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Prevalence of Asthma by Industry in the US Population: A Study of 2001 NHIS Data

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Background *The estimated number of US workers potentially exposed to asthmagens ranges from 8 to 20 million. This study was undertaken to estimate the US prevalence of asthma in adults by industry of employment and to identify industries with elevated risk of asthma.*

Methods *Prevalence analysis was performed on 20,991 adults, 18 years of age and older who participated in the 2001 National Health Interview survey. We used SUDAAN software to estimate the prevalence of self-reported physician diagnosed asthma by industry, and odds ratios (ORs) for asthma and industry adjusted for age, sex, race, and smoking status.*

Results *The overall prevalence of physician diagnosed asthma was 6.5% (95% CI 6.1–6.9); 4.7% (95% CI 4.1–5.3) for males and 8.5% (95% CI 7.9–9.1) for females. In whites, the prevalence and ORs were significantly elevated for printing, publishing, and allied industries (OR = 2.4, 95% CI 1.2–5.0) and health care (OR = 1.3, 95% CI 1.0–1.7). In blacks, ORs were elevated for furniture, lumber, and wood (OR = 5.9, 95% CI 1.4–25.4) and entertainment and recreation industries (OR = 4.1, 95% CI 1.1–15.9). Other industries with elevated ORs included automobile dealers and gasoline station; durable goods; elementary, secondary schools, and colleges; other personal services; eating and drinking places; entertainment and recreation services; and utility and sanitary.*

Conclusions *Industries with elevated prevalence of asthma are identified. This information helps to target workplaces where detailed investigations for prevention and control may be appropriate.* Am. J. Ind. Med. 47:500–508, 2005. © *2005 Wiley-Liss, Inc.*

KEY WORDS: asthma; prevalence; respiratory diseases; industry

INTRODUCTION

Asthma is a chronic inflammatory disorder of the airways characterized by variable airflow obstruction and airways hyperresponsiveness [Sheffer and Taggart, 1993]. In the year 2000, there were 14.6 million US adult asthma cases as estimated from the Behavioral Risk Factor Surveillance System [Centers for Disease Control and Prevention (CDC), 2001]. An average annual estimate of 13.7 million ambulatory care visits for asthma was measured during 1993–1994, an annual rate of 53.4 visits per 1,000 persons [Burt and Knapp, 1996]. In 1997, the total estimated cost of asthma treatment was $15.1 billion, including $11.8 billion in direct costs and $3.3 billion in indirect costs [Musich et al., 1999].

The estimated number of US workers potentially exposed to occupational asthmagens ranges from 8 to 20 million [de la Hoz et al., 1997; Mannino et al., 1998]; this represents approximately 24% of the workforce according to the National Occupational Exposure Survey (NOES) [de la Hoz et al., 1997]. Over 250 different agents have been identified as potential occupational asthmagens and work-related asthma is becoming the most frequently diagnosed

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occupational respiratory disease in the United States [Chan-Yeung and Malo, 1994, 1995].

In the 1978 Social Security Disability Survey, 7.7% of the participants identified asthma as a personal medical condition and 1.2% attributed it to workplace exposure [Blanc, 1987]. The American Thoracic Society states that the estimated occupational contribution to the population burden of adult asthma is about 15% [Balmes et al., 2003]. In other studies, the prevalence of occupational asthma ranged from 2% to 15% in the general population in the early 1980s [Salvaggio, 1979; Kobayashi, 1980]. In a 1990s survey, the prevalence of work-related asthma in various workplaces (e.g., detergent industry workers, laboratory animal workers) ranged from 8% to 53% of workers [Becklake et al., 1999]. However, cross-sectional studies of asthma in the workplace usually underestimate the prevalence because affected workers often leave the industry.

Although industry-based studies of work-related asthma are frequently reported in the literature, only a few population-based studies have investigated the prevalence of asthma and its association with industry in the United States. The purpose of this study is to present the prevalence and odd ratios (ORs) for current asthma by industry categories, as estimated from the 2001 National Health Interview Survey (NHIS) data.

