Prevalence of exposure to multiple occupational carcinogens among exposed workers in Australia

[Original Article]

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Word count:

3,103 words (excluding title page, abstract, references, figures, and tables)

KEY MESSAGES

1. **What is already known about this subject?**

   Approximately 3.6 million Australian workers are thought to be currently exposed to occupational carcinogens. It is recognised that workers are likely to be simultaneously exposed to multiple carcinogens; however, the prevalence of exposure to multiple carcinogens is not well understood.

2. **What are the new findings?**

   The vast majority of exposed workers were exposed to more than one carcinogen, and one-quarter were exposed to five or more carcinogens. Patterns of multiple exposure vary by demographic and occupational factors, with male and younger workers being most likely to be exposed to multiple carcinogens.

3. **How might this impact on policy or clinical practice in the foreseeable future?**

   This information could be useful for the intervention and control of exposure to multiple occupational carcinogens, by providing more information about where multiple exposures are most likely to occur.

ABSTRACT

Objectives: Workers can be exposed to a range of different carcinogenic agents in the workplace. However, previous studies have often focused on prevalence of exposure to a single carcinogen, resulting in substantial knowledge gaps regarding the extent of multiple exposures in the workplace. This study aims to investigate the current prevalence of occupational exposure to multiple carcinogens among exposed workers in Australia.

Methods: The data for this study comes from the Australian Work Exposures Study (AWES), a nationwide cross-sectional telephone survey of Australian workers aged between 18 and 65. Information was collected about the respondents' current employment and numerous demographic factors using a web-based application (OccIDEAS) to conduct the interview, with predefined algorithms used to automatically assign exposures to carcinogens based on the respondents' job tasks.

Results: The majority (81%) of exposed respondents were assessed as being probably exposed to more than one carcinogen, and 26% reported exposure to 5 or more carcinogens. We found that after adjusting for occupation, exposure to multiple carcinogens was more likely among male respondents, while older workers (aged between 55 and 65) were less likely to be exposed to multiple carcinogens.

Conclusions: This study provides information on the prevalence of exposure to multiple carcinogens in the general population that has not previously been reported. This information could be useful for the intervention and control of occupational exposures to the prioritised carcinogens identified in this study.

Keywords: Carcinogens; Multiple exposure; Occupational exposure; Prevalence; Workplace

INTRODUCTION

It is well-known that occupational carcinogens represent a significant burden on worker health,[1] with occupational cancers estimated to account for 5,000 invasive cancers and 34,000 non-melanoma skin cancers per year in Australia.[2] An Australian study estimated the future cancers attributable to occupational carcinogen exposure in 2012, with 1.4% of cancers due to occupational exposure.[3] Additionally, a study in the UK estimated that occupational cancers represented 8.2% of all cancers in 2005 in males and 2.3% in females.[4] As of 2019, the International Agency for Research on Cancer (IARC) has classified 202 agents as known (Group 1) or probable (Group 2A) human carcinogens.[5] From these a priority list of occupational carcinogens for preventative action in Australia has been established, with 38 probable or known carcinogenic agents identified as present in Australian workplaces.[6]

Information on the number of workers exposed to carcinogens in Australia and other countries is not routinely collected.[2] The Australian Work Exposures Study (AWES) estimated that about 3.6 million people (40% of workers) were probably exposed to occupational carcinogens in Australia in 2012.[7] This study found that, after adjusting for occupational group, females were less likely to be exposed to carcinogens, while those with a trade certificate (compared to high school education) and those living in regional areas (compared to major cities) were more likely to be exposed to carcinogens. Among males, farmers, heavy vehicle operators, and miners were more likely to be exposed to one or more carcinogens, while among females, farmers, drivers, and transport workers were more likely to be exposed. However, results from AWES have so far only been presented for prevalence of exposure to a single hazard, rather than co-exposure to multiple carcinogens. Similarly, studies investigating the prevalence of exposure to occupational carcinogens in other countries, including the European Union,[8, 9] Costa Rica,[10] and Canada,[11,12] have generally focused on the prevalence of individual exposures rather than the prevalence of exposure to multiple carcinogens.

It is recognised that workers are more likely to be simultaneously exposed to multiple hazards in the workplace.[13,14] For example, farmers perform a diverse selection of tasks that result in potential exposure to several carcinogenic agents, including diesel engine exhaust, organic solvents, metals, wood dust, crystalline silica, and solar radiation.[15,16] Accordingly, AWES found that Australian farmers were exposed to an average of five different carcinogens.[17] Shift workers have also been found to be exposed to multiple carcinogens at work.[18] Safe Work Australia conducted the National Hazard Exposure Worker Surveillance Survey (NHEWS) to establish the extent of exposure to multiple hazards among Australian workers.[19] NHEWS found that 62% of workers reported that they were exposed to more than one hazard, with one in five reporting being exposed to more than five hazards. However, these studies, and many others, investigated exposure to multiple hazards for a specific industry or occupation (or a range of priority industries, as in NHEWS), rather than exposure at a population level, and so do not represent an overall estimate of multiple exposure for the

Australian workforce. The need for improved research of multiple hazard exposures has previously been identified as an area of priority for worker health and safety.[20]

The aim of the current study was therefore to examine the demographic and occupational factors associated with occupational exposure to multiple carcinogens in Australia, using AWES data. While several papers have been published using the rich AWES dataset, the prevalence of exposure to multiple carcinogens among Australian workers as a whole has not previously been investigated. This dataset provides the unique opportunity to investigate the predictors of multiple exposures to carcinogens within Australia.

Specifically, the objectives of this study were to determine the average number of carcinogens Australian workers are exposed to; to determine which demographic and occupational factors are associated with being exposed to multiple occupational carcinogens; to identify the most common co-exposures; and to determine which factors are associated with exposure to multiple bladder and lung carcinogens.

METHODS

Study population

The data for this study is from AWES, a nationwide cross-sectional telephone survey conducted in 2011-2012 that investigated the prevalence of occupational exposure to 38 known or probable human carcinogens [6] among Australian workers.[7] The carcinogens investigated had previously been prioritised based on evidence of their carcinogenicity according to IARC (as of 2012) and their relevance to occupational circumstances in Australia (see Supplementary Table 1 for the full list of carcinogens).[6] Full details of the survey methodology have been published elsewhere.[7,21] In brief, male and female Australian residents in current employment and aged between 18 and 65, with sufficient English speaking and hearing ability, were eligible to participate. Ethics approval for this study was obtained from the Human Research Ethics Committee of Curtin University (HRE 2019-0692).

Data collection

Trained interviewers collected data from respondents using computer-assisted telephone interviews, after first receiving verbal informed consent. Demographic information comprising age, sex, residential postcode, birth country, year of arrival in Australia, language spoken at home, and education level was obtained from respondents. Household socio-economic status and remoteness were determined in accordance with the Australian Bureau of Statistics Socio-Economic Indexes for Areas Index of Relative Socio-Economic Disadvantage (SEIFA IRSD) [22] and the Accessibility and Remoteness Index of Australia (ARIA) [23]. Interviewers also collected basic information about respondents' current employment in order to assign them into one of 57 job modules or classify them as unexposed.

The job modules were part of the web-based tool Occupational Integrated Database Exposure Assessment System (OccIDEAS), an application used to manage the interviews and the exposure assessment process.[24] Each interview took approximately 15 minutes. Jobs were coded according to the Australian and New Zealand Standard Classification of Occupations (ANZSCO) at a 4-digit level [25] and then classified into 30 occupational groups based on potential for exposure to the carcinogens investigated.[7] Each group was thought to contain occupations which were relatively homogeneous in terms of exposure to the carcinogens under investigation, with reference to job tasks outlined in ABS occupation definitions [25] and likely exposures that may result from these tasks.

Exposure assessment

Assessment of the probability of exposure to each of the 38 carcinogens was provided automatically by the built-in algorithms in OccIDEAS.[24] OccIDEAS provided automatic assessment based on predetermined rules that were developed in consultation with experts and scientific literature. The rules were linked to and triggered by reported job tasks to assign exposure.

Statistical analysis

All analysis was conducted using Stata v14. The average number of exposures was determined by summing the number of carcinogens each worker was exposed to and then dividing by the total number of respondents. Prevalence of exposure was determined by dividing the number of respondents exposed to multiple hazards by the total number of respondents. Poisson regression with robust error variance was used to estimate incidence rate ratios (IRR) and 95% confidence intervals (CIs) to explore associations between exposure to multiple carcinogens and demographic and occupational factors. Pearson's correlation coefficients were used to determine the most common co-exposures among those exposures with a prevalence of exposure of 15% or greater. Poisson regression with robust error variance was then used to examine associations between co-exposure to multiple bladder and lung carcinogens [5] and demographic and occupational factors.

RESULTS

Summary of exposures

A total of 5,493 respondents (3,069 male and 2,424 female) completed the interview. Of these, 2,083 respondents (37.9%) were assessed as being probably exposed to one or more of the identified priority carcinogens. The following analysis is restricted to those assessed as being exposed (n=2,083).

The majority of exposed respondents (81.3%, n=1,694) were found to be exposed to more than one carcinogen. The number of carcinogens individual respondents were exposed to ranged from one to 13, with an average of 3.7 carcinogens for males and 2.7 carcinogens for females. Over one-quarter of exposed male respondents (29.1%, n=469) and 15.7% (n=74) of exposed female respondents were exposed to five or more carcinogens (Table 1).

Table 1. Prevalence of exposure to multiple occupational carcinogens among exposed workers, by sex

Number of carcinogens	Male		Female	
	Sample (n) exposed	**%**	**Sample (n) exposed**	**%**
1	226	14.0	163	34.6
2	322	20.0	103	21.9
3	324	20.1	72	15.3
4	271	16.8	59	12.5
5	178	11.0	34	7.2
6	118	7.3	21	4.5
7	70	4.3	10	2.1
8	47	2.9	4	0.8
9 or more	56	3.6	5	1.1
Total	**1,612**	**100.0**	**471**	**100.0**

Demographic characteristics associated with exposure to multiple carcinogens

Exposure to multiple carcinogens varied by demographic characteristic, with males and those living in remote and outer regional areas (compared to major cities) exposed to a higher number of carcinogens (Table 2). After adjusting for other demographic characteristics, exposure to multiple carcinogens was predicted by sex and remoteness of residence. After additionally adjusting for occupation, age, sex, education level, and socioeconomic status (SES) also emerged as significant predictors of multiple exposure. Specifically, females and older workers (aged 55 and over) were less likely to be exposed to multiple carcinogens, while those with a trade certificate (compared to high school education), and those living in lower SES areas and regional and remote areas were more likely to be exposed to multiple carcinogens.

In addition, exposure to multiple carcinogens differed significantly by occupational group (Table 3). Compared with office workers, farmers, engineers, painters, nurses, plumbers, vehicle workers, carpenters, emergency workers, heavy vehicle workers, miners, and handypersons were more likely to be exposed to multiple carcinogens. Teachers, health professionals, and food service workers were less likely than office workers to be exposed to multiple carcinogens. Emergency workers and miners had the highest mean number of exposures, with both groups being exposed to over six different carcinogens on average.

Table 2. Incidence rate ratios (IRRs) and 95% confidence intervals (CIs) for association between demographic characteristics and prevalence of multiple exposures among exposed workers (n=2,083)

Demographic characteristic	n	Mean (SD)	Range	Model 1[a] aIRR (95% CI)	Model 2[b] aIRR(95% CI)
Sex					
Male	1,612	3.7 (2.2)	1-13	1.00	1.00
Female	471	2.7 (1.9)	1-12	0.74 (0.69-0.79)	0.77 (0.72-0.82)
Age					
18-34	359	3.4 (2.2)	1-12	1.00	1.00
35-54	1,184	3.5 (2.2)	1-13	1.04 (0.96-1.11)	0.99 (0.93-1.06)
55-65	533	3.3 (2.0)	1-13	0.96 (0.88-1.04)	0.91 (0.85-0.98)
Country of birth					
Australia	1,658	3.5 (2.2)	1-13	1.00	1.00
Other	424	3.2 (2.0)	1-13	0.97 (0.91-1.04)	1.02 (0.95-1.08)
Language spoken at home					
English	2,043	3.5 (2.2)	1-13	1.00	1.00
Other	40	2.8 (1.7)	1-7	1.14 (0.93-1.39)	1.08 (0.91-1.28)
Highest level of education					
High school or lower	842	3.6 (2.2)	1-13	1.00	1.00
Trade certificate/diploma	773	3.6 (2.2)	1-13	1.01 (0.96-1.07)	1.06 (1.00-1.12)
Bachelor degree or higher	465	3.0 (2.1)	1-13	0.94 (0.87-1.01)	0.97 (0.91-1.05)
Socioeconomic status					
Highest quintile	466	3.1 (2.0)	1-13	1.00	1.00
Fourth	493	3.5 (2.1)	1-13	1.08 (0.99-1.17)	1.08 (1.00-1.16)
Third	463	3.5 (2.2)	1-11	1.05 (0.96-1.15)	1.05 (0.97-1.14)
Second	421	3.8 (2.2)	1-13	1.10 (1.01-1.21)	1.09 (1.01-1.18)
Lowest	240	3.6 (2.3)	1-10	1.10 (0.99-1.23)	1.13 (1.03-1.24)
Remoteness					
Major city	1,076	3.2 (2.0)	1-13	1.00	1.00
Inner regional	643	3.5 (2.2)	1-13	1.07 (1.00-1.15)	1.02 (0.95-1.08)
Outer regional	293	4.0 (2.2)	1-12	1.21 (1.12-1.32)	1.08 (1.00-1.17)
Remote/very remote	71	4.5 (2.5)	1-10	1.33 (1.16-1.53)	1.17 (1.05-1.30)

SD: Standard Deviation

[a] Model 1 adjusted for all demographic variables in table plus state of residence

[b] Model 2 adjusted for all variables in Model 1 plus occupational group

Table 3. Incidence rate ratios (IRRs) and 95% confidence intervals (CIs) for association between occupational group and prevalence of multiple exposures among exposed workers (n=2,083)

Occupational group	n	Mean (SD)	Range	aIRR[a] (95% CI)
Office workers	239	2.9 (1.5)	1-10	1.00
Animal/horticultural workers	99	3.1 (2.0)	1-9	1.05 (0.91-1.21)
Automobile drivers	69	3.0 (1.2)	1-9	1.06 (0.94-1.20)
Carpenters	91	3.8 (1.7)	1-8	1.22 (1.09-1.37)
Cleaners	12	3.2 (1.9)	1-6	1.14 (0.83-1.57)
Construction workers	56	3.4 (1.5)	1-10	1.09 (0.95-1.25)
Electrical workers	113	2.5 (1.5)	1-9	0.81 (0.70-0.93)
Emergency workers	58	6.6 (3.9)	1-13	2.22 (1.87-2.62)
Engineers	91	3.8 (2.0)	1-9	1.24 (1.09-1.40)
Farmers	137	5.3 (1.5)	2-9	1.72 (1.58-1.89)
Food factory workers	19	3.3 (1.5)	1-6	1.06 (0.87-1.30)
Food service workers	48	1.8 (1.5)	1-7	0.65 (0.51-0.82)
Forklift drivers	30	2.3 (1.7)	1-8	0.78 (0.60-1.01)
Handypersons	39	3.8 (2.3)	1-9	1.29 (1.06-1.57)
Health professionals	59	1.9 (1.4)	1-6	0.68 (0.56-0.83)
Health support workers	58	2.4 (1.8)	1-8	0.98 (0.80-1.20)
Heavy vehicle drivers	164	4.4 (2.3)	1-11	1.41 (1.27-1.57)
Hospitality workers	42	2.1 (1.8)	1-7	0.78 (0.60-1.02)
Machinery operators	50	2.7 (2.2)	1-12	0.89 (0.71-112)
Metal workers	98	3.4 (1.7)	1-9	1.07 (0.95-1.22)
Miners	28	6.1 (2.7)	2-10	1.89 (1.61-2.23)
Nurses	114	3.6 (2.0)	1-8	1.46 (1.28-1.66)
Outdoor workers NEC	27	3.5 (2.5)	1-11	1.12 (0.87-1.45)
Painters	28	4.5 (1.5)	1-6	1.44 (1.25-1.66)
Passenger transport workers	43	2.6 (1.5)	1-6	0.91 (0.76-1.08)
Plumbers	76	4.0 (1.6)	1-8	1.27 (1.13-1.43)
Printers	6	1.8 (1.2)	1-4	0.61 (0.38-0.98)
Scientists	63	2.8 (1.8)	1-8	1.02 (0.86-1.20)
Teachers	36	1.7 (1.3)	1-6	0.65 (0.50-0.84)
Vehicle workers	90	3.9 (2.0)	1-10	1.23 (1.09-1.40)

SD: Standard Deviation; NEC: not elsewhere classified

[a] Adjusted for sex, age group, country of birth (Australia vs. other), main language spoken at home (English vs. other), highest level of education, socioeconomic status, area of residence, and state of residence

Demographic characteristics associated with co-exposure to bladder and lung carcinogens

A total of nine exposures had a prevalence of greater than 15% overall. These included solar radiation (59.0% of exposed), diesel engine exhaust (DEE; 49.4%), environmental tobacco smoke (ETS; 35.9%), benzene (25.4%), respirable crystalline silica (18.4%), wood dust (18.1%), lead (16.6%), shift work (16.6%), and polycyclic aromatic hydrocarbons other than vehicle exhausts (other PAHs; 16.4%). Strong positive correlations were found between many of these carcinogens (Table 4). In particular, strong correlations were observed between carcinogens known to be associated with bladder (DEE and other PAHs) and lung (DEE, ETS, silica, and other PAHs) cancers [5]. The following analyses therefore examine the demographic and occupational characteristics associated with co-exposure to bladder and lung carcinogens.

Of the exposed sample, 10.5% (n=219) were exposed to both bladder carcinogens (DEE and other PAHs). A further 38.8% (n=809) were exposed to DEE but not other PAHs, and 5.9% (n=122) were exposed to other PAHs but not DEE. After adjusting for demographic and occupational characteristics, those exposed to both bladder carcinogens were more likely to be male and to have achieved a trade certificate or diploma compared to those exposed to neither (Table 5). Those residing in the highest socioeconomic status quintile were less likely to be exposed to both bladder carcinogens. Differences were also seen by occupational group, although regression results could not be presented due to low (or nil) numbers in some groups. Over half (51.1%, n=112) of those exposed to both bladder carcinogens were farmers. Of all farmers, 81.8% were exposed to both DEE and other PAHs, along with 51.5% (n=34) of all emergency workers, 22.5% (n=23) of animal/horticultural workers, and 14.3% (n=4) of miners.

A total of 20 respondents (1.0% of exposed) were exposed to all four lung carcinogens (DEE, ETS, silica, and other PAHs). Over one-third of all exposed workers (37.6%, n=784) were exposed to one lung carcinogen, 26.5% (n=552) were exposed to two, and 8.5% (n=177) were exposed to three lung carcinogens. After adjusting for demographic and occupational characteristics, co-exposure to multiple lung carcinogens was less likely among female workers, those residing in the highest socioeconomic status quintile, and those residing in major cities (Table 5). Co-exposure to multiple lung carcinogens was more likely among automobile drivers, construction workers, emergency workers, engineers, farmers, heavy vehicle drivers, miners, and plumbers compared with office workers (Supplementary Table 2). Animal/horticultural workers, carpenters, electrical workers, food factory workers, health professionals, health support workers, hospitality workers, nurses, passenger transport workers, and teachers were less likely than office workers to be exposed to multiple lung carcinogens.

More than half of all miners (89.3%, n=25), farmers (83.9%, n=115), heavy vehicle drivers (67.7%, n=111), construction workers (63.9%, n=39), emergency workers (53.0%, n=35) and engineers (52.5%, n=52) were exposed to more than one lung carcinogen. The mean number of exposures to

Table 4. Pearson's correlation coefficients for associations between carcinogens with prevalence of exposure >15%

Carcinogen	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
1.Solar radiation	0.618***	0.487***	0.449***	0.402***	0.403***	0.270***	0.025	0.226***
2.Diesel engine exhaust		0.356***	0.515***	0.349***	0.216***	0.264***	0.120***	0.300***
3.Environmental tobacco smoke			0.146***	0.279***	0.141***	0.210***	0.046**	0.023
4.Benzene				0.144***	0.249***	0.206***	0.020	0.333***
5.Silica					0.268***	0.183***	0.076***	0.161***
6.Wood dust						0.236***	-0.500**	0.298***
7.Lead							0.026	0.213*
8.Shiftwork								0.067***
9.Other PAHs [a]								

* $p<.05$, ** $p<.01$, *** $p<.001$

[a] Polycyclic aromatic hydrocarbons other than vehicle exhausts

Table 5. Incidence rate ratios (IRRs) and 95% confidence intervals (CIs) for association between demographic characteristics and prevalence of co-exposure to bladder and lung carcinogens

	Bladder carcinogens[a]		Lung carcinogens[b]	
Demographic characteristic	**n(%)**	**aIRR[c], 95% CI**	**n(%)**	**aOR[c], 95% CI**
Sex				
Male	190 (86.8)	1.00	666 (88.9)	1.00
Female	29 (13.2)	0.65 (0.49-0.86)	83 (11.1)	0.81 (0.74-0.89)
Age				
18-34	34 (15.6)	1.00	132 (17.7)	1.00
35-54	124 (56.9)	0.92 (0.69-1.23)	418 (56.0)	0.95 (0.88-1.03)
55-65	60 (27.5)	0.76 (0.57-1.03)	196 (26.3)	0.92 (0.84-1.01)
Country of birth				
Australia	202 (92.2)	1.00	623 (83.2)	1.00
Other	17 (7.8)	0.73 (0.47-1.14)	126 (16.8)	0.98 (0.90-1.06)
Language spoken at home				
English	219 (100.0)	-	740 (98.8)	1.00
Other	0 (0.0)	-	9 (1.2)	1.02 (0.79-1.31)
Highest level of education				
High school or lower	130 (59.4)	1.00	360 (48.1)	1.00
Trade certificate/diploma	47 (21.5)	0.78 (0.61-0.99)	273 (36.5)	0.97 (0.91-1.04)
Bachelor degree or higher	42 (19.2)	0.88 (0.68-1.12)	115 (15.4)	0.93 (0.84-1.02)
Socioeconomic status				
Highest quintile	22 (10.0)	1.00	133 (17.8)	1.00`
Fourth	48 (21.9)	1.77 (1.18-2.66)	186 (24.8)	1.16 (1.06-1.27)
Third	52 (23.7)	1.51 (1.00-2.21)	166 (22.2)	1.09 (0.99-1.20)
Second	68 (31.0)	1.65 (1.10-2.48)	170 (22.7)	1.14 (1.04-1.26)
Lowest quintile	29 (13.2)	1.75 (1.11-2.78)	94 (12.5)	1.15 (1.03-1.29)
Remoteness				
Major city	58 (26.4)	1.00	348 (46.5)	1.00
Inner regional	70 (32.0)	0.88 (0.64-1.22)	219 (29.2)	1.00 (0.93-1.07)
Outer regional	70 (32.0)	0.97 (0.68-1.37)	142 (19.0)	1.15 (1.04-1.27)
Remote/very remote	21 (9.6)	0.97 (0.64-1.46)	40 (5.3)	1.18 (1.04-1.34)

[a] Exposed to both bladder carcinogens (comprising diesel engine exhaust and polycyclic aromatic hydrocarbons other than vehicle exhausts).

[b] Exposed to more than one lung carcinogen (comprising diesel engine exhaust, environmental tobacco smoke, silica, and polycyclic aromatic hydrocarbons other than vehicle exhausts).

[c] Adjusted for all demographic variables in table plus state of residence and occupational group.

lung carcinogens was highest among miners (2.6), farmers (2.1), and heavy vehicle drivers (2.0) (Supplementary Table 2).

DISCUSSION

This study found that the majority of respondents assessed as being exposed to occupational carcinogens were exposed to more than one carcinogen. Overall, we found that 81% of exposed respondents were exposed to more than one carcinogen, with 26% reporting exposure to five or more carcinogens. These results are similar to a previous Australian study that found that 73% of exposed workers self-reported exposure to more than one hazard, with 23% reporting exposure to five or more hazards.[19]

We also found that the prevalence of exposure to multiple carcinogens varied by demographic characteristics. Males were significantly more likely to be exposed to multiple carcinogens in the workplace compared to females, with over one-quarter of males (29%) being exposed to more than five carcinogens (compared with 16% of females). Sex was also found to be a significant predictor of co-exposure to multiple bladder and lung carcinogens. While previous studies have found that males are more likely to be exposed to carcinogens and other hazards in the workplace [7, 19], this study adds that males are also more likely to be exposed to multiple carcinogens simultaneously, resulting in a potentially additive or synergistic effect on their cancer risk. The higher prevalence of multiple exposures among males is likely a result of the assignment of different tasks within the same occupation. For example, females have been found to complete more repetitive tasks in comparison to males in the same occupation, while males are more likely to complete physically demanding tasks.[27,28] Thus, it may be that the assignment of different tasks in the workplace may have contributed to the sex difference found in the current study.

After adjustment for demographic factors and occupation, older workers (aged 55 and over) were also found to be less likely to be exposed to multiple carcinogens than their younger counterparts. Interestingly, however, age was not a predictor of exposure to multiple bladder or lung carcinogens. A previous Australian study has also found exposure to multiple hazards to decrease with increasing age,[19] while studies in the US have reported high exposures to multiple hazards in the workplace among younger workers.[29,30] This may suggest that older workers may be assigned to different tasks than younger workers, and/or that they may have progressed to more senior positions in the workforce (for example, supervisors or managers), and may therefore no longer perform hands-on tasks. Preliminary analysis on our data suggests that this may indeed be the case, with a significantly higher proportion of older workers being employed in managerial positions than expected ($p<.001$).

We also found a higher prevalence of exposure to multiple carcinogens among those living in regional and remote areas of Australia. On average, those living in outer regional and remote areas were exposed to 4-4.5 different occupational carcinogens, compared with an average of 3.2 carcinogens among those living in major cities. Those in outer regional and remote areas were also more likely to be exposed to multiple lung carcinogens, with differences persisting after controlling for occupation. To our knowledge, AWES is the only study which has investigated differences in exposure prevalence by remoteness of residence, finding that the overall prevalence of exposure to occupational carcinogens is higher among those living in regional areas. [7] It is also known that the incidence of some cancers, including lung cancer, is higher in remote areas compared with major cities.[31] Differences in exposure may be partially explained by differences in industry between regional and metropolitan areas, with agriculture and mining industries more common in regional and remote areas;[32] however, differences persisted after controlling for occupation. It may also be that individuals within the same job complete different tasks depending on the remoteness of their work location; this requires further investigation. Regardless, this finding suggests that, at least within Australia, efforts to reduce exposure to occupational carcinogens should focus on regional and remote areas of the country.

Several occupational groups were found to have a significantly higher prevalence of exposure to multiple carcinogens. In particular, emergency workers, engineers, farmers, heavy vehicle drivers, miners, and plumbers were found to be more likely to be exposed to multiple carcinogens in general, as well as to multiple lung carcinogens, compared with office workers. Higher exposures to hazards among certain occupational groups has also been identified in several other population-based studies. In Australia, labourers and technicians and trades workers have been found to be more likely to be exposed to multiple hazards compared with managers. [19] Similarly, a study in the US found that construction workers and machine operators had the highest prevalence of exposure to airborne hazards, chemicals, and outdoor work. [33]

Some limitations to this study should be noted. Firstly, the assessment of exposure was based on self-reported tasks, which may be subject to recall or social desirability biases. However, respondents were only required to answer questions in relation to their current job tasks, rather than their exposures, and so the impact of these biases is likely to be minimal. Secondly, we classified exposure dichotomously, and did not consider the duration or intensity of exposure. Therefore, our prevalence estimates likely include exposure at multiple levels and intensities. We also focused on only 38 carcinogens and may have excluded some important exposures. However, this is expected to have a minor impact on the overall prevalence of exposure to multiple carcinogens as we included the most common carcinogens in Australia, and found very low prevalence of exposure to some carcinogens, suggesting we erred on the side of over-inclusion.[7] This study also focussed on exposure in the respondents' current job only. Given that individuals typically have more than one job over their lifetime, it is likely that the prevalence of exposure to multiple carcinogens over a lifetime may be higher than that presented here. Our sample contained a lower proportion of younger and migrant workers compared to the general population, which may have led to the under-representation of certain occupational groups. Finally, chance findings cannot be excluded due to the large number of associations investigated.

In conclusion, this study provides important information on the prevalence of exposure to multiple carcinogens among the Australian working population. We found that the majority of exposed workers were exposed to more than one carcinogen in the workplace. This study provides insight into the prevalence of multiple carcinogen exposure and identifies the need for routinely collected national surveillance to better understand and monitor the extent of exposure.

ACKNOWLEDGEMENTS

The authors acknowledge the AWES study team: Professor Lin Fritschi, Associate Professor Deborah Glass, Professor Tim Driscoll, Dr Geza Benke, and Associate Professor Alison Reid. The authors also acknowledge Dr Renae Fernandez for her role in preparing the study questionnaires, Troy Sadkowsky for his technical support, and the Survey Research Centre at Edith Cowan University for their assistance in data collection.

FUNDING

This work was supported by National Health and Medical Research Council (NHMRC) grant 1003563 and Cancer Council Western Australia.

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