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Respiratory Symptoms and Occupational Exposures in New Zealand Plywood Mill Workers

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Objectives: To study work exposure and respiratory symptoms in New Zealand plywood mill workers.

Methods: Personal inhalable dust (n = 57), bacterial endotoxin (n = 20), abietic acid (n = 20), terpene (n = 20) and formaldehyde (n = 22) measurements were taken and a respiratory health questionnaire was administered to 112 plywood mill workers.

Results: Twenty-six percent of the dust exposures exceeded 1 mg/m^3, however, none of the samples exceeded the legal limit of 5 mg/m^3 [geometric mean (GM) = 0.7 mg/m^3, geometric standard deviation (GSD) = 1.9]. Workers in the composer area (where broken sheets are joined together) were significantly (P < 0.01) more highly exposed. Endotoxin levels were low to moderate (GM = 23.0 EU/m^3, GSD = 2.8). Abietic acid levels ranged from 0.3 to 2.4 μg/m^3 (GM = 0.7 μg/m^3, GSD = 1.8) and were significantly (P < 0.05) higher for workers in the composer area of the process. Geometric mean levels of α-pinene, β-pinene and Δ^3-carene were 1.0 (GSD = 2.7), 1.5 (GSD = 2.8) and 0.1 (GSD = 1.4), respectively, and α-pinene and β-pinene levels were significantly (P < 0.001) higher for workers in the 'green end' of the process, up to and including the veneer dryers. Formaldehyde levels ranged from 0.01 to 0.74 mg/m^3 [GM = 0.08 mg/m^3 (= 0.06 p.p.m.), GSD = 3.0]. Asthma symptoms were more common in plywood mill workers (20.5%, n = 112) than in the general population [12.8%, n = 415, adjusted OR (95% CI) = 1.5 (0.9–2.8)]. Asthma symptoms were associated with duration of employment and were reported to lessen or disappear during holidays. No clear association with any of the measured exposures was found, with the exception of formaldehyde, where workers with high exposure reported more asthma symptoms (36.4%) than low exposed workers [7.9%, adjusted OR (95% CI) = 4.3 (0.7–27.7)].

Conclusions: Plywood mill workers are exposed to inhalable dust, bacterial endotoxin, abietic acid, terpenes and formaldehyde, and they appear to have an increased risk of developing work-related respiratory symptoms. These symptoms may be due to formaldehyde exposure, although a potential causal role for other exposures cannot be excluded.

Keywords: asthma; exposure; woodworkers

INTRODUCTION

A number of studies have reported that workers in wood processing industries are exposed to relatively high levels of dust in their working environment (Norrish *et al.*, 1992; Mandryk *et al.*, 1999; Teschke *et al.*, 1999; Cormier *et al.*, 2000; Demers *et al.*, 2000) and that they report higher rates of both lower and upper respiratory tract symptoms than do non-exposed controls (Norrish *et al.*, 1992; Demers *et al.*, 1997). A recent study in New Zealand has reported an increased prevalence of asthma and cough symptoms and of eye and nose irritation for sawmill workers (Douwes *et al.*, 2001). Whereas studies in the sawmill industry are plentiful, only a few studies have been conducted specifically in plywood mills.

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Previous studies in plywood mills have reported that workers are exposed to terpenes in the veneer drying process and to formaldehyde in the pressing section, causing irritation of eyes, nose and throat (National Institute of Safety and Health, 1981, 1982; Paustenbach *et al.*, 1997) and that, in addition, exposure to formaldehyde is associated with decrements in baseline spirometric values and various respiratory symptoms (Malaka and Kodama, 1990; Makinen *et al.*, 1999), as well as an increased risk of nasopharyngeal cancer (Vaughan *et al.*, 2000). The relationship between respiratory symptoms and exposure to both bacterial endotoxin and abietic acid has not yet been studied in the plywood mill industry. However, previous studies in sawmills have shown that sawmill workers are exposed to both bacterial endotoxin (Mandryk *et al.*, 1999; Cormier *et al.*, 2000; Douwes *et al.*, 2000) and abietic acid (Demers *et al.*, 2000), which could both be related to the occurrence of respiratory symptoms.

