AMERICAN JOURNAL OF INDUSTRIAL MEDICINE 47:411–418 (2005)

Effects of Theatrical Smokes and Fogs on Respiratory Health in the Entertainment Industry

Sunil Varughese, MSc,[1] Kay Teschke, PhD,[1,2] Michael Brauer, ScD,[1] Yat Chow, MSc,[1] Chris van Netten, PhD,[1,2] and Susan M. Kennedy, PhD[1,2,*]

Background *Theatrical fogs (glycol or mineral oil aerosols) are widely used in the entertainment industry to create special effects and make lighting visible.*
Methods *We studied 101 employees at 19 sites using fogs and measured personal fog exposures, across work shift lung function, and acute and chronic symptoms. Results were also compared to an external control population, studied previously.*
Results *Chronic work-related wheezing and chest tightness were significantly associated with increased cumulative exposure to fogs (mineral oil and glycols) over the previous 2 years. Acute cough and dry throat were associated with acute exposure to glycol-based fogs; increased acute upper airway symptoms were associated with increased fog aerosol overall. Lung function was significantly lower among those working closest to the fog source.*
Conclusions *Mineral oil- and glycol-based fogs are associated with acute and chronic adverse effects on respiratory health among employees. Reducing exposure, through controls, substitution, and elimination where possible, is likely to reduce these effects.* Am. J. Ind. Med. 47:411–418, 2005. *© 2005 Wiley-Liss, Inc.*

KEY WORDS: theatrical smokes and fogs; glycols; mineral oil; occupational exposure; entertainment industry

INTRODUCTION

Theatrical smokes and fogs, referred to here as 'fogs,' are widely used in the entertainment industry in motion picture and television productions, live theater, concerts, nightclubs, raves, and video arcades; and more recently have been marketed for use at home parties, including those for children. They are used for creating special effects and making lighting visible and are produced primarily by the heating of glycol mixtures or the atomization of mineral oil. Fogs are also used in the military to mask troop movement, [Palmer, 1990] and for emergency responder training to simulate fires [Weislander et al., 2001].

Anecdotal reports have appeared in the media suggesting respiratory health problems among singers stemming from exposure to theatrical fogs, with several workers' compensation claims filed since 1990 from members of the San Francisco Opera and one from a singer in a Disney musical [Kosman, 2001; Russell, 2001; Squatriglia, 2001; Willman, 2003]. A recent analysis of data from the third United States National Health and Nutrition Examination Survey (NHANES) found that the entertainment industry had the highest risk of work-related asthma-like symptoms and the fifth highest risk of work-related wheezing of all industries [Arif et al., 2002]. In previous investigations of potential health effects associated with exposure to fogs, restricted to Broadway musical productions and published only in report form, mucous membrane irritation and respiratory symptoms among performers were associated with exposure [Burr et al., 1994; Moline et al., 2000].

[1]School of Occupational and Environmental Hygiene, University of British Columbia, Vancouver, BC, V6T 1Z3, Canada
[2]Department of Health Care and Epidemiology, University of British Columbia, Vancouver, BC, V6T 1Z3, Canada
Contract grant sponsor: Safety and Health in Arts, Production, and Entertainment; Contract grant sponsor: British Columbia Lung Association.
*Correspondence to: Dr. Susan M. Kennedy, UBC School of Occupational and Environmental Hygiene, Room 360A, 2206 East Mall, Vancouver, BC V6T 1Z3, Canada.
E-mail: kennedy@interchange.ubc.ca

Accepted 24 January 2005
DOI 10.1002/ajim.20151. Published online in Wiley InterScience (www.interscience.wiley.com)

In response to industry concern in our region, we conducted a cross-sectional study, in British Columbia, Canada, of exposure to theatrical fogs and potential health impacts in a variety of production types. The objective was to investigate the acute and chronic effects of exposures to fogs on respiratory symptoms and lung function among production employees.

MATERIALS AND METHODS

Study Sites and Subjects

Productions using fogs were identified by weekly review of film and television production lists and by individual contacts with concert promoters and theater directors. All willing sites using fogs were included. The study included multiple measurement days at individual sites if fogs were used for more than 1 day and sufficient new subjects could be recruited.

