

Asthma and Other Respiratory Symptoms in New Zealand Pine Processing Sawmill Workers

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Background To study respiratory symptoms in pine sawmill workers.

Methods A respiratory health questionnaire was administered to 772 pine sawmill workers and the association between symptoms and job-title-based exposure was studied.

Results Asthma in exposed workers (18%, $n = 704$) was more common than in the general population (12.1%, $n = 592$; adjusted OR (95% CI): 1.6 (1.1–2.3)). Asthma was also more common in the low exposure group (15.6%, $n = 294$) and high exposure groups (high exposure to 'green dust'; 20.4%, $n = 212$ and high exposure to 'dry dust'; 18.8%, $n = 198$) than in the non-exposed workers (9.2%, $n = 65$). Adjusted odds ratios were 1.9 (0.7–4.9), 2.7 (0.9–7.6), and 2.1 (0.8–5.7), respectively. Adjusted odds ratios for symptoms of cough were 2.7 (1.2–6.5) for the low, 5.2 (2.1–13.0) for the high 'green dust' and 3.3 (1.4–7.9) for the high 'dry dust' exposure groups. Moreover, eye and nose irritations were significantly more prevalent in the high and low exposure groups.

Conclusions Working in pine sawmilling is associated with an increased prevalence of asthma and cough symptoms and eye and nose irritation. *Am. J. Ind. Med.* 39:608–615, 2001. © 2001 Wiley-Liss, Inc.

KEY WORDS: respiratory health; sawmill workers; wood dust; asthma; pine

INTRODUCTION

In addition to sino-nasal cancer [IARC, 1995], exposure to dust of both hard (broad-leaved trees or Angiosperms) and softwood (conifers or Gymnosperms) has been shown to be associated with upper and lower respiratory symptoms, reduced lung function, increased bronchial responsiveness, occupational asthma, and eye and nose irritations [Chan-Yeung et al., 1984; Shamssain, 1992; Malo et al., 1994; Rask-Andersen et al., 1994; Hessel et al., 1995; Malmberg et al., 1996; Noertjojo et al., 1996; Demers et al., 1997]. The

underlying pathophysiological mechanisms are unclear, and in case of Western red cedar asthma both allergic and non-allergic mechanisms have been suggested [Chan-Yeung, 1982, 1994; Frew et al., 1998]. Also, it is not entirely clear what specific exposures cause these respiratory symptoms.

Western red cedar asthma is the most common form of occupational asthma in the Pacific North West [Chan-Yeung, 1994] and has been studied quite extensively, whereas occupational asthma caused by wood dust exposure from other sources (e.g. pine, spruce etc) has only received limited attention. The prevalence of occupational asthma caused by western red cedar has been estimated to be approximately 4–15% by different investigators [Brooks et al., 1981; Chan Yeung et al., 1984; Vedal et al., 1986]. Although several studies (mainly in furniture workers) show that pine dust also induces respiratory symptoms and reduced lung function [Whitehead et al., 1981; Samssain, 1992; Hessel et al., 1995], valid asthma prevalence data in pine sawmill workers are currently lacking. In addition, dose - response relationships for pine dust and/or specific components therein (e.g. abietic acid) have not been reported. One study found that pine mill workers were

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Contract grant sponsor: Health Research Council New Zealand; Contract grant number: HRC 99/525/PHR/RJ/U OF O

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approximately 2.5–3.0 times more likely to report asthma symptoms than non-wood-dust-exposed workers [Hessel et al., 1995].

We have, therefore, conducted a questionnaire survey assessing the prevalence of respiratory symptoms among 772 sawmill workers processing exclusively pine trees (*Pinus radiata*). The prevalence of respiratory symptoms in workers with high exposure, and those with low/intermittent exposure, was compared with the prevalence in the general population in the same areas and with non-exposed workers from the same work force.

MATERIALS AND METHODS

Subjects

Approximately 900 sawmill workers were asked to participate in a respiratory health questionnaire. Sawmill workers were approached through the site managers directly therefore, we did not have an exact number of workers that were asked to participate. Based on personnel records the number was estimated to be around 900. For practical reasons we did not include night shift workers in our selection. Workers were selected from 5 large sawmills situated in the central North Island and one in the North of the South Island of New Zealand. Of the total number of workers approached, 772 (approximately 86%) agreed to participate in the study. All subjects gave written informed consent and the study was approved by the Wellington ethics committee.