In the current study, we measured exposure in New Zealand plywood mill workers to a range of agents with known or suspected potential to cause respiratory symptoms [i.e. inhalable dust, bacterial endotoxin, abietic acid, terpenes (α-pinene, β-pinene, Δ^3-carene) and formaldehyde] and related these to the prevalence of respiratory symptoms. In addition, we compared the prevalence of respiratory symptoms with general population symptom prevalence rates in the same area of New Zealand.

MATERIALS AND METHODS

Plywood manufacturing process

The plywood mill that we studied is located in the central North Island of New Zealand and employs 200 workers. A single pine species (*Pinus radiata*) is used in the process. This process consists of four main activities: (i) ‘green end’—peeling veneer from steam preconditioned and debarked logs and cutting the veneer into sheets; (ii) ‘dryers’—drying the sheets in high temperature (200°C) veneer dryers, with broken sheets being joined together at the ‘composers’; (iii) ‘pressing’—glueing (phenol-formaldehyde adhesive) and hot pressing (140°C) the plywood sheets together; (iv) ‘finishing end’—sawing sheets to size, filling knot holes and sanding, grading, stacking and banding of finished plywood sheets. Compressed air and dry sweeping are used to remove dust and dirt from machinery and floors. Extraction fans are provided for the veneer dryers, hot presses and sanders, but extensive fugitive emissions contribute to the emission of a ‘blue haze’.

Study participants

As the workers at the mill were approached through the site managers or team leaders we were unable to calculate the exact number of workers that were asked to participate in the respiratory health questionnaire. However, based on personnel records this number was estimated to be 170. Of the total number of workers approached, 112 (66%) agreed to participate in the study. All subjects gave written informed consent and the study was approved by the Massey University Ethics Committee (MUHEC, PN Protocol 01/24).

Exposure measurements

Inhalable dust. Sixty full-shift (8 h) personal inhalable dust samples were collected over a range of job titles in the sections ‘green end’, ‘dryers’, ‘composers’, ‘pressing’ and ‘finishing end’. Within these job titles, workers were randomly selected and the measurements were taken over 8 work days. Dust was sampled on glassfiber filters at a flow rate of 2.0 l/min using portable pumps (Casella) and IOM heads. One field blank was taken each measurement day. The filters (taken out of the cassette) were pre- and post-weighed on an analytical balance (0.01 mg sensitivity).

Bacterial endotoxin and abietic acid. Twenty of the inhalable dust samples were selected from a range of job titles in the mill (representing all the sections of the mill) for endotoxin analyses and using the same approach another 20 samples were selected for abietic acid analyses. The selection of samples within a job title was random. Endotoxin extraction and analysis were performed as described previously (Douwes *et al.*, 1995), with a limit of detection of 0.5 EU/m^3. Abietic acid analyses were performed using GC/MS with a limit of detection of 0.5 $\mu g/m^3$, as has been described previously (Demers *et al.*, 2000).

Terpenes. Twenty full-shift personal monoterpene samples were collected using SKC (model 575-003) diffusion samplers. The samples were taken on two consecutive work days from 10 job titles in the sections ‘green end’, ‘dryers’ and ‘pressing’, which were expected to have the highest levels of volatiles in the mill. No samples were taken in the ‘finishing end’, where only dried veneer is processed. One field blank was taken for each measurement day. Terpene analyses were performed as described previously (Demers *et al.*, 2000). Limits of detection were 0.60 µg for α-pinene, 0.55 µg for β-pinene and 0.59 µg for Δ^3-carene.

