ y				1.27 (0.58, 2.55)	
	2–5 y				1.75 (0.90, 3.12)	
	1–2 y				1.82 (0.94, 3.56)	
	91 d– 1 y				2.01 (1.06, 3.78)	
	2–90 d				1.58 (0.74, 3.38)	
Lees et al. (1980)	Noise exposure	Medical events	140		p = 0.702	a, y, sh
	≥90 dBA ≤85 dBA	Head-aches			p = 0.714	
		Accidents			p = 0.954	
Melamed et al. (1992)	Noise exposure	Accidents:	2368	χ^2		
	high (≥85 dBA),	M			7.9 (p = 0.02)	
	moderate (75–84 dBA)	F			2.8 (n.s.)	
	low (<75 dBA)	Sickness: absence				
		M			35.9 (p < 0.005)	
		F			8.0 (p < 0.005)	
		Job satisfaction:				
		M			6.8 (p < 0.001)	
		F			17.3 (p < 0.001)	
Melamed et al. (2004)	Noise exposure >80 dBA	Accident with 1 lost work day	6014	OR	5.96 (0.99–15.67)	r, a, b, y, e, o
Moll van Charante and Mulder (1990)	>82 dBA	Recordable injuries	600	OR	1.83 (1.17, 2.88)	al
Picard, Girard, Simard, et al. (2008)	Noise >90 dBA	WC accidents	52,900	AF	6.2%	a, n
Picard, Girard, Courteau, et al. (2008)	Noise ≥100 dBA	Traffic accident	46,030	PR	1.07 (1.01,1.15)	a, y

Design first author	Definition of exposure*	Injury or health measure	Sample size	Effect measure**	Point estimate (CI)†	Factors considered‡
Sbihi et al. (2008)	Noise (dBA) >115	Hypertension,		RR	1.3 (0.9, 1.7)	a, yr, ra
	110–115	3 doctor visits, death,			1.3 (0.9, 1.6)	
	105–110	or hospital visit			1.1 (0.8, 1.5)	
	100–105				1.1 (0.8, 1.5)	
	95–99				0.8 (0.6, 1.2)	
	Cumulative exposure				32%	
	>95, >19 y				1.3 (1.05, 1.6)	
	>90, >19 y				1.3. (1.0, 1.5)	
	>85, >29 y				1.5 (1.1, 2.0)	
Yoon et al. (2015)	≥90 dB	Injury claims by company	1,790 companies	OR	3.68 (2.35–5.78)	sh
	80–89 dB				1.72 (1.25–2.37)	
	<80 dB				1	

Notes to Table 1:

*PTA — Pure Tone Audiometry.

**OR — odds ratio, RR — relative risk, HR — hazard ratio, AF — attributable fraction, PR — prevelance ratio.

†CI — confidence interval, n.s. not significant.

‡a — age, al — alcohol, B — BMI, c — cohabitation, ch — children in home, co — coworkers, e — education level, h — HPD type, l — location, li — heavy lifting, o — occupation/job, ov — overtime, n — noise exposure level, ra — race, r — self-reported physical work environment exposure or risk of injury, s — sex, sh — shiftwork, sm — smoking status, t — time period, w — weekly work hours, y — years experience, yr — calendar year.

Table 2

Studies on hearing loss and risk of occupational injury, absence, or symptom.

Design first author	Definition of exposure*	Injury or health measure	Sample size	Effect measure**	Point estimate (CI)†	Factors considered‡
Amjad-Sardrudi et al. (2012)	HL	Workplace Injury	1062	OR		a, y
	>40 dB				4.58 (1.00, 20.89)	
	>30–40 dB				7.87(2.01, 20.82)	
	15–30 dB				1.72(0.97,3.05)	
Cantley et al. (2015)	HL	All occup. injuries	9,220 workers	RR		a, h, li, ra, s, y
	>25 dB				1.21 (1.09–1.33)	
	10–24.9 dB				1.06 (1.00–1.13)	
	<10 dB				1.00	
Girard, Leroux, Verreault, et al. (2015)	Hearing Loss	Death from CVD	5,524 workers over	OR		a, o, n
	Mild		55 years		1.64 (1.04–2.60)	
	Moderate				1.66 (1.06–2.61)	
	Severe				1.00	
Girard, Leroux, Courteau, et al. (2015)	Hearing loss (for 1 dB of hearing loss)	Work-related hospital admission	46,550	HR	1.01 (1.006 to 1.013)	a, y
Ide (2007)	HL > 45 dB at one frequency	FF with ill-health retirement	121 cases	%	68%	a, o
			112 controls		16% (p < 0.001)	
Crawford et al. (1998)	HL by questionnaire	Injury by questionnaire	90 cases	OR	1.62 (0.82, 4.40)	a, e, sm, al
			1,475 controls			
			Male farm workers			
Hwang et al. (2001)	HL by questionnaire	Injury by questionaire	1,706 farmers	OR	1.86 (1.22, 2.83)	a, w
Moll van Charante and Mulder (1990)	HL >20 dBA	Record-able injuries	600	OR		al, o
	Noise > 82				1.69 (0.77, 3.70)	
	Noise < 82				4.63 (2.20, 9.74)	
Picard, Girard, Simard, et al. (2008)	HL	WC accidents	52,900	AF	7.0%	a, n, y
	>51 dB			PR	1.29	
	41–50 dB				1.25	
	31–40				1.14	
	16–30				1.09	

Design first author	Definition of exposure*	Injury or health measure	Sample size	Effect measure**	Point estimate (CI)†	Factors considered‡
Picard, Girard, Courteau, et al. (2008)	HL	Traffic accidents	46,030	PR		a, y
	>50 dB				1.31 (1.2, 1.42)	
	16–30 dB				1.06 (1.01, 1.11)	
Viljoen, Nie, and Guest (2006)	HL	Injury from moving or	1080	OR		
	20–54%	falling object			2.28 (0.84, 6.22)	
	10– < 20%				0.82 (0.32, 2.12)	
	<10%				1.5 (0.85, 2.64)	
Sprince et al. (2007), Sprince et al. (2002), Sprince, Park, et al. (2003), Sprince, Zwerling, Lynch, Whitten, Thu, Gillette, et al. (2003), Sprince, Zwerling, Lynch, Whitten, Thu, Logsden-Sackett, et al. (2003)	Hearing loss or difficulty hearing or wear hearing aid by questionnaire		Cases/controls	OR		a e
		All injuries	431/473		2.36 (1.07, 5.20)	
		Machine injuries	205/473		2.02 (1.38, 2.94)	
		Falls	79/473		1.82 (1.07, 3.08)	
		Low back injury	49/465		1.98 (1.02, 3.80)	
		Animal-related injury	116/342		5.35 (1.59, 18.0)	
Xiang, Stallones, and Chiu (1999)	Hearing loss by questionnaire	Injury by questionnaire	112 farmers	OR	1.88 (0.67, 5.26)	a, e, al
Zwerling et al. (1996)	Impaired hearing	Workplace injuries in past year	7089	OR	1.60 (1.11, 2.30)	o, li
Zwerling et al. (1997)	Hearing loss	Workplace injury	459,827	OR	1.55 (1.29, 1.87)	a, o

Table adapted from (Palmer et al., 2008).

** OR — odds ratio, RR — relative risk, HR — hazard ratio, AF — attributable fraction, PR — prevalence ratio.

† CI — confidence interval, n.s. Not significant.

‡ a — age, al — alcohol, B — BMI, c — cohabitation, ch — children in home, co — coworkers, e — education level, h — HPD type, l — location, li- heavy lifting, o — occupation/job, ov — overtime, n — noise exposure level, ra — race, r — self-reported physical work environment exposure or risk of Injury, s — sex, sh — shiftwork, sm — smoking status, t — time period, w — weekly work hours, y — year's experience, yr — calendar year.

Table 3

Solvent exposure relationship with occupational injury, absence, or symptom. Table adapted from (Palmer et al., 2008).

Design first author	Definition of exposure*	Injury or health measure	Number analyzed	Effect measure**	Point estimate (CI)†	Factors considered‡
Attarchi, Golabadi, Labbafinejad, and Mohammadi (2013)	Noise	Hypertension	471	OR	9.43 (2.81, 23.46)	a, b, y, sm, sa, ex, sh, o, f
	Solvent				4.38 (1.27, 10.53)	
	Noise & solvent				14.22 (3.21, 40.84)	
Herpin et al. (2008)	Solvent exposed	Equilibrium score	23	z	−2.07 p=0.03	
Hunting et al. (1991)	Weekly solvent exposure	Slips, trips, and falls	123	OR		
	high				0.96 (0.45, 2.06).	
	moderate				0.66 (0.24, 1.77)	
	low				1.62 (1.27,5.41)	
Iwata et al. (2005)	Solvent exposed	Eyes closed	98	p		s, al, a, sm
		Sagittal sway				
		Sway area			p=0.0172	
		Romberg quotient			p=0.0408	
		sagittal sway			p=0.0222	
Kilburn et al. (1987)	Formaldehyde	Memory of story 1	305	R^2	0.1473 p<0.05	
		S-Romberg Sway			0.3372 p<0.05	
		Memory of story 1			0.0032 p<0.05	
	Solvents	S-Romberg Sway			0.0142 n.s.	
Kuo et al. (1996)	Solvent exposure	Sway Area/Length	28	R^2		a, s
		Eyes Open,			0.37, 0.35 (n.s.)	
		Eyes Closed			0.54, 0.40	
		Foam Open,			0.40, 0.39	
		Foam Closed			0.32, 0.43	
Park, Lee, Lee, & Lim (2009)	Cumulative biological exposure	Sway area eyes open	131	p	p-0.001	s, a, h, al, sm, ho
Sabbath et al. (2012)	Solvent exposure	<25th% on cognition test (less-educated)	4134	RR	1.24 (1.09, 1.41)	al, sm, y
Stollery and Flindt (1988)	Accidental solvent poisoning versus control group	Memory tasks:	9	F		
		Paired-associate			2.8, p=0.08	

Design first author	Definition of exposure*	Injury or health measure	Number analyzed	Effect measure**	Point estimate (CI)†	Factors considered‡
		Serial position			3.4, p=0.05	
		Brown Peterson			7.9, p=0.003	
Zamyslowska-Szmytke and Sliwinska-Kowalska (2011)	Solvent exposure	Videonystagmography abnormalities	61	p	64, 28, p=0.0003	
		Reaction time			86, 84% p<0.0001	
		Movement direction			0.9, 0.6 s, p=0.000	
		Velocity			3.3, 5.35 (°/s),	
		Postural sway			p=0.000	
		Foam, eyes closed			2.1 versus 1.6 (°/s), p=0.00007	
Zamyslowska-Szmytke et al. (2011)	Solvent exposure	ENG	170	p		a, s, h
		Caloric test				
		L44			0.000	
		L30			0.025	
		R30			0.077	
		Reactivity			0.029	
		DP SPV			0.005	
		DP			0.028	
		Balance			0.003	
		Reaction time			0.049	
		Eyes open firm			0.000	

*PTA — Pure Tone Audiometry.

**OR — odds ratio, RR — relative risk, HR — hazard ratio, AF — Attributable fraction, PR — prevalence ratio, n.s. — not significant.

†CI — confidence interval, n.s. — not significant.

‡a — age, al — alcohol, B — BMI, ca — calcium intake, d — diabetes, e — education level, ex — exercise, f — family history of hypertension, h — height, ho — hospital visits in last year, ir — iron intake, o — occupation/job, ra — race, s — sex, sa — salt, sh — shiftwork, sm — smoking status, st — stroke, y — years' experience.