Sawmills

All five mills processed pine trees (*Pinus radiata*) exclusively and are representative of the larger sawmills that make up most of New Zealand's sawmill industry. The sawmill process has been described in more detail previously [Douwes et al., 2000]. Briefly, the process consists of three main activities: 1) sawing logs to green lumber and subsequently sorting, grading, trimming and stacking the green lumber; 2) kiln drying of green lumber; and 3) planing and moulding of dry lumber in the planing and moulding mill, respectively, and sorting, grading, stacking and strapping of the planed dry lumber.

Questionnaire

Questionnaires were administered face-to-face and consisted of 3 parts, including: 1) personal and work characteristics; 2) respiratory health symptoms; and 3) smoking habits (current and ex-smoking). Respiratory health questions were adopted from the International Study of Asthma and Allergies in Childhood [ISAAC; Asher et al., 1995], the British Medical Research Council questionnaire

[BMRC, 1976] and the European Community Respiratory Health Survey [ECRHS; Burney et al., 1994] and supplemented with additional questions to assess whether symptoms were work related (e.g. 'do symptoms lessen or disappear in the weekend or during holidays'). Moreover, we included several questions on nose, eye and skin irritations and included questions about the frequency that certain symptoms occurred. As well as analyses of the responses to individual questions, overall asthma prevalence was estimated using the ECRHS definition [Burney et al., 1994] which is based on the proportion of subjects answering 'yes' to: 1) woken by shortness of breath in last 12 months; 2) asthma attack in last 12 months; or 3) current asthma medication.

Exposure Categories

Dust exposure categories were constructed by two qualified industrial hygienists with specific experience in this industry and were based on the workers' work area and job title. Four 'crude' exposure categories were distinguished: 1) non-exposed: administration and other office workers, 2) low or intermittent exposure: yard, maintenance, dispatch, export workers, and saw filers, 3) high exposure to 'green' dust: all workers in green mill, and 4) high exposure to 'dry' dust: workers in planer mill, remanufacturing and moulding. In addition, we asked whether respiratory equipment was used, and if so, how often.

General Population

In the preliminary analysis, the data for non-exposed and exposed workers (all three exposure categories combined) were compared to the findings in the general population in the same areas in a previous random population survey [Lewis et al., 1997]. The methodology for the general population survey has been described in detail elsewhere [Crane et al., 1994; Lewis et al., 1997]. Briefly, a one-page questionnaire on asthma symptoms was mailed to 31,470 people aged 20–44 chosen at random from the 1991 electoral rolls for all electorates in New Zealand and of them 25,664 responded (82% response rate). The questions were identical to the questions on asthma symptoms used in the current sawmill study. For the comparison with our sawmill data we selected all 592 subjects from the three electorates in which the sawmills were located.

Analysis

Data were analyzed using SAS statistical software (SAS 6.12; SAS Institute; Cary, NC). After initial comparison with the general population data (see above),

the various exposure groups were compared with the non-exposed workers. Prevalence odds ratios to describe the association between exposure and the occurrence of symptoms were calculated by means of a logistic regression analysis [Harrell, 1983]. Associations were adjusted for sex, age, ethnicity, current and ex smoking and mill number. For the comparison with the general population data, associations were only adjusted for sex, age and ethnicity, since smoking data were not available for the general population survey. Although some authors [Lee and Chia, 1993, Thompson et al., 1998] have argued for the use of prevalence ratios, the standard effect measure in prevalence studies is the prevalence odds ratio [Rothman and Greenland, 1998; Checkoway et al., 1989] since, in a stable population, this provides an estimate of the ratio of the products of disease incidence and average disease duration in the two populations being compared. Thus, if an exposure does not affect disease duration, then the prevalence odds ratio directly estimates the incidence rate ratio [Pearce et al., 1998].

RESULTS

Table I shows the characteristics of the study population stratified by exposure category. Significant differences existed in age, smoking status, sex and ethnicity between non-exposed (the reference group) and exposed workers, and these factors were therefore adjusted for in multivariate analyses.