MATERIALS AND METHODS

The 2001 NHIS was conducted by the National Center for Health Statistics (NCHS) to measure and monitor the health status of the US population. The sample design of the NHIS was a stratified multistage probability cluster sample of households, whose target population consisted of civilian non-institutionalized persons residing in the United States [National Center for Health Statistics (NCHS), 2001]. The sample size of the 2001 NHIS was approximately 100,000 individuals. The interview response rate of NHIS was 90%. The analysis included adults (18 years and older) who were employed at the time of the interview (n = 20,991).

The case definition of current asthma was a positive response to two interview questions: ''Have you ever been told by a doctor or other health professional that you had asthma?'' and ''Do you still have asthma?''

Information on industry was obtained from the questions: What kind of business were you doing during the past 2 weeks (e.g., agriculture production, mining)? Industrial information was coded by the NCHS according to the 1990 Standard Industry Classification schemes [U.S. Bureau of Labor Statistics (BLS), 1987] and regrouped into 42 industrial categories.

Because of small sample size for some industries, we combined industries with similar potential for exposure to asthmagens. For example, we combined hospital services with hospitals as a ''health care'' industry, and trucking service with other transportation as a ''transportation'' industry category. The ''other industries'' category included industries with small sample sizes (mining, railroads, and armed forces). The referent group included several industries with office employment since their potential exposures to occupational asthmagens were assumed to be lowest: insurance, real estate, and other finance; public administration; communication; social services; legal and other professional services; business services; other educational services; and banking and credit agencies. For final analysis, we used 26 industry categories.

The NHIS survey included questions on smoking status. In the analysis, subjects were categorized as non-smokers, current smokers, and former smokers based on the smoking status. Non-smokers were defined as those who smoked fewer than 100 cigarettes during their entire life.

We used the SUDAAN program [Shah et al., 1991] to estimate the US national estimates of asthma prevalence and the adjusted ORs. The SUDAAN software program adjusts for the sampling design effect in calculating the standard errors of the estimated prevalence [Graubard and Korn, 1999], and uses individual sampling weights to adjust for the number of individuals in the population. The weighted estimators are unbiased estimators of the US population parameters [Graubard and Korn, 1996]. The ORs for asthma and industry were adjusted for age, sex, race, and smoking status.

We also developed a list of potential exposures in industries associated with asthma; we searched several databases, including the National Library of Medicine HazMap database [National Institute of Health (NIH), 2003], U.K. asthma homepage [Health and Safety Executive (HSE), 2003], and reviewed literature [Weill, 1975; Chan-Yeung et al., 1999].

RESULTS

Table I presents the overall estimated prevalence of current asthma by sex, age categories, race/ethnicity, and smoking status. The overall prevalence of asthma was 6.5% (95%, CI 6.1–6.9). The prevalence of asthma was significantly ($P < 0.05$) higher for females (8.5%, 95% CI 7.9–9.1) than for males (4.7%, 95% CI 4.1–5.3). The prevalence decreased with increasing age and whites had significantly higher prevalence than blacks or others ($P < 0.05$). The prevalence of asthma between non-smokers and current smokers was not significantly different.

Table II presents the prevalence and adjusted ORs of current asthma by industry, sorted by decreased ORs. The highest prevalence was found in automobile dealers and gasoline station workers (9.8%, 95% CI 5.5–14.1) and for durable goods (9.8%, 95% CI 5.5–14.1). The ORs were also significantly higher for these industries. Other industries with the elevated ORs that exceed 1.0 are other personal services

TABLE I. Estimated Prevalence and Current Asthma by Selected Characteristics in the NHIS Adult (≥18 Years) Working Population, 2001

Variable	n	P	95% CI	Estimated asthma (in thousands)
Sex				
Total	20,991	6.5	6.1–6.9	8,595
Male	10,339	4.7	4.1–5.3	3,326
Female	10,652	8.5	7.9–9.1	5,269
Age categories				
18–29	4,825	7.9	6.9–8.9	2,554
30–39	5,563	6.5	5.7–7.3	2,179
40–49	5,416	5.9	5.3–6.5	2,088
50–59	3,565	5.9	4.9–6.9	1,344
≥60	1,622	4.6	3.4–5.8	429
Race/ethnicity				
White	16,427	6.6	6.2–7.0	7,144
Black	2,852	6.6	5.6–7.6	967
Other	1,712	5.0	3.8–6.2	484
Smoking status				
Non-smoker	11,945	6.7	6.1–7.3	5,037
Current smoker	5,156	6.2	5.4–7.0	1,984
Former smoker	3,890	6.1	5.3–6.8	1,574

n, numbers responded; P, estimated prevalence.

(OR = 1.4); printing, publishing, and allied industries (OR = 1.3); elementary, secondary school, and colleges (OR = 1.2); health care (OR = 1.1); eating and drinking places (OR = 1.1); utilities and sanitary (OR = 1.1).

Table III presents estimated prevalence of current asthma and ORs by industrial category in whites. The prevalence and ORs were significantly elevated only for printing, publishing, and allied industries (OR = 2.4, 95% CI 1.2–5.0) for white males and health care industries (OR = 1.3, 95% CI 1.0–1.7) for white females. Other industries with a greater than onefold increase in risk were durable goods (OR = 1.9); automobile dealers and gasoline stations (OR = 1.8); other personal services (OR = 1.4); textile mill and finished textile products (OR = 1.3); health care (OR = 1.1); and elementary, secondary schools, and colleges (OR = 1.1) for white males. For white females, industries with greater than onefold increase in risk were utilities and sanitary (OR = 2.0); other industries (OR = 1.9); automobile dealers and gasoline stations (OR = 1.8); chemicals and allied products (OR = 1.7); durable goods (OR = 1.5); repair services (OR = 1.5); transportation equipment (OR = 1.5); other personal services (OR = 1.3); elementary, secondary schools, and colleges (OR = 1.2); eating and drinking places (OR = 1.2); general merchandise stores (OR = 1.2); and food, bakery and dairy stores (OR = 1.1).

Table IV presents estimated prevalence of current asthma and ORs by industrial category in blacks. For black females, the prevalence and ORs were only significantly elevated for furniture, lumber, and wood (OR = 5.9, 95% CI 1.4–25.4) and entertainment and recreation services (OR = 4.1, 95% CI 1.1–15.9). For black males, industries with greater than twofold increase in risk include: construction (OR = 5.4); chemicals and allied products (OR = 5.4); durable goods (OR = 4.0); furniture, lumber, and wood (OR = 2.9); eating and drinking places (OR = 2.5); and other personal services (OR = 2.3).

Table V shows potential exposures in industries associated with asthma. For example, potential exposures associated with asthma in furniture, lumber, and wood industries are formaldehyde, isocyanates, resins and glues, and wood dust.

DISCUSSION

The contribution of occupational exposure to adult asthma has been estimated as 15% [Balmes et al., 2003]. According to our study findings, the 6.5% asthma prevalence in the NHIS translates to approximately 8.6 million asthmatic patients among the 133 million workers in the United States. Based on the 15% estimate, approximately 1.3 million adult asthma cases could be attributed to occupational exposure. The estimated prevalence of asthma from the NHIS is comparable with other population estimates such as the 7.7% sample-based prevalence of asthma in the 1978 Social Security Disability Survey [Blanc, 1987]. The second National Health and Nutrition Examination Survey (1976–1980) reported that the prevalence of asthma among individuals 45–64 years of age was 5.7% [Evans et al., 1987]. In the Tucson community sample of 3,860 subjects, the overall prevalence of asthma was 9.6% [Barbee et al., 1985].

In industrial populations, the prevalence of asthma can be influenced by the effect of occupational exposures. For example in some industries, a large population can be exposed to asthmagens. In 1996, NIOSH issued a hazard alert requesting assistance to prevent asthma from isocyanate exposure in approximately 280,000 workers potentially exposed to diisocyantes [National Institute for Occupational Safety and Health (NIOSH), 1996]. A study has reported that approximately 4% of workers exposed to western red cedar dust developed asthma [Chan-Yeung et al., 1984]. Clinical symptoms of asthma have been estimated to occur among 10%–45% of workers exposed to proteolytic enzymes [Blanc, 1987].

This study identified several industries and occupations with elevated prevalence and ORs for asthma. The prevalence of asthma and ORs shows somewhat different patterns by race and sex. For white males, printing, publishing, and allied industry has the highest asthma prevalence and

TABLE II. Overall Estimated Prevalence of Asthma and Odds Ratios by Industrial Category, NHIS Adult Working Population, 2001

Industrial category	n	*P*	95% CI	OR	95% CI
Automobile dealers and gasoline stations	305	9.8	5.5–14.1	1.6	1.0–2.7
Durable goods	286	9.8	5.5–14.1	1.6	1.0–2.7
Other personal services	574	9.8	6.5–13.1	1.4	0.9–2.1
Printing, publishing, and allied industries	254	8.0	3.9–12.1	1.3	0.7–2.2
Elementary/secondary schools and colleges	1,785	8.6	7.0–10.2	1.2	0.9–1.5
Health care	2,040	8.5	7.1–9.9	1.1	0.9–1.4
Eating and drinking places	923	7.8	5.6–10.0	1.1	0.8–1.4
Utilities and sanitary	186	7.3	2.6–10.0	1.1	0.6–2.2
Entertainment and recreation services	401	6.7	3.8–9.6	1.0	0.6–1.6
Chemicals and allied products	179	5.4	1.3–9.5	0.9	0.4–2.0
Food, bakery, and dairy stores	436	6.5	3.8–9.2	0.9	0.6–1.5
Wholesale and retail trade	1,704	5.8	4.4–7.2	0.9	0.7–1.2
Transportation equipment	315	6.1	3.2–9.0	0.9	0.5–1.7
Transportation	853	5.3	3.5–7.1	0.9	0.6–1.3
Furniture, lumber, and wood	208	5.7	2.6–8.8	0.9	0.5–1.6
General merchandise stores	379	6.9	4.0–9.8	0.9	0.6–1.5
Other nondurable goods	211	6.6	2.3–8.1	0.9	0.5–1.6
Private households	194	6.0	0.3–11.7	0.8	0.3–2.0
Textile mill and finished textile products	192	5.0	1.5–8.5	0.8	0.4–1.6
Construction	1,354	3.2	2.2–4.2	0.6	0.4–0.8
Repair services	305	3.6	1.1–6.1	0.6	0.3–1.4
Agriculture/forestry/fisheries	503	3.8	1.8–5.8	0.6	0.4–1.1
Machinery	525	3.9	2.1–5.7	0.6	0.4–1.0
Other industries	860	3.5	0.2–6.8	0.6	0.2–1.6
Metal industries	291	2.5	0.7–4.3	0.4	0.2–0.9
Referent group	5,728	6.8	6.0–7.6	1.0	

n, number responded; P, prevalence (%); CI, confidence interval; OR, adjusted for age, sex, race, and smoking.

significant OR. For these industries, the exposures that are known to cause asthma include acrylic resins, dyes, glues, and sealants (Table V). For white females, the asthma prevalence was elevated in the health care industry. Some of the potential asthmagens in health care industry are natural rubber latex (NRL), glutaraldehydes, and other sensitizing agents (Table V). There is accumulating evidence that NRL represents a significant cause of immediate hypersensitivity reaction among individuals who are repeatedly exposed to NRL-containing materials in medical environments. NRL was reported to induce 2.5% of the occupational asthma among hospital employees [Vandenplas et al., 1995]. A recent NIOSH report shows that health services accounted for 16% of all work-related asthma cases reported to the Sentinel Event Notification Systems for Occupational Risks (SENSOR) program between 1993 and 1999 [U.S. Department of Health and Human Services (USDHHS), 2003]. For black females, one of the significant asthma risks was employment in entertainment and recreation industry. This finding is consistent with a recent report from the NHANES III adult study population [Arif et al., 2002] and a community based study [Forastiere et al., 1998]; both reported an increased risk of asthma among women in entertainment business. Entertainment and recreation industry group includes artists, recreation producers, designers, and photographers. Potential risky exposures in this industry include art materials, cleaning chemicals, and photographic development chemicals. A few studies reported an increased risk of asthma among cleaners [Kogevinas et al., 1996; Nielsen and Bach, 1999]. In a recent report, 12% of 1,915 confirmed cases of work-related asthma were associated with exposure to cleaning products [Rosenman et al., 2003]. Cleaning products used in industries and work places as well as in the home contain a diverse group of chemicals. Based on data from occupational health surveillance program in 2003 [Massachusetts Department of Public Health, 2003], the Massachusetts Department of Health reported that cleaning products associated with asthma symptoms contain amines; two ammonium compounds (*n*-alkyl dimethyl benzyl ammonium chloride and didecyl dimethyl ammonium

TABLE III. Estimated Prevalence of Asthma and Odds Ratios by Industrial Category in Whites, NHIS Working Population, 2001

	Male				Female			
Industrial category	**n**	***P***	**OR**	**95% CI**	**n**	***P***	**OR**	**95% CI**
Printing, publishing and allied industries	107	11.4	2.4	1.2–5.0	99	6.3	0.8	0.3–2.1
Durable goods	151	9.8	1.9	0.9–4.1	84	11.9	1.5	0.8–2.9
Automobile dealers and gasoline stations	186	8.7	1.8	0.9–3.7	80	14.5	1.8	0.9–3.7
Other personal services	143	6.7	1.4	0.6–3.5	268	10.5	1.3	0.8–2.2
Textile mill and finished textile products	75	6.4	1.3	0.5–3.4	75	3.4	0.4	0.1–2.0
Elementary/secondary schools and colleges	419	6.0	1.1	0.7–1.8	1,025	9.5	1.2	0.9–1.6
Health care	266	5.8	1.1	0.6–2.2	1,242	10.1	1.3	1.0–1.7
Transportation	436	5.5	1.1	0.6–1.9	175	3.8	0.5	0.2–1.0
Transportation equipment	190	4.9	1.0	0.4–2.2	67	11.7	1.5	0.6–3.7
Machinery	288	5.0	1.0	0.6–1.7	139	1.8	0.2	0.1–0.7
Utilities and sanitary	110	4.5	0.9	0.3–2.6	41	14.5	2.0	0.8–5.0
Furniture, lumber, and wood	108	4.7	0.9	0.3–2.3	54	3.2	0.4	0.1–2.2
Eating and drinking places	315	5.3	0.9	0.4–1.8	401	10.0	1.2	0.7–1.8
Entertainment and recreation services	193	4.9	0.9	0.4–2.0	131	8.3	1.0	0.5–2.0
Wholesale and retail trade	715	4.4	0.8	0.5–1.3	635	9.1	1.1	0.8–1.6
Chemicals and allied products	87	1.9	0.4	0.1–1.9	52	13.2	1.7	0.6–4.8
Food, bakery, and dairy stores	141	4.4	0.7	0.2–2.3	199	9.1	1.1	0.6–2.0
General merchandise stores	85	3.8	0.7	0.2–2.9	204	9.7	1.2	0.7–2.0
Other nondurable goods	122	3.8	0.7	0.3–2.1	43	7.0	0.8	0.3–2.7
Repair services	228	2.9	0.6	0.2–1.4	31	11.0	1.5	0.4–5.8
Agriculture/forestry/fisheries	331	3.3	0.6	0.3–1.3	104	6.1	0.7	0.3–1.7
Construction	1,003	2.7	0.5	0.3–0.9	130	6.9	0.8	0.3–2.0
Metal industries	196	1.8	0.4	0.1–1.1	50	5.6	0.6	0.2–2.3
Other industries	485	2.5	0.4	0.1–1.9	311	14.9	1.9	0.4–10.6
Private households	9	—	—	—	125	7.2	0.9	0.3–2.9
Referent group	2,021	5.3	1.0		2,432	8.1	1.0	

n, number responded; P, prevalence (%); CI, confidence interval; OR, adjusted for age and smoking; —, indicates no cases responded.

chloride); and two phenolic compounds. The OR in furniture, lumber, and wood was elevated for black females. Potential exposures that can cause asthma in this industry (Table V) are formaldehyde, isocyanates, resins and glues, and wood dust. For example, occupational exposures to red cedar dust lead to bronchial mucosal injury and boosted allergen permeability which may trigger an asthmatic or allergic response [Chan-Yeung and Malo, 1995].

For some occupations with elevated prevalence, limited occupational risk factors have been reported. In our study, school teachers have an 8.6% asthma prevalence which is similar to that of teachers (8.8%) based on data from the 1988 NHIS Occupational Supplement [Whelan et al., 2003]. Teachers are potentially exposed to environmental indoor allergens, mold, and art materials. A study has reported that anatomy teachers developed asthma due to prolonged exposure to formaldehyde [Thrasher et al., 1988]. In a study of asthma and allergy in urban Canadian schools, the teachers with asthmatic condition were identified and their asthma was associated with exposure to clay and odorous ink markers, wallpaper paste, and sand [Landrus and Axcel, 1990]. A recent NIOSH report shows that educational services accounted for 9.1% of all work-related asthma cases reported to the SENSOR program between 1993 and 1999 [U.S. Department of Health and Human Services (USDHHS), 2003].

In this study, unexpectedly, the metal industry had a significantly lower OR and prevalence of asthma. The potential exposures in this industry include chromium, cobalt, isocyanates, nickel, and aluminum. Several studies have reported asthma cases associated with exposure to metals such as platinum [Brooks et al., 1990], chromium [Joules, 1932], steel welding fumes [Keskinen et al., 1980], cobalt and nickel [Shirakawa et al., 1990]. The possible explanation for lower OR in our study can be that the high use of respirators in metal industries could reduce the prevalence of asthma. A recent national respirator survey reported that primary metal industry has the highest percentage (28.2) of

TABLE IV. Estimated Prevalence of Asthma and Odds Ratios by Industrial Category in Blacks, NHIS Working Population, 2001

	Male				Female			
Industrial category	**n**	***P***	**OR**	**95% CI**	**n**	***P***	**OR**	**95% CI**
Construction	85	3.9	5.4	0.6–46.6	9	—	—	—
Chemicals and allied products	10	20.5	5.4	0.6–46.6	11	—	—	—
Durable goods	18	14.1	4.0	0.6–24.9	13	3.8	0.3	0.1–2.3
Furniture, lumber, and wood	22	11.4	2.9	0.5–15.9	7	37.1	5.9	1.4–25.4
Eating and drinking places	50	12.5	2.5	0.7–8.5	66	10.8	1.2	0.5–3.0
Other personal services	30	9.3	2.3	0.4–11.8	62	11.3	1.2	0.4–4.1
Machinery	17	8.5	1.9	0.2–17.9	18	3.9	0.4	0.1–3.2
Other nondurable goods	17	4.9	1.2	0.1–11.5	9	7.9	0.7	0.1–5.8
Transportation	115	4.1	0.9	0.3–2.8	63	14.9	1.7	0.7–3.9
Whole sale and retail trade	104	3.8	0.8	0.2–3.0	83	2.5	0.3	0.1–0.8
Automobile dealers and gasoline stations	10	3.7	0.8	0.1–7.0	8	15.3	1.6	0.2–12.0
Metal industries	15	3.9	0.8	0.1–7.5	8	4.0	0.4	0.0–3.4
Elementary/secondary schools and colleges	60	3.1	0.7	0.2–2.5	185	11.1	1.2	0.6–2.4
Entertainment and recreation	28	3.5	0.7	0.1–6.0	17	29.9	4.1	1.1–15.9
Repair services	21	3.0	0.7	0.1–6.7	2	—	—	—
General merchandise stores	14	3.3	0.7	0.1–6.5	44	6.7	0.7	0.2–2.3
Health care	60	1.9	0.4	0.1–2.1	322	5.6	0.6	0.3–1.0
Agriculture/forestry/fisheries	19	2.0	0.4	0.1–2.9	6	0	—	—
Food, bakery, and dairy stores	22	—	—	—	39	7.1	0.7	0.1–2.7
Printing, publishing, and allied industries	12	—	—	—	16	5.6	0.6	0.1–4.7
Transportation equipment	22	—	—	—	16	7.2	0.7	0.1–4.2
Utilities and sanitary	23	—	—	—	7	10.3	1.1	0.1–8.8
Private households	5	—	—	—	25	1.8	0.2	0.0–1.1
Textile mill and finished textile products	4	—	—	—	21	7.6	0.8	0.2–3.0
Other industries	37	—	—	—	7	6.1	0.6	0.1–5.1
Referent group	276	4.4	1.0		576	9.7	1.0	

n, number responded; P, prevalence (%); CI, confidence interval; OR, adjusted for age and smoking; —, indicates no cases responded.

respirator use among manufacturing industries [U.S. Department of Labor, 2003], and that some individuals sensitized to agents in the metal industries have migrated to other industries.

In this study, the prevalence of asthma among nonsmokers and current smokers and also former smokers was not statistically different. Cigarette smoking appears to be a confounding factor in the prevalence of asthma [Flodin et al., 1995]. Among adult smokers, self-reported asthma could be a misclassification of chronic obstructive pulmonary disease/chronic bronchitis/emphysema, thus confounding the association. For some asthma-causing agents, cigarette smoking seems to promote the development of asthma and may increase risk of IgE-mediated occupational asthma [Venables et al., 1989; Calverley et al., 1995]. For example, for platinum salts, smoking is more important than atopy in predisposing people to sensitization [Venables et al., 1989]. The American Thoracic Society states that cigarette smokers may be at increased risk of workplace sensitization from certain asthma-causing agents and the prohibition of cigarette smoking in the workplace would be a primary prevention of occupational asthma [American Thoracic Society (ATS), 2003]. In contrast, several studies have not found any association between asthma and smoking [Christiani and Kern, 1993; Senthilselvan et al., 1993].

The advantage of using NHIS data is that the estimates of national prevalence of asthma are from a large population-based sample. However, there are several limitations of these data for estimating the asthma prevalence associated with industry. First, the NHIS provides no temporal information on onset of asthma, or on prior work history of respondents. Second, for a working adult with asthma, the industry of current employment may not be the industry of employment when asthma developed. In fact, our referent group had an asthma prevalence higher than the overall average US prevalence, suggesting the possibility that asthmatic individuals were preferentially employed in the referent industries, which could have attenuated the industry-specific adjusted

TABLE V. Potential Exposures in Industries Associated With Asthma

Industry (SIC)	Potential exposures*
Automobile dealers and gasoline stations (551–557, 559)	Isocyanates in paint and cleaning chemicals
Elementary, secondary schools, and colleges (821–822)	Art supplies, formaldehyde, isocyanates, resins and glues, wood dust
Chemicals and allied products (281–287, 289)	Chromium, cobalt, formaldehyde, isocyanates, resins and adhesives
Health care (801–803, 8041–8043, 8049, 805–809)	Detergents, latex, formaldehyde, glutaraldehyde
Food, bakery, and dairy stores (541–544, 546, 549, 201–209)	Coffee beans, cockroach materials, crustacean proteins, egg proteins, flour, soybean dust, storage mites
Food and kindred products (manufacturing) (201–209)	Coffee beans, cockroach materials, crustacean proteins, egg proteins, flour, soybean dust, storage mites
Repair services (753, 7549, 762–764, 7692, 7694, 7699)	Chromium, detergents, isocyanates in paints, solder, welding stainless steel
Entertainment and recreation services (781–784, 791–794, 799)	Art materials, cleaning chemicals, photographic development chemicals
Printing, publishing and allied industries (271–279)	Acrylic resins, dyes, glues and sealants
Utilities and sanitary (491–497)	Fluxes, soldering, welding stainless steel
Furniture, lumber and wood (241–245, 249)	Formaldehyde, isocyanates, resins and glues, wood dust
Construction (15–17)	Isocyanates in paints, solder, welding stainless steel, wood dust
Machinery (351–359, 361–367, 369)	Isocyanates in paints, solder, welding stainless steel
Textile mills and finished textile products (221–229, 231–239)	Cotton, dyes, flax, hemp
Metal industries (339, 341–349, 331–332, 334, 3331, 3339, 3351, 3353–3357, 3363–3366, 369)	Aluminum potlines, chromium, cobalt, formaldehyde, isocyanates, nickel, vanadium, zinc
Transportation and transportation equipment (371–376, 379, 421–423)	Isocyanates from paint and welding stainless steel
Agriculture/forestry/fisheries (01, 02, 08, 09, 071, 072, 074–076, 078)	Coffee beans, cockroach material, crustacean proteins, detergents, grain dust, soybean dust, wood dust, salmon, trout, tuna, sardines, shrimp, snow crab
General merchandise stores (532, 533, 539)	Coffee beans, cockroach materials, crustacean proteins, detergents, egg proteins, flour, soybean dust, storage mites
Other nondurable goods (manufacturing) (21, 261–263, 265, 267, 291, 295, 299, 301–306, 308, 311–312, 317, 319)	Chromium, plastic dust, wood dust

SIC, standard industry classification.
*Weill [1975]; Chan-Yeung and Malo [1994]; Chan-Yeung et al. [1999]; Health and Safety Executive (HSE) [2003]; National Institute of Health (NIH) [2003].

ORs. Even though we assume that ''offices'' employment would have lowest exposure risk for asthma in comparison to other industry categories, it is possible that many asthma cases could migrate or preferentially change to industries at low risk for asthma. Indoor air contaminants can also cause asthma in those who are working in offices [Menzies, 1999]. Third, sample sizes in some industry groups were small, resulting in wide confidence intervals of estimates, especially for race/sex-specific analyses. Fourth, the reliability of respondents' self-reported asthma in the NHIS is not known and may have lead to disease misclassification. For example, a study of medical record confirmation of chronic disease conditions elicited by patient interviews found that only 49% of asthma cases could be verified [Madow, 1973]. However, the NHIS did not attempt to verify either physician diagnosed asthma or self-reported asthma with any diagnostic test. Several studies on asthma prevalence have used a definition of asthma determined by available medical records [Ferris and Anderson, 1962; Dodge and Burrow, 1980]. Lastly, without information on childhood asthma history and asthma onset on the NHIS dataset, it was impossible to identify adults who had asthma onset during working periods after 18 years old. Cross-sectional studies have limitations of asthma prevalence estimation. Like the NHIS, most cross-sectional studies of employed workers usually underestimate asthma cases in the workplace due to the ''healthy worker effect'' [Brooks, 1992] and the survivor bias referred to under cohort studies [Becklake et al., 1999]. As affected workers often leave the industry, the cross-sectional sample does not provide a good representation of the accurate asthma prevalence.

Future study in this area may need to apply standardized and practical survey instruments to identify work-related asthma in population based studies. However, broad conceptualization of occupational asthma could be useful for developing surveillance methods and prevention of asthma caused by workplace exposures. Comprehensive strategies for preventing occupational asthma should be developed by looking broadly at the relationship between work and asthma in order to protect workers with and without hyper-

responsive airways [Wagner and Wegman, 1998]. To validate and confirm the current asthma prevalence rate, future national surveys need to include symptom questions, asthma onset, exposures, more detailed occupational information, and socio-economic factor. This information will help to identify more precise determinants of asthma risk and establish prevalence data for public health purposes and as a guide to the need for preventive services and/or surveillance in any industry at risk. Defining occupational asthma is important for its understanding and prevention. Recently, the American Thoracic Society stated that asthma could be defined in several ways: clinically recognized occupational asthma through physician reports; asthma meeting a working definition of occupational or work-related asthma based on exposure, symptoms or clinical data; and excess asthma occurrence among workers exposed to noxious agents as compared with referents [Balmes et al., 2003].

This study identified several industries with high prevalence and ORs for asthma, indicating that appropriate prevention and control strategies for these industries would be useful. However, further epidemiologic studies are warranted to evaluate possible elevated risks in these industries, including assessment of occupational exposures that may either cause asthma or exacerbate pre-existing asthma.

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