Formaldehyde. Twenty-two personal formaldehyde samples were taken using silica gel tubes impregnated with 2,4-dinitrophenylhydrazine (DNPH) (flow rate 1 l/min) (NIOSH method 2016). The sampling time of each sample was 15 min. The samples were desorbed in acetonitrile and analyzed for formaldehyde using high performance liquid chromatography. The limit of detection for formaldehyde was 0.03 mg/m^3 (= 0.03 p.p.m.).

Questionnaire

Questionnaires were administered face-to-face and consisted of three parts, including: (i) personal and work characteristics; (ii) respiratory health symptoms; (iii) smoking habits. They were the same as those used in a previous study of sawmill workers (Douwes *et al.*, 2001). 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: (i) woken by shortness of breath in last 12 months; (ii) asthma attack in last 12 months; or (iii) current asthma medication.

General population data

We have previously conducted a random population survey (Lewis *et al.*, 1997) in several areas of New Zealand. We compared the asthma symptom prevalence in the plywood mill with that in the previously collected general population data for the same area.

Statistical analysis

The data were analyzed using SAS statistical software (version 8.01; SAS Institute, Cary, NC). In situations where sample values were less than the limit of detection (LOD), the LOD divided by $2^{1/2}$ was substituted for sample values to calculate average exposure levels. All measured air contaminants approximated a log-normal rather than a normal distribution. Pearson correlation coefficients were calculated to examine the relationship between the different agents using natural log-transformed data. Differences in exposure levels among areas in the plywood mill were tested using the *t*-test procedure on natural log-transformed data. Symptom prevalences were compared in workers with 'high' and 'low' exposure to various factors (terpenes and formaldehyde). Crude and adjusted prevalence odds ratios (and 95% confidence intervals) to describe the association between exposure and the occurrence of symptoms were calculated by means of logistic regression analysis (Rothman and Greenland, 1998). For the comparison with the general population, the analyses were only adjusted for age, gender and ethnicity, since smoking data were not available for the general population survey.

RESULTS

Characteristics of study participants

Table 1 shows the characteristics of the study participants. The plywood mill workers were slightly older than the general population comparison sample (mean ages of 34.5 and 32.5 yr, respectively) and included a higher proportion of males (71 and 44%, respectively) and Polynesians (67 and 39%, respectively). The key analyses were therefore adjusted for age, gender and ethnicity.

Table 1. Characteristics of study participants

	General population	Plywood mill
n	415	112
Mean age (SD)	32.5 (7.2)	34.5 (9.1)
Male (%)	183 (44%)	80 (71%)
Female (%)	232 (56%)	32 (29%)
Duration of employment[a] (SD)		4.7 (3.5)
Duration of employment[b] (SD)		2.7 (2.6)
Hours/week of work (SD)		44.8 (4.4)
Smoker		
Current smokers (%)		43 (38%)
Ex-smokers (%)		13 (12%)
Never smokers (%)		56 (50%)
Ethnicity		
Polynesian (%)[c]	163 (39%)	75 (67%)
Non-Polynesian (%)	252 (61%)	37 (33%)

[a]In mill.
[b]In current job title.
[c]Maori or Pacific Islander.

Exposure results

Inhalable dust. Three out of 60 inhalable dust samples were lost due to pump failure. All of the remaining 57 samples were above the LOD (0.06 mg), and of these 15 (26%) had dust concentrations >1 mg/m^3 (a recommended standard for exposure to softwood dust) (Table 2). None of the samples exceeded the New Zealand workplace exposure standard for inspirable dust of 5 mg/m^3. The geometric mean (GM) of all samples was 0.7 mg/m^3 [geometric standard deviations (GSD) = 1.9] and workers in the composer area were significantly (P < 0.01) more highly exposed to inhalable dust (GM = 1.6, GSD = 2.1).