Asthma symptoms in the exposed workers were all higher than in the general population from the same geographical area with an OR of 1.6 (95% CI = 1.1–2.3) for asthma defined as a positive response to either 'woken by shortness of breath in last 12 months' or 'asthma attack in last 12 months' or 'current asthma medication' (Table II). The use of asthma medication was also elevated in the exposed workers (OR = 1.8, 95% CI = 1.1–2.9). No significant differences in asthma symptom prevalence existed between the non-exposed workers and the general population with the exception of the symptom 'woken by shortness of breath' that was significantly less prevalent in the non-exposed workers. However, after adjusting for potential confounders this difference was no longer statistically significant.

Symptoms of cough (in last 12 months) were more common in the low/intermittent and high exposure groups than in the non-exposed group (Table III). After adjusting for various confounding factors including smoking, significant differences in the prevalence of cough between exposed and non-exposed subgroups remained, with odds ratios of 5.2 (95% CI = 2.1–13.0) and 3.3 (95% CI = 1.4–7.9) for the high 'green dust' and high 'dry dust' exposure groups, respectively, and an odds ratios of 2.7 (95% CI = 1.2–6.5) for the low and intermittent exposure group. A similar pattern was observed for the symptoms 'cough with phlegm' and 'woken due to cough' (only significant for high exposure groups). The prevalence of cough symptoms seemed somewhat higher in the high 'green dust' than in the

TABLE I. Characteristics of Study Participants; Sawmill Workers in New Zealand

	Non-exposed (n = 65)	Intermittent and low exposed (n = 294)	High exposed to 'green' dust (n = 212)	High exposed to 'dry' dust (n = 198)
Age (y, SD)	40.2 (11.0)	38.3 (10.7)	33.2 (10.3)**	34.1 (10.8)**
Duration of employment (y, SD) ^a	7.6 (7.4)	8.6 (7.8)	7.1 (6.8)	5.7 (6.2)
Duration of employment (y, SD) ^b	3.4 (3.8)	5.1 (5.3)**	3.7 (4.4)	3.2 (4.6)
Hours/week of work (SD)	43.9 (6.2)	44.5 (6.4)	44.3 (5.9)	43.9 (6.2)
	(%)	(%)	(%)	(%)
Smokers	24.6	31.0	56.6**	34.3
Ex-smokers	29.2	25.9	22.2	24.7
Female workers	60.9	9.2**	7.6**	16.7**
Maori	6.3	21.2*	52.4**	35.8**
Pacific Islander	3.1	7.8	17.9*	3.1
European	90.6	71.8	31.6**	62.2*
Work > 50% outdoors	0.0	31.0**	22.2**	13.6*
Daily use of respiratory equipment	0.0	7.5	16.0*	7.6

^a In current saw mill.

^b In current job title.

* $P < 0.05$, ** $P < 0.01$; compared to non-exposed group.

TABLE II. Asthma Symptom Prevalence (%) and Adjusted Prevalence ratios (OR) with 95% Confidence Intervals (CI) for the General Population, Non-Exposed Workers and Exposed Workers (Low and High Exposure Groups Combined). ORs were Adjusted for Age, Sex, and Ethnicity; Sawmill Workers in New Zealand

Symptom in last 12 months	General population (n = 592)		Non-exposed workers (n = 65)		Exposed workers (n = 704)	
	%	OR	%	OR (CI)	%	OR (CI)
Wheezing	23.7	1.0	20	0.8 (0.4–1.7)	29.6*	1.4 (1.1–1.9)*
Wheezing without cold	14.3	1.0	10.8	0.9 (0.4–2.1)	16.0	1.0 (0.7–1.5)
Woken by SOB ^a	9.0	1.0	1.5*	0.2 (0.0–1.6)	13.5*	1.4 (0.9–2.1)
Asthma attack	5.6	1.0	6.2	1.4 (0.4–4.2)	7.0	1.4 (0.8–2.4)
Asthma medication	6.4	1.0	4.6	0.9 (0.3–3.2)	9.8*	1.8 (1.1–2.9)*
Asthma ^b	12.1	1.0	9.2	1.0 (0.4–2.4)	18.0	1.6 (1.1–2.3)*

^a SOB, shortness of breath.^b 'Woken by SOB in last 12 months' or 'asthma attack in last 12 months' or 'current asthma medication.'* $P < 0.05$; compared to general population.

high 'dry dust' exposure group, however these differences were not statistically significant.

Asthma symptoms (in last 12 months) and current use of asthma medication were also more common in the low/intermittent and high exposure groups compared to the reference group, with highest prevalence rates and odds ratios in the high exposure groups (significant only for the symptoms 'woken by shortness of breath' and 'wheezing, shortness of breath or chest tightness in relation to work'; Table III). The adjusted odds ratios for asthma defined as above and in the material and methods were 2.7 (95% CI = 0.9–7.6), 2.1 (95% CI = 0.8–5.7) and 1.9 (95% CI = 0.7–4.9) for the high 'green dust', high 'dry dust' and the 'low/intermittent' exposure groups, respectively. Particularly high odds ratios were found for 'woken by shortness of breath' with ORs of 7.7 (95% CI = 1.0–61.1) for the high 'dry dust' exposure group and 9.3 (95% CI = 1.1–76.0) for the high 'green dust' exposure group and 7.3 (95% CI = 0.9–57.3) for the low and intermittent exposure group. The use of asthma medication was approximately 2–5 times higher in the high exposure groups compared to the reference group (significant only for the high 'green dust' exposure group).

Nose and eye irritations were more dominant in the exposed groups with the highest prevalence in the high exposure groups (Table III). Eye irritations in particular were highly associated with exposure with ORs of 14.6 (95% CI = 1.8–118.0) and 10.8 (95% CI = 1.4–85.1) in the high 'green dust' and high 'dry dust' exposure groups, respectively, and an OR of 8.0 (95% CI = 1.0–62.7) in the low and intermittent exposure group. Symptoms of allergy or sensitivity (sneezing or running nose, itching or watering eyes, shortness of breath, itching or red skin) to house dust, foods, animals or grasses/plants were not associated with exposure.

Table IV shows the symptom prevalence and adjusted ORs for regularly occurring symptoms that lessen or

disappear during weekends or holidays. In the non-exposed group hardly any cough, asthma, nose or eye symptoms that lessen or disappear during leisure periods were reported (0–3%) in contrast to the low/intermittent and high exposure groups where these symptoms were reported significantly more (5–20%). Symptoms were more common in the high exposure groups than in the low and intermittent exposure group, whereas no large differences existed between the two high exposure groups.

DISCUSSION

In this study we found an increased prevalence of respiratory, nose and eye symptoms in exposed sawmill workers with the highest prevalence in the high exposure groups, and somewhat lower prevalence rates in the low and intermittent exposure group, suggesting a dose-response relationship. However, differences between the high exposure groups and the low and intermittent exposure group were relatively small and not statistically significant.

Non-differential misclassification of exposure for particularly the high and low/intermittent exposure categories may be the most important reason for the lack of a clearer dose-response relationship. Whereas, it is relatively easy to distinguish non-exposed workers based on their job-title it proved difficult to create detailed exposure categories for the exposed workers since no reliable exposure data are currently available for this industry. The exposure classification used in this study is therefore rather crude and thus misclassification is likely to have occurred. In fact, in a previous study [Douwes et al., 2000] we collected personal exposure data in 37 workers from two sawmills that were represented in the current study. This indicated that some subjects classified in the current study as 'low' and 'intermittent exposed' had similar dust exposures to that of the 'high exposed' subjects in the previous study, and some workers classified as 'high exposed' in the current

TABLE III. Symptom Prevalence (%) and Adjusted Prevalence Ratios (OR) with 95% Confidence Intervals (CI) Stratified for the Various Exposure Categories. ORs were Adjusted for Age, Sex, Ethnicity, Current and Ex-Smoking, and Mill Number; Sawmill Workers in New Zealand