Eligible participants included members of the production crew with potential fog exposure on the study day. On each measurement day, up to five eligible individuals were asked to participate. Due to the unstructured nature of these workplaces, recruitment was mostly undertaken by having the study team approach potential subjects prior to the start of work (and fog use) until five participants were identified or until time constraints limited the number or participants eligible for testing. At each site, attempts were made to recruit one person each from the special effects department (i.e., those who produce the fog effects) and the makeup/hair/prosthetics department (since these employees may have had exposures to glycols contained in cosmetics).

External Comparison Population

Comparison data for baseline pulmonary function and chronic symptoms were obtained from an age-matched sample of workers we had previously assessed using the same testing equipment and questionnaire. This population consisted of passenger service employees of the British Columbia Ferry Corporation who had been previously studied because of concern about past exposure to asbestos.[1] The comparison subgroup was restricted to employees without significant asbestos exposure but who may have had occupational exposures to respiratory irritants such as vehicle exhaust, kitchen smoke, and cleaning and disinfecting chemicals. This group was considered a suitable comparison group for obtaining 'expected' rates of chronic symptom prevalence and lung function since it was selected from a group of actively employed British Columbia residents who were concerned about workplace respiratory hazards.

Design and Procedures

The study was approved by the Clinical Research Ethics Board at the University of British Columbia. Written informed consent was obtained from all participants.

On the testing day, each participant wore a personal exposure monitoring device and completed pre- and post-'shift' pulmonary function testing and a pre- and post-shift interviewer administered questionnaire on the frequency and severity of acute symptoms in the previous several hours. The exposure measurement period (the 'shift') was approximately 4 hr during which fogs were present for at least some of the time. These periods started at all times throughout the day, from early morning to late evening.

Personal aerosol monitoring was carried out using a 7-hole inhalable aerosol sampler (JS Holdings Ltd., Stevenage, UK) mounted with a 0.45-μ pore size Teflon filter (Gelman Sciences, Ann Arbor, MI). Details of the exposure monitoring is reported in detail elsewhere [Teschke et al., 2005]. Factors potentially related to exposure levels (including work tasks and locations for each study subject) were recorded by an industrial hygienist, every 10 min during the shift period. Area monitoring was conducted to evaluate the size distribution of aerosol particles using a Marple 290 personal cascade impactor (Thermo Andersen, Smyrna, GA) mounted with five 34-mm diameter 5-μ pore size polyvinyl chloride filters (PVC; Thermo Andersen). The impactor separated the aerosol into five size fractions: $\geq$21 microns in aerodynamic diameter, $\geq$15 to <21, $\geq$10 to <15, <3.5 to 10, and <3.5 microns, respectively.

Participants completed an interview administered general health questionnaire focusing on chronic symptoms and work history. This questionnaire was a modification of the American Thoracic Society (ATS) standardized questionnaire for use in epidemiologic surveys [Ferris, 1978], plus questions from the European Community Respiratory Health Survey [Burney et al., 1994], and voice questions adapted from the Voice Handicap Index [Jacobsen et al., 1997]. Allergy skin prick testing was conducted using three common environmental antigens (mixed Pacific grasses, cat epidermal antigen, and house dust mite) and both positive (histamine 2.5 mg/mL) and negative (normal saline) controls. Atopy was defined as having one or more positive skin tests with a wheal diameter $\geq$3 mm compared to the negative control. For 19 subjects who refused skin testing, those who reported current hayfever were categorized as atopic (n = 7).

Pulmonary function testing was conducted by a trained technician using a volume sensitive dry rolling seal spirometer (Pulmonary Data Services, Louisville, CO), following ATS standard procedures [Standardization of Spirometry, 1995]. Testing was carried out before any fog

[1] Although the group was studied for concern about past asbestos exposure, health effects associated with asbestos were found to be limited to maintenance and engine room crew only. See www.soeh.ubc.ca/research/index.html and Kennedy et al. [2005] for details.

exposure on the testing day and immediately following the exposure monitoring period.