Bacterial endotoxin. All of the endotoxin samples were above the LOD (0.5 EU/m^3). Of the 20 samples, seven (35%) had levels higher than 50 EU/m^3, a recommended exposure limit in The Netherlands (Heederik and Douwes, 1997; Dutch Expert Committee on Occupational Standards, 1998). The correlation between inhalable dust and endotoxin exposure was moderate with a Pearson correlation coefficient of 0.54 (P = 0.01, n = 20). Endotoxin exposure levels appeared to be higher in the composer area (not statistically significant), but that was based on only two samples (Table 2).

Table 2. Personal exposure levels (GM and GSD) by work area for inhalable dust, bacterial endotoxin and abietic acid

	Inhalable dust (mg/m^3)			Endotoxin (EU/m^3)			Abietic acid (μg/m^3)		
	N	*N* > LOD	GM (GSD)	*N*	*N* > LOD	GM (GSD)	*N*	*N* > LOD	GM (GSD)
All samples	57	57	0.7 (1.9)	20	20	23.0 (2.8)	20	10	0.7 (1.8)
Area									
Green end	7	7	0.8 (2.7)	3	3	23.2 (2.9)	3	1	0.8 (2.4)
Dryers	20	20	0.6 (1.7)	6	6	34.2 (2.9)	8	3	0.5 (1.6)
Composers	6	6	1.6 (2.1)[a]	2	2	75.7 (1.1)	2	2	1.7 (1.6)[b]
Pressing	9	9	0.6 (1.4)	3	3	16.6 (2.2)	4	4	0.8 (1.5)
Finishing end	12	12	0.8 (1.9)	6	6	12.2 (2.3)	3	0	0.4 (1.0)

EU, endotoxin units; LOD, limit of detection.
[a]$P < 0.01$ compared with the other areas.
[b]$P < 0.05$ compared with the other areas.

Table 3. Personal exposure levels (GM and GSD) by work area for terpenes and formaldehyde

	Terpenes (mg/m^3)							Formaldehyde (mg/m^3)		
		α-Pinene		β-Pinene		Δ^3-Carene		*N*	*N* > LOD	GM (GSD)
	N	*N* > LOD	GM (GSD)	*N* > LOD	GM (GSD)	*N* > LOD	GM (GSD)			
All samples	20	20	1.0 (2.7)	20	1.5 (2.8)	6	0.10 (1.4)	22	17	0.08 (3.0)
Area										
Green end	4	4	2.4 (2.6)[a]	4	3.9 (2.6)[a]	0	0.10 (1.0)			
Dryers	8	8	1.3 (2.7)	8	2.0 (2.9)	5	0.12 (1.4)[a]	14	11	0.07 (3.2)
Composers								2	0	0.03 (1.0)
Pressing	8	8	0.5 (1.2)[b]	8	0.7 (1.2)[b]	1	0.08 (1.1)[b]	5	5	0.16 (2.7)
Finishing end								1	1	0.04 (–)

LOD, limit of detection.
[a]$P < 0.05$ compared with the other area.
[b]$P < 0.01$ compared with the other area.

Abietic acid. Abietic acid was above the LOD (0.5 μg/m^3) in 10 of the 20 samples. Exposure to abietic acid was significantly ($P < 0.05$) higher for job titles in the composer area compared with the other areas in the mill (Table 2). Dust levels were highly correlated with abietic acid levels ($r = 0.86$, $P < 0.001$, $n = 20$).

Terpenes. All α-pinene and β-pinene analyses were above the LOD (0.60 and 0.55 μg, respectively). Δ^3-Carene was above the LOD (0.59 μg) in six samples (Table 3). Exposure to α-pinene and β-pinene was significantly ($P < 0.001$) higher in the job titles before the veneer dryers (workers in the 'green end' and the dryer infeed operator) with GM of 2.8 (GSD = 2.0) and 4.4 (GSD = 2.1), respectively, than in job titles after the veneer dryers (dryer table hand, dryer tender and workers in the 'pressing section') with GM of 0.5 (GSD = 1.2) and 0.7 (GSD = 1.2), respectively.