Symptom	Non-exposed (n = 65)		Intermittent and low exposed (n = 294)		High exposed to 'green' dust (n = 212)		High exposed to 'dry' dust (n = 198)	
	%	OR	%	OR (CI)	%	OR (CI)	%	OR (CI)
Cough symptoms								
in last 12 months								
Cough ^a	12.3	1.0	25.9*	2.7 (1.2–6.5)*	46.2**	5.2 (2.1–13.0)**	32.3**	3.3 (1.4–7.9)**
Cough up phlegm ^a	10.8	1.0	23.1*	2.1 (0.9–5.2)	35.1**	2.9 (1.1–7.5)*	25.8*	2.4 (1.0–6.0)
Woken regularly due to cough ^b	0.0	1.0	5.8	Undef (0.9–∞)	16.6**	Undef (3.1–∞)**	6.6*	Undef (1.0–∞)*
Asthma symptoms								
in last 12 months								
Wheezing	20.0	1.0	27.6	1.5 (0.7–3.1)	31.3	1.6 (0.7–3.6)	31.0	1.6 (0.7–3.3)
Wheezing without a cold	10.8	1.0	12.9	1.0 (0.4–2.6)	18.5	2.0 (0.7–5.6)	17.8	1.6 (0.6–4.0)
SOB ^c with wheezing	4.7	1.0	13.3	2.7 (0.8–9.6)	13.7	2.8 (0.7–10.8)	13.1	2.5 (0.7–9.3)
Woken by SOB ^c	1.5	1.0	11.6*	7.3 (0.9–57.3)	16.1*	9.3 (1.1–76.0)*	13.7*	7.7 (1.0–61.1)
Asthma attack	6.2	1.0	6.1	1.5 (0.4–5.4)	7.6	3.2 (0.8–12.6)	7.6	1.7 (0.5–6.1)
Asthma medication	4.6	1.0	9.2	2.4 (0.6–9.2)	10.4	4.5 (1.1–18.5)*	10.2	2.6 (0.7–10.2)
Asthma ^d	9.2	1.0	15.6	1.9 (0.7–4.9)	20.4*	2.7 (0.9–7.6)	18.8	2.1 (0.8–5.7)
Wheezing, SOB ^c or chest	4.6	1.0	19.3**	4.7 (1.3–16.4)*	18.0*	4.0 (1.1–14.8)*	24.6**	7.0 (2.0–24.6)**
Tightness in relation to work								
Nose, eye, and skin symptoms								
Runny nose, sneezing > 1/week	13.8	1.0	19.4	1.7 (0.7–4.0)	30.7**	2.6 (1.0–6.5)*	27.8*	2.5 (1.0–6.0)*
Itching, watering eyes > 1/week	1.5	1.0	10.5*	8.0 (1.0–62.7)*	17.0*	14.6 (1.8–118.0)*	13.6*	10.8 (1.4–85.1)*
Itchy skin, skin rash > 1/month	12.3	1.0	8.5	0.5 (0.2–1.4)	9.9	0.7 (0.2–2.0)	12.1	0.9 (0.3–2.3)
Allergy/sensitivity symptoms								
Sensitive to house dust or food or animal or grasses/plants	49.2	1.0	43.2	0.9 (0.5–1.7)	38.7	0.8 (0.4–1.6)	41.9	1.0 (0.5–1.8)

^a Daily for at least part of the year.^b Odds ratios were undefined because none of the subjects in the reference group had the specific symptom; *P*-values and 95% CI were calculated using Fisher exact test.^c SOB, shortness of breath.^d Woken by SOB in last 12 months' or 'asthma attack in last 12 months' or 'current asthma medication'.* *P* < 0.05, ** *P* < 0.01; compared to non-exposed group.

study had substantially lower dust exposures than expected based on their job title and work area. Moreover, misclassification may even be more prominent when causal agents are considered that are not directly associated with exposure to dust. For instance, we previously showed that exposure levels to dust were only poorly correlated with other potentially relevant exposures such as bacterial endotoxin and fungal $\beta(1,3)$ -glucans [Douwes et al., 2000]. However, the main differences found between non-exposed workers (office and administration workers who virtually never conduct work outside the office) on the one hand and high and low/intermittent exposed workers on the other hand are unlikely to have been significantly biased due to exposure misclassification. Furthermore, random misclassification between exposure categories is likely to produce a bias towards the null and is unlikely to explain our positive findings [Pearce et al., 1998]. Misclassification

of exposure due to the use of respiratory equipment was not significant since excluding subjects that regularly used respiratory equipment from the analyses did not alter the results (data not shown). Differences in smoking habits, ethnicity, gender etc, existed between the various exposure categories and the reference group (Table I) but we adjusted for those potential confounders in the multivariate regression analyses and it did not make much difference to the findings. In addition, the non-exposed or reference group may have differed with respect to social class and they are sedentary and work indoors in contrast to the mill workers who are physically active and work outdoors for a significant proportion of the time. Moreover, the reference group (non-exposed workers) was relatively small and it is thus possible that the observed differences could have been a chance finding. However, the asthma symptom prevalence in the reference group was comparable to what we have

TABLE IV. Prevalence and Adjusted Odds Ratios (OR) with 95% Confidence Intervals (CI) for Symptoms that Lessen or Disappear During Weekends and Holidays in the Various Exposure Categories. ORs were Adjusted for Age, Sex, Ethnicity, Current and Ex-Smoking, and Mill Number; Sawmill Workers in New Zealand

	Non-exposed (n = 65)		Intermittent and low exposed (n = 294)		High exposed to 'green' dust (n = 212)		High exposed to 'dry' dust (n = 198)	
	%	OR	%	OR (CI)	%	OR (CI)	%	OR (CI)
Cough symptoms > once a month (in last 12 months)								
Dry cough	1.5	1.0	13.6*	11.5 (1.5–89.0)**	23.1**	18.7 (2.4–148.3)**	19.2**	16.0 (2.1–124.3)**
Cough up phlegm ^a	0	1.0	13.3**	Undef (2.5–∞)**	18.4**	Undef (3.6–∞)**	14.6**	Undef (2.7–∞)**
Asthma symptoms > once a month (in last 12 months)								
Wheezing ^a	0	1.0	5.1	Undef (0.8–∞)	11.3**	Undef (2.0–∞)**	8.6*	Undef (1.4–∞)**
Breathlessness with wheezing ^a	0	1.0	4.1	Undef (0.6–∞)	8.5**	Undef (1.4–∞)**	5.6	Undef (0.8–∞)
SOB ^{a,b}	0	1.0	5.8	Undef (0.9–∞)	8.5**	Undef (1.4–∞)**	10.1**	Undef (1.7–∞)**
Chest tightness	1.5	1.0	3.4	2.6 (0.3–22.4)	5.7	4.8 (0.5–45.7)	7.1	5.0 (0.6–43.2)
Nose, eye, and skin symptoms (in last 12 months)								
Stuffy, runny nose, sneezing > 1/week	3.1	1.0	8.8	2.6 (0.6–11.7)	17.5*	3.9 (0.8–18.4)	19.2**	6.0 (1.3–27.3)**
Itching, burning, watering eyes > 1/week ^a	0	1.0	4.8	Undef (0.7–∞)	9.0**	Undef (1.5–∞)**	7.1*	Undef (1.1–∞)*
Itchy skin, skin rash > 1/month	1.5	1.0	3.1	1.2 (0.1–10.4)	4.7	1.6 (0.2–14.9)	6.6	3.1 (0.4–27.6)

^a Odds ratios were undefined because none of the subjects in the reference group had the specific symptom; *P*-values and 95% CI were calculated using Fisher exact test.

^b SOB, shortness of breath.

P* < 0.05, *P* < 0.01; compared to non-exposed group.

previously found in a large sample of the general population from the same geographical area (with the exception of “woken by shortness of breath”; Table II), and thus the lower symptom prevalence estimate in the reference group seems valid. Finally, the healthy worker effect may have biased our results, but excluding workers who had worked in the sawmill for more than 5 years did not alter the results. Moreover, the mean number of years worked in the industry was relatively small for all exposure groups (Table I) which makes a significant bias caused by the healthy worker effect less likely.

Our findings are consistent with other studies [Whitehead et al., 1981; Hessel et al., 1985; Shamssain, 1992; Halpin et al., 1994; Mandryk et al., 1999] in that they demonstrate that working with pine (or a mix of tree species including pine) is associated with an increased prevalence of respiratory symptoms and eye and nose symptoms. The majority of these studies were, however, conducted in furniture workers and only very few studies have been done in pine sawmill workers. The fact that most of the symptoms reported by exposed workers disappeared or lessened during the weekends and holidays (Table IV) suggests that symptoms were indeed work related. While the participants

in this study were grouped primarily according to estimates of wood dust exposure based on work area and job title, it was recognized that additional exposures to chemical extractives occur during sawmilling and lumber processing. In softwoods (including *Pinus radiata*) these include the volatile monoterpenes and the higher molecular weight resin acids, primarily abietic and pimaric acids, which have been suggested as possibly having a relationship with the health effects under study [Demers et al., 1997]. Abietic acid is a major constituent of colophony, a natural product derived from pine and other softwoods which has been associated with occupational asthma in other industries [Sadhra et al., 1994]. Furthermore, it was recognized that the relative composition of the contaminants of interest would vary throughout the milling process [Teschke et al., 1999], although information on the composition of emissions from *radiata* pine is limited. Two distinct high exposure categories were defined, high ‘green’ and high ‘dry’, on the assumption that green milling was likely to produce higher monoterpene emissions than the processing of kiln dried lumber. Comparison of symptom prevalences between these two groups showed that the differences were small, indicating that the monoterpenes are unlikely to be

the underlying cause, although most symptoms did appear to be slightly more common in the high "green" than the high 'dry' group. Therefore, wood dust and resin acids that remain after kiln drying might be more important.

Symptoms seem to occur at levels well below the current occupational exposure limit for soft wood dust (5 mg/m^3) used in New Zealand and many other countries, including the USA, since the majority of exposure measurements performed previously in the same mills (Douwes et al., 2000) did not exceed the 1 mg/m^3 level and only one sample out of 37 exceeded the 5 mg/m^3 . This finding is in line with a recent recommendation by Demers et al [1997] to lower the current standard for dust exposure. However, in order to establish a more appropriate exposure limit for pine wood dust more studies are needed that include extensive exposure assessment of both dust and other potential causal agents (abietic acid, terpenes, microbial agents etc).

In conclusion, exposure to pine wood dust and specific agents therein is associated with cough and asthma symptoms as well as nose and eye irritations. These symptoms appear to be more common in the workers with the highest exposures. However, a more rigorous exposure assessment is needed to establish a dose-response relationship.

ACKNOWLEDGMENTS

The authors are indebted to the management and workers of the sawmills for their participation. The authors also thank Suzanne O' Tool, Judy Campbell, Naera Wilton, Sheryl Minhinnick, Roy Deer, Klare Braye and Susan Peelen for their assistance in the data collection and Ellen van der Maarl for her involvement in the design of the questionnaire. The Centre for Public Health Research is supported by a Programme Grant, this project is supported by a Limited Budget Grant, and Dave McLean is supported by a Public Health Research Training Fellowship from the Health Research Council of New Zealand. Jeroen Douwes is supported by a research fellowship from the Netherlands Organization for Scientific Research (NWO).

REFERENCES

- Asher MI, Keil U, Anderson HR, Beasley R, Crane J, Martinez F, Mitchell EA, Pearce N, Sibbald B, Stewart AW, Strachan D, Weiland SK, Williams HC. 1995. International study of asthma and allergies in childhood (ISAAC): rationale and methods. *Eur Respir J* 8:483–491.
- British Medical Research Council. 1976. Questionnaire on respiratory symptoms. London: Medical Research Council.
- Brooks SM, Edwards JJ, Apol A, Edwards FH. 1981. An epidemiologic study of workers exposed to western red cedar and other wood dust. *Chest* 80 (Suppl 1):30–32.
- Burney PGI, Luczynska C, Chinn S, Jarvin D. 1994. The European Community Respiratory Health Survey. *Eur Respir J* 7:954–960.
- Chan-Yeung M. 1982. Immunologic and nonimmunologic mechanisms in asthma due to western red cedar (*Thuja plicata*). *J Allergy Clin Immunol* 70:32–37.
- Chan-Yeung M. 1994. Mechanism of occupational asthma due to western red cedar (*Thuja plicata*). *Am J Ind Med* 25:13–18.
- Chan-Yeung M, Vedal S, Kus J, Maclean L, Enarson D, Tse KS. 1984. Symptoms, pulmonary function, and bronchial hyperreactivity in western red cedar workers compared with those in office workers. *Am Rev Respir Dis* 130:1038–1041.
- Checkoway H, Pearce NE, Crawford-Brown DJ. 1989. Research methods in occupational epidemiology. New York: Oxford University Press, 344 p.
- Demers PA, Teschke K, Kennedy SM. 1997. What to do about softwood? A review of respiratory effects and recommendations regarding exposure limits. *Am J Ind Med* 31:385–398.
- Douwes J, McLean D, Maarl van der E, Heederik D, Pearce N. 2000. Worker exposures to airborne dust, endotoxin and $\beta(1,3)$ -glucan in two New Zealand sawmills. *Am J Ind Med* 38:426–430.
- Frew A, Chang JH, Chan H, Quirce S, Noertjojo K, Chan-Yeung M. 1998. T-Lymphocyte responses to plicatic acid-human serum albumin conjugate in occupational asthma caused by western red cedar. *J Allergy Clin Immunol* 101:841–847.
- Harrell F. 1983. The LOGIST procedure. In SAS Supplemental Library Users Guide. Cary, NC: SAS Institute.
- Hessel PA, Herbert AF, Melenka LS, Yoshida K, Michealchuk D, Nakaza M. 1995. Lung health in sawmill workers exposed to pine and spruce. *Chest* 108:642–646.
- IARC Working Group. 1995. 'Wood dust and formaldehyde. IARC monographs on the evaluation of the carcinogenic risk of chemicals to humans. Vol 62.' Lyon, France: International Agency for Research on Cancer.
- Lee J, Chia KS. 1993. Estimation of prevalence rate ratios for cross sectional data: an example in occupational epidemiology. *Br J Ind Med* 50:861–862.
- Lewis S, Hales S, Slater T, Pearce N, Crane J, Beasley R. 1997. Geographical variation in the prevalence of asthma symptoms in New Zealand. *NZ Med J* 110:286–289.
- Malmberg PO, Rask-Andersen A, Larsson KA, Stjernberg N, Sundbalt B-M, Eriksson K. 1996. Increased bronchial responsiveness in workers sawing scots pine. *Am J Respir Crit Care Med* 153:948–952.
- Malo JL, Carter A, L'Archeveque J, Trudeau C, Courteau JP, Bherer L. 1994. Prevalence of occupational asthma among workers exposed to eastern white cedar. *J Respir Crit Care Med* 150:1697–1701.
- Mandryk J, Alwis KU, Hocking AD. 1999. Work-related symptoms and dose-response relationships for personal exposure and pulmonary function on woodworkers. *Am J Ind Med* 35:481–490.
- Noertjojo HK, Dimich-Ward H, Peelen S, Ditttrick M, Kennedy SM, Chan-Yeung M. 1996. Western red cedar dust exposure and lung function: Dose-response relationship. *Am J Resp Crit Care Med* 154:968–973.
- Pearce N, Beasley R, Burgess C, Crane J. 1998. Asthma epidemiology: principles and methods. New York: Oxford University Press. 266 p.
- Pisaniello DL, Connell KE, Muriale L. 1991. Wood dust exposure during furniture manufacture—Results from an Australian survey and considerations for threshold limit value development. *Am Ind Hyg Assoc J* 52:485–492.

- Rask-Andersen A, Land CJ, Enlund K, Lundin A. 1994. Inhalation fever and respiratory symptoms in the trimming department of Swedish sawmills. *Am J Ind Med* 25:65–67.
- Rothman KJ, Greenland S. 1998. *Modern epidemiology*. 2nd ed. Philadelphia: Lippincott-Raven. 737 p.
- Sadhra S, Foulds IS, Gray CN, Koh D, Gardiner K. 1994. Colophony—uses, health effects, airborne measurements and analysis. *Ann Occup Hyg* 38:385–396.
- Shamssain MH. 1992. Pulmonary function and symptoms in workers exposed to wood dust. *Thorax* 47:84–87.
- Teschke K, Demers PA, Davies HW, Kennedy SM, Marion SA, Leung V. 1999. Determinants of exposure to inhalable particulate, wood dust, resin acids, and monoterpenes in a lumber mill environment. *Ann Occup Hyg* 43:247–255.
- Thompson ML, Myers JE, Kriebel D. 1998. Prevalence odds ratio or prevalence ratio in the analysis of cross sectional data: what is to be done? *Occup Environ Med* 55:272–277.
- Vedal S, Chan-Yeung M, Enarson D, Fera T, MacLean L, Tse KS, Langille R. 1986. Symptoms and pulmonary function in western red cedar workers related to duration of employment and dust exposure. *Arch Environ Health* 41:179–183.
- Whitehead LW, Ashikaga T, Vacek P. 1981. Pulmonary function status of workers exposed to hardwood or pine dust. *Am Ind Hyg Assoc J* 42:178–186.