Definitions and Data Analysis

Chronic symptoms were identified as being 'work-related' if the symptom was reported as usually present, with either: improvement on days off or long holidays, or triggered or worsened by work situations or environments; and if the symptom was absent before age 16. Current asthma symptoms were defined as present if the participant responded 'yes' to 3 or more of the following in the past 12 months: wheezing or whistling in the chest without having a cold, awakened by chest tightness, an attack of coughing, an attack of shortness of breath, an attack of shortness of breath when not doing anything strenuous, an attack of shortness of breath coming on after stopping exercise.

An acute symptom was considered present if it was reported as increased in severity or frequency post-shift compared to pre-shift. Individual acute symptoms were grouped as follows: acute airway or voice symptoms (2 or more of: runny/stuffy nose, bleeding nose, congestion, sneezing, sinus problems, sore throat, irritated throat, dry throat, voice problems); cough (either dry cough or cough with phlegm or both); dryness symptoms (dry cough and/or dry throat); chest symptoms (any of: chest tightness, wheezing, breathlessness); eye symptoms (any of: irritated, red, watery, or itchy eyes); and systemic symptoms (any of: nausea, stomach ache, drowsiness, dizziness, headache, tiredness).

Maximum values (from at least three acceptable blows) for forced vital capacity (FVC) and forced expiratory volume in 1 s (FEV_1) were used. Values were expressed as a percentage of predicted values [Crapo et al., 1981]. The pre-shift value was used for comparisons to the external control group. The cross-shift change in each parameter was calculated as the post-shift value minus the pre-shift value and expressed as a percentage of the pre-shift value.

Estimated cumulative exposure to smokes and fogs (in hr × mg/m^3) over the past 2 years was calculated as the sum (over all entertainment industry jobs held) of the total number of days worked times the proportion of days exposed to fogs times the average number of hours per day exposed to fogs times an estimated aerosol concentration based on the average distance worked from the fog source, as follows:

$\sum$ For all jobs in the past 2 years [(total no. of days worked × % of days exposed to fog × average hours/day exposed to fog on the fog days) × estimated aerosol concentration for the job (mg/m^3)]/1,000

where the estimated aerosol concentration was based on an empirical model developed using our exposure measurement data [Teschke et al., 2005].

SAS v 8.01 (SAS Institute, Inc., Cary, NC) was used for statistical analyses. Multivariable regression modeling was used to examine the effect of work and personal factors on baseline and across work shift lung function parameters (linear regression) and acute and chronic symptoms (logistic regression). Prior to modeling, univariate analyses were conducted and correlations among all potential predictor variables were examined. For highly correlated predictor variables, choices were made as to which to include in the model based on theoretical expectations. In all models, the following demographic and other 'non-work' factors believed to influence health outcomes were considered: age, sex, race, history of childhood asthma, atopic status, cigarette smoking status and cumulative amount smoked [American Thoracic Society, 1991].

RESULTS

A total of 111 of 144 subjects (77%) from 19 different sites (television/film productions, live theater, music concerts, a video arcade and a dog show) participated in the study although complete data were available for only 101 subjects. The main reason for non-participation was employees' concern about noise from the sampling pumps and their possible interference with the ability to work.

Personal aerosol concentrations ranged from 0.02 to 4.11 mg/m^3 (mean 0.70 mg/m^3). The mean concentration for employees exposed only to glycol-based fog on the testing day was 0.49 mg/m^3 (maximum 3.22 mg/m^3) and for those exposed only to mineral oil-based fogs on the testing day, 0.94 mg/m^3 (maximum 4.11 mg/m^3) ($P = 0.02$, comparing exposures to the two fog types). Of the total aerosol mass collected on area sampling filters (n = 30), on average, 76% was in the thoracic size range (aerosol particles <10 μm aerodynamic diameter) and 61% was in the respirable range (<3.5 μm aerodynamic diameter).

The external comparison group was older on average than the entertainment industry group and current smokers among the comparison group had smoked more than those in the entertainment industry group (Table I). No other important demographic or health history differences were seen comparing the two groups. As planned, the study population represented a variety of jobs within the entertainment industry, with production assistants, makeup/hair/prosthetics technicians, special effects technicians, and video arcade staff making up the largest groups.

Average lung function parameters (percentage-predicted baseline FEV_1 and FVC) were both significantly lower in the entertainment industry participants than in the comparison group, with FVC also showing a significantly decreasing trend across increasing cumulative exposure categories (Table II). Within the entertainment industry, individuals usually working 10 feet or less from the fog generating machine had decreased FEV_1 and FVC of

TABLE I. Demographic and Baseline Health Characteristics of a Canadian Entertainment Industry Cohort and an External Comparison Group

	Entertainment industry group	Comparison group	P^a
n	101	70	
Age [mean (sd), range]	33.5 (10.2), 18.5–56.1	39.8 (8.7), 22.4–55.9	<0.0001
Female, n (%)	33 (32.7%)	28 (40.0%)	0.3
History of childhood asthma, n (%)	12 (11.9%)	5 (7.1%)	0.3
Current asthma diagnosis, n (%)	9 (8.9%)	5 (7.1%)	0.7
Atopic, n (%)	46 (45.5%)	28 (40.0%)	0.5
Smoking status			
Non-smokers, n (%)	45 (44.6%)	26 (37.1%)	
Ex-smokers, n (%)	24 (23.8%)	21 (30.0%)	0.6
Current smokers, n (%)	32 (31.7%)	23 (32.9%)	
Smoking amount (packs/day × yrs smoked)			
Current smokers [mean (sd), range]	11.0 (10.9), 0.6–43.9	18.2 (10.7), 0.7–39.5	0.02
Ex-smokers [mean (sd), range]	10.0 (12.7), 0.1–54.0	11.9 (12.8), 0.5–44.0	0.6

[a] *P*, comparing entertainment industry and control groups, chi-square analysis (categorical variables) or ANOVA (continuous variables).

approximately 5% compared with those working farther from the machine after adjusting for smoking, age, gender, and history of asthma (Table III). Makeup/hair/prosthetics technicians also had significant decreases in FVC of roughly 8% (Table III). No significant associations were found between acute changes in lung function and personal aerosol concentrations on the testing day (results not shown).

Prevalence rates for most chronic respiratory symptoms were elevated in the entertainment industry employees relative to the comparison group (Table IV) and significantly so for shortness of breath, current asthma symptoms and nasal symptoms. Internal analysis within the entertainment industry group showed exposure-related trends of increasing prevalence with increasing cumulative aerosol exposure (glycol and mineral oil aerosols combined) for chronic work-related wheezing and chest tightness (Table V).

For acute symptoms (i.e., those with onset or exacerbation over the testing day), upper airway/voice symptoms were significantly associated with total fog aerosol concentration (regardless of aerosol type); dryness symptoms (dry cough or throat) and systemic symptoms were associated with the use of glycol-based theatrical smoke, but not with overall aerosol concentration (Table VI). Further analysis revealed that the association between glycol use and systemic symptoms was limited to increased acute headache, dizziness, drowsiness, and tiredness (but not nausea and stomach ache—results not shown).

DISCUSSION

This is the first comprehensive study of exposures and health outcomes related to theatrical smokes and fogs in the

TABLE II. Mean Levels of Pulmonary Function According to Category of Cumulative Exposure in the Previous 2 Years Among a Canadian Entertainment Industry Cohort and an External Comparison Group

	External comparison group	Entertainment industry group (total)	Entertainment industry group exposure subgroups Cumulative exposure category (hr-mg/m^3)			
			<20	20–200	200–800	>800
n	70	101	23	29	28	21
FVC (% predicted), mean (se)[a,b]	105.5 (1.4)	101.9 (1.2)[c]	103.5 (2.4)	100.5 (2.2)	101.8 (2.2)	101.5 (2.5)
FEV_1 (% predicted), mean (se)[a,b]	100.6 (1.6)	96.3 (1.3)[c]	98.3 (2.7)	94.9 (2.5)	95.3 (2.4)	98.7 (2.8)

[a] Values are adjusted mean levels (standard errors), after taking into account between group differences in age, smoking status and amount, and atopic status, using generalized linear modeling).
[b] Test for linear association between each lung function outcome and cumulative exposure: FVC, $P = 0.05$; FEV1, $P = 0.1$ (from generalized linear models as described above).
[c] Comparing adjusted mean values for entertainment industry group (total) to external comparison group: FVC, $P = 0.05$; FEV_1, $P = 0.04$.

TABLE III. Demographic and Work-Related Factors Related to Pulmonary Function Outcomes (Multiple Linear Regression Coefficients from Analyses Including Subjects from the Canadian Entertainment Industry Cohort only, n = 101)

	FVC (% predicted)			FEV_1 (% predicted)		
	Coefficient[a]	se	*P*	Coefficient	se	*P*
Intercept	96.8	4.5	<0.0001	101.2	5.1	<0.0001
Personal factors						
Age, yrs	0.34	0.11	0.003	0.06	0.12	0.6
Female	5.9	2.3	0.01	5.5	2.6	0.04
Cumulative amount smoked—current smokers (packs/day × yrs smoked)	−0.10	0.14	0.5	−0.36	0.15	0.02
Cumulative amount smoked—former smokers (packs/day × yrs smoked)	−0.07	0.14	0.6	−0.05	0.16	0.7
History of childhood asthma (yes/no)	2.0	3.2	0.5	−4.2	3.6	0.2
Work factors						
Usually works within 10 feet of fog machine—current production (yes/no)	−5.2	2.1	0.02	−4.8	2.4	0.04
Makeup/hair/prosthetics technician (yes/no)	−8.4	3.4	0.03	−3.3	4.3	0.4

[a]Regression coefficient from multiple linear regression models in which all the variables listed were included.

entertainment industry. Two previous studies (not published in peer-reviewed journals) were restricted to Broadway musical performers in New York City.

The United States National Institute for Occupational Health and Safety (NIOSH) conducted a health hazard evaluation in live theater productions in 1991, with a follow-up in 1993 [Burr et al., 1994]. This study compared frequency and severity of respiratory and irritant symptoms among 134 actors in four 'fog' productions to 90 actors in five 'non-fog' productions. Actors in 'fog' productions had a higher prevalence of nasal, respiratory, and mucous membrane symptoms than actors in 'non-fog' productions. The 1993 follow up was designed to evaluate the relationship between occupational asthma symptoms and fog exposures among 37 actors who had reported symptoms consistent with asthma in 1991, and 68 asymptomatic controls. Only 62% of participants submitted complete or partial information (including medical and work histories, and peak flow measurements). Five subjects met the case definition for work-related asthma, three of these worked in 'fog' productions at the time. Performers with asthma-like symptoms and bronchial lability were not more likely to have been exposed to fogs [Burr et al., 1994].

A more recent study, conducted by Moline and colleagues [2000] in collaboration with Actors Equity, assessed exposures and irritant health effects among performers from among 16 Broadway musicals. Increased respiratory, throat, and nasal symptoms were associated with higher peak, but

TABLE IV. Prevalance of Chronic Respiratory Symptoms Among a Canadian Entertainment Industry Cohort and an External Comparison Group

	Entertainment industry group n (%)	External comparison group n (%)	*P*[a]
Cough	19 (18.8)	7 (10.0)	0.1
Phlegm	27 (26.7)	14 (20.0)	0.2
Wheezing	31 (30.7)	17 (24.3)	0.1
Chest tightness with breathlessness	19 (18.8)	9 (12.3)	0.3
Shortness of breath walking up hill	26 (25.7)	10 (14.3)	0.04
Current asthma symptoms	17 (16.8)	5 (7.1)	0.03
Eye irritation	13 (12.9)	12 (17.6)	0.3
Nasal symptoms	69 (68.3)	33 (47.1)	0.008
Voice symptoms	11 (10.9)	n/a[b]	

[a]*P*-values from multiple logistic regression models, including age, smoking status and amount, and atopic status.
[b]Chronic voice symptoms were not assessed in the external comparison group; results are included here for future comparison with results from other populations.

TABLE V. Prevalence of Work-Related Symptoms in a Canadian Entertainment Industry Cohort and External Comparison Group According to Category of Estimated Cumulative Exposure in the Previous 2 Years

	Control group	Entertainment industry group Estimated cumulative exposure category (hr-mg/m^3)			
		<20	20–200	200–800	>800
n	70	23	29	28	21
Work-related cough	10.0%	4.4%	3.4%	3.7%	14.3%
Work-related phlegm	5.7%	0%	3.4%	10.7%	14.3%
Work-related wheezing[a]	4.3%	0%	6.9%	10.7%	14.3%
Work-related chest tightness[a]	1.4%	4.4%	10.3%	14.3%	14.3%
Work-related nasal symptoms	42.9%	65.2%	51.7%	57.1%	57.1%

[a]$P = 0.05$ for wheezing; $P = 0.006$ for chest tightness, evaluating the trend for rates to increase across groups (from logistic models including age, smoking status and amount, and a single indicator variable for cumulative exposure category).

not average, levels of exposure to glycol fogs in 218 actors with detailed exposure assignments (participation rate not stated). Throat irritant symptoms were associated with high average exposures to mineral oil. No acute cross-shift changes in vocal cord appearance or lung function were observed. In those with long-term exposures to high peak levels of glycols, increased vocal cord inflammation was observed but there was no observed effect on lung function parameters. Actors with the highest exposures (greater than five times the average levels) to mineral oil had significant decreases in FEV_1 and FVC, while those actors with moderately high exposures (greater than two times the average levels) had decreases in FVC only. Despite these findings, lung function results for performers were reported as being within the normal range.

Our study was designed to build upon these initial findings by including a much greater variety of job titles and exposure scenarios, assessing acute exposures concurrently with health outcome monitoring, including lung function testing, assessing the relation of ongoing exposure with chronic health outcomes and by ensuring a higher participation rate.

In this study, external comparison analysis and internal 'exposure-response' analyses suggested that exposure to theatrical fogs may contribute to both acute and chronic respiratory health changes in entertainment industry personnel. Significant increases, compared to an external blue-collar population, were found for chronic breathlessness on exertion, nasal symptoms, current asthma symptoms (although not diagnosed asthma), and for work-related chest tightness and nasal symptoms. Internal analyses suggested an

TABLE VI. Adjusted Odds Ratios for Acute Respiratory Symptoms Among a Canadian Entertainment Industry Cohort

	Upper Airway/ Voice Symptoms	Dry cough and/or dry throat	Any cough (dry or with phlegm)	Chest symptoms	Eye symptoms	Systemic symptoms
Personal factors						
Female (yes/no)	4.1	2.1	0.6	2.9	1.4	1.5
	(1.0, 17.0)[a]	(0.8, 5.7)	(0.1, 3.1)	(0.6, 14.3)	(0.4, 4.4)	(0.5, 4.1)
Current smoker (yes/no)	1.3	1.8	1.3	3.9	0.9	1.7
	(0.3, 6.4)	(0.6, 5.1)	(0.2, 6.6)	(0.6, 27.2)	(0.2, 3.2)	(0.6, 5.4)
Former smoker (yes/no)	0.6	1.1	0.9	2.8	0.5	1.7
	(0.1, 4.4)	(0.3, 3.5)	(0.1, 5.8)	(0.3, 24.7)	(0.1, 2.1)	(0.5, 5.6)
Work factors						
Glycol (yes/no)	1.6	**4.7**	2.3	1.7	2.5	**3.9**
	(0.4, 6.7)	**(1.7, 12.9)**	(0.5, 10.7)	(0.3, 8.8)	(0.8, 7.9)	**(1.4, 10.9)**
Aerosol	**2.2**	1.1	0.6	0.7	0.4	1.1
Concentration (mg/m^3)	**(1.1, 4.4)**	(0.6, 2.0)	(0.2, 2.1)	(0.3, 1.9)	(0.1, 1.6)	(0.6, 2.0)

Multiple logistic regression analyses (odds ratios, 95% confidence intervals) of demographic and work-related factors related to acute symptoms (internal analyses, within the entertainment industry subjects only, n = 101).

[a]Odds ratios (and 95% confidence intervals) from logistic regression models including all variables with values listed and an indicator variable to identify subjects for whom the 'shift' period was less than 3 hr; bold indicates work factors with 95% confidence intervals that exclude 1.

exposure-response relationship between increased cumulative exposure to fogs (both glycol and mineral oil aerosols combined) and increased reporting of work-related wheezing and chest tightness. Decreased lung function (both FEV_1 and FVC) was also found in the entertainment industry compared to the external population, in particular among those in the entertainment industry working in closest proximity to the fog source (regardless of the type of fog being generated); decreased FVC was associated with increased cumulative exposure to fog. These findings suggest that ongoing exposure to fogs (undifferentiated by type) is associated with respiratory irritation and airway obstruction. The reason for reduced FVC among hair, makeup, and prosthetics employees is not evident from this study and warrants investigation in future studies.

Acute exposure-response relationships were also seen in this study. Increasing personal exposure to fog aerosol on the testing day was associated with increasing acute upper airway or voice symptoms, as was seen in previous work [Moline et al., 2000; Weislander et al., 2001]. Irritated mucous membrane symptoms (dry throat/dry cough and eye symptoms) were associated with acute exposure to glycol-based fog, in keeping with the effects of exposure to glycols reported previously in both humans [Moline et al., 2000; Weislander et al., 2001] and animals [Suber et al., 1989]. The association of systemic symptoms (acute headache, dizziness, drowsiness and tiredness) with glycol fog use is consistent with our finding that 61% of the mean proportion of the total aerosol mass was small enough to reach the gas exchange region of the lungs. In previous case reports of poisonings from triethylene and propylene glycol (two of the glycol compounds found in this study) [Teschke et al., 2005], subjects presented with mild CNS depression, lethargy, and drowsiness [Vassiliadis et al., 1999; Brooks and Wallace, 2002; Guillot et al., 2002].

Although asthma-like symptom prevalence rates (both acute and chronic) were increased in this study population, it is not clear from our results whether or not entertainment industry employees are at increased risk for asthmatic sensitization from exposure to glycols or other agents in theatrical smoke, or if these symptoms result from other mechanisms such as mucous membrane dehydration from glycol exposure [Suber et al., 1989]. Many of the glycols used in creating theatrical smoke have been found to cause allergic skin sensitization in a small percentage of study populations [Fisher, 1977; Hannuksela and Forstrom, 1978; Eguino et al., 2003; Farrar et al., 2003; Connolly and Buckley, 2004]; however, their potential to elicit respiratory sensitization has not been demonstrated. The NIOSH study did not find a link between exposure to fogs and work-related asthma in the small number of asthmatics identified; however, the low participation rate may have limited the reliability of those findings [Burr et al., 1994]. Given that glycols may cause sensitization in a small proportion of the population, it is possible that our study was also too small to detect an association between glycol exposure and asthma or skin sensitization if in fact one exists.

In summary, our findings suggest that exposure to theatrical smokes and fogs has the potential to generate both acute and chronic adverse effects on respiratory health. Although some of the acute effects seen appeared to be specific to glycol fogs, the chronic effects on work-related symptoms and lung function were linked to increasing cumulative exposure, for which it was not possible to distinguish the role of glycol or mineral oil fogs. Efforts should therefore be made to reduce exposure levels overall and to find alternative post-production methods for producing special effects in the entertainment industry. Further work should also be undertaken to assess exposures to fogs and health impacts on audiences at entertainment venues and members of the public at other sites where these products are used, and to determine an occupational exposure limit for glycol-based theatrical smokes as it appears that no specific workplace exposure limit currently exists in any jurisdiction.

ACKNOWLEDGMENTS

The authors acknowledge the important contribution of the employees and producers of the venues that participated in this study.

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