Formaldehyde. Seventeen out of the 22 formaldehyde analyses were above the LOD (0.03 mg/m^3). None of the 22 samples exceeded the New Zealand workplace exposure standard for formaldehyde of 1.25 mg/m^3 (= 1.00 p.p.m.) (Table 3). Formaldehyde levels were not significantly higher for job titles in the pressing section [where the glue (which contains formaldehyde) is added to the process] compared with the other areas. One major outlier was found in the dryers section for the worker that worked closest to the pressing section. When this outlier was included in the pressing section, the pressing section had significantly ($P < 0.05$) higher formaldehyde levels compared with the other areas.

Respiratory symptoms

Reported 'attacks of shortness of breath with wheezing in the last 12 months' were significantly higher in plywood mill workers than in the general population, with an OR of 1.8 (95% CI = 1.0–3.1). All other asthma symptoms were also elevated (but did not reach statistical significance), with the exception of 'asthma attack in last 12 months' (Table 4).

'Shortness of breath with wheezing in last 12 months', 'woken by shortness of breath in last 12 months' and 'asthma' were significantly ($P < 0.05$) higher in workers with a duration of employment longer than 6.5 yr, when compared with the general population (adjusted for age, gender and ethnicity) (Table 5). Workers with a work history of <2 yr in the

Table 4. Unadjusted asthma symptom prevalence (%) and adjusted prevalence odds ratios (OR) with 95% confidence intervals (CI) for plywood mill workers compared with the general population

Symptoms in last 12 months	General population (n = 415)		Plywood mill (n = 112)	
	Percent	OR[a]	Percent	OR[a] (CI)
Wheezing	25.1	1.0	29.5	1.2 (0.7–2.0)
Wheezing without a cold	15.2	1.0	17.9	1.1 (0.6–2.1)
SOB[b] with wheezing	15.0	1.0	24.3[d]	1.8 (1.0–3.1)[d]
Woken by SOB[b]	8.7	1.0	15.2[d]	1.5 (0.8–2.9)
Asthma attack	6.8	1.0	2.7	0.4 (0.1–1.3)
Asthma medication	7.2	1.0	8.9	1.3 (0.6–3.0)
Asthma[c]	12.8	1.0	20.5[d]	1.5 (0.9–2.8)

[a]Adjusted for age, gender, ethnicity.
[b]SOB, shortness of breath.
[c]'Woken by SOB in last 12 months' or 'asthma attack in last 12 months' or 'current asthma medication'.
[d]$P < 0.05$ compared with general population.

Table 5. Unadjusted asthma symptom prevalence (%) and adjusted prevalence odds ratios (OR) with 95% confidence intervals (CI) stratified for duration of employment in the plywood mill compared with the general population

Symptoms in last 12 months	General population (n = 415)		Duration of employment in plywood mill					
			<2 yr (n = 34)		2–6.5 yr (n = 39)		>6.5 yr (n = 39)	
	%	OR[a]	%	OR[a]	%	OR[a]	%	OR[a]
Wheezing	25.1	1.0	17.7	0.5 (0.2–1.2)	35.9	1.4 (0.6–3.0)	33.3	1.2 (0.6–2.7)
Wheezing without a cold	15.2	1.0	8.8	0.4 (0.1–1.6)	20.5	1.4 (0.6–3.6)	23.1	1.8 (0.7–4.3)
SOB[b] with wheezing	15.0	1.0	20.6	1.1 (0.4–3.0)	18.0	1.0 (0.4–2.7)	34.2[d]	2.6 (1.1–5.8)[d]
Woken by SOB[b]	8.7	1.0	8.8	0.8 (0.2–3.0)	12.8	1.6 (0.5–5.1)	23.1[d]	3.8 (1.4–10.0)[d]
Asthma attack	6.8	1.0	0.0		2.6	0.3 (0.0–2.2)	5.1	0.6 (0.1–2.8)
Asthma medication	7.2	1.0	2.9	0.3 (0.0–2.3)	7.7	1.0 (0.2–3.8)	15.4	2.1 (0.7–6.1)
Asthma[c]	12.8	1.0	11.8	0.5 (0.2–1.7)	15.4	1.0 (0.3–2.7)	33.3[d]	3.1 (1.3–7.2)[d]

[a]Adjusted for age, gender, ethnicity.
[b]SOB, shortness of breath.
[c]'Woken by SOB in last 12 months' or 'asthma attack in last 12 months' or 'current asthma medication'.
[d]$P < 0.05$ compared with general population.

plywood industry appeared to be less symptomatic compared with the general population (Table 5).

Symptom prevalences by level of exposure were calculated. While the numbers of exposure measurements taken were not sufficient to adequately characterize the exposure of every job title, we used the following assumptions to classify workers as to high or low exposure. Terpenes showed a clear pattern of higher exposure in those parts of the process up to the veneer dryers (i.e. workers in the 'green end' and the dryer infeed operators), with much lower exposure levels ($P < 0.01$) in job titles after the veneer dryers (i.e. dryer table hand, dryer tender and job titles in the 'pressing section'). We therefore used the questionnaire results of workers in all job titles in the plywood mill for the terpene analyses, although some of these job titles had not been sampled. However, forklift drivers and employees with no fixed workstation among all job titles in the plywood mill were not included, due to uncertainty about their work area. None of the other compounds measured (inhalable dust, abietic acid, endotoxin and formaldehyde) showed any clear pattern of exposure, although workers in the composer area had the highest levels of exposure to inhalable dust, endotoxin and abietic acid. However, only a few workers are working in the composer area and, therefore, job titles in the plywood mill were divided into 'low' and 'high' exposure categories based on the median exposure. In this case, questionnaire results only from workers with the same job titles as those actually sampled were used to compare symptom prevalences between exposure groups.

Table 6 shows symptom prevalences and adjusted ORs by level of exposure to terpenes and formaldehyde. Symptoms were more common in workers with high exposure to formaldehyde (Table 6), with a significantly ($P < 0.05$) higher prevalence of 'woken by shortness of breath in last 12 months' [adjusted OR of 9.5 (95% CI = 1.2–74.7)] (Table 6). Also, prevalences of 'asthma medication in last 12 months' and 'asthma' were elevated (not statistically signifi-

Table 6. Unadjusted symptom prevalence (%) and adjusted prevalence odds ratios (OR) with 95% confidence intervals (CI) for workers in the plywood mill by level of exposure to terpenes and formaldehyde

	Plywood mill	Total terpenes				Formaldehyde			
	Total (n = 112)	Low (n = 71)		High (n = 24)		Low (n = 38)		High (n = 11)	
	%	%	OR	%	OR (CI)	%	OR	%	OR (CI)
Cough symptoms in last 12 months									
Cough[b]	40.2	40.9	1.0	41.7	1.3 (0.5–3.9)	44.7	1.0	45.5	0.8 (0.2–3.6)
Cough up phlegm[b]	28.6	29.6	1.0	29.2	1.2 (0.4–3.7)	26.3	1.0	18.2	0.5 (0.1–3.2)
Woken regularly due to cough	24.3	25.4	1.0	16.7	0.8 (0.2–2.9)	26.3	1.0	45.5	1.9 (0.4–9.7)
Asthma symptoms in last 12 months									
Wheezing	29.5	25.4	1.0	29.2	1.7 (0.5–5.4)	21.1	1.0	36.4	2.0 (0.4–10.4)
Wheezing without a cold	17.9	18.3	1.0	16.7	0.9 (0.2–3.5)	13.2	1.0	18.2	1.6 (0.2–13.2)
SOB[c] with wheezing	24.3	25.4	1.0	26.1	1.0 (0.3–3.2)	21.1	1.0	45.5	3.5 (0.6–19.1)
Woken by SOB[c]	15.2	12.7	1.0	16.7	1.7 (0.4–7.2)	7.9	1.0	36.4[e]	9.5 (1.2–74.7)[e]
Asthma attack	2.7	0.0	1.0	12.5		5.3	1.0	0.0	
Asthma medication	8.9	5.6	1.0	20.8[e]	3.0 (0.6–14.3)	10.5	1.0	9.1	1.0 (0.1–15.3)
Asthma[d]	20.5	16.9	1.0	29.2	2.0 (0.6–6.8)	15.8	1.0	36.4	4.3 (0.7–27.7)
Wheezing, SOB[c] or chest tightness in relation to work	21.4	21.1	1.0	16.7	1.0 (0.3–4.0)	15.8	1.0	9.1	0.4 (0.0–5.4)
Nose, eye and skin symptoms									
Runny nose, sneezing >1/week	35.7	33.8	1.0	37.5	1.5 (0.5–4.3)	28.9	1.0	36.4	1.3 (0.3–6.8)
Itching watering eyes >1/week	25.0	23.9	1.0	25.0	1.0 (0.3–3.4)	26.3	1.0	9.1	0.2 (0.0–2.3)
Itchy skin, skin rash >1/month	19.6	21.1	1.0	25.0	1.5 (0.4–5.0)	23.7	1.0	36.4	1.1 (0.2–5.7)
Allergy/sensitivity symptoms									
Sensitive to house dust, food, animals or grasses/plants	39.3	35.2	1.0	37.5	1.5 (0.5–4.3)	31.6	1.0	45.5	2.4 (0.5–11.8)

[a]Adjusted for age, gender, ethnicity and smoking.
[b]Daily for at least part of the year.
[c]SOB, shortness of breath.
[d]'Woken by SOB in last 12 months' or 'asthma attack in last 12 months' or 'current asthma medication'.
[e]$P < 0.05$ compared with low exposed workers.

cantly) in workers with high exposure to terpenes, with adjusted ORs of 3.0 (95% CI = 0.6–14.3) and 2.0 (95% CI = 0.6–6.8), respectively, compared with workers with low terpene exposure.

Symptom prevalence did not show a very strong relationship to any of the other measured exposures (inhalable dust, abietic acid or endotoxin). However, prevalences of nose, eye and skin symptoms appeared to be slightly higher in high exposed workers for all types of exposure (data not shown), but these differences were not statistically significant.

A high proportion of workers with respiratory symptoms (53–83% for the different symptoms) reported that these symptoms lessened or disappeared during holidays or days off (data not shown).

DISCUSSION

This study has found that plywood mill workers are exposed to a number of airborne contaminants known to have the potential to cause respiratory symptoms (Demers *et al.*, 1997; Heederik and Douwes, 1997; Dutch Expert Committee on Occupational Standards, 1998; Mandryk *et al.*, 1999). Workers in one area (composers) had a significantly higher exposure to inhalable dust compared with the rest of the workers in the plywood mill, probably due to band saw and chipper operations (two sources of wood dust) in this area. Inhalable dust levels did not differ markedly in the remaining areas, probably due to numerous sources of dust in the different sections, the use of compressed air for cleaning and limited ventilation throughout the plywood mill to reduce dust levels.

Levels of inhalable dust in the plywood mill were similar to those previously found in sawmills (Mandryk *et al.*, 1999; Teschke *et al.*, 1999; Cormier *et al.*, 2000; Demers *et al.*, 2000; Douwes *et al.*, 2000). In contrast, bacterial endotoxin levels were lower than those found in sawmills (Mandryk *et al.*, 1999; Cormier *et al.*, 2000; Douwes *et al.*, 2000), most likely due to a combination of factors, including the steam preconditioning of the logs used to make plywood and the shorter time period between cutting veneer and drying and processing the sheets, allowing bacteria less time to grow. Abietic acid and terpene levels were lower than those found in sawmills and joinery shops (Eriksson *et al.*, 1996, 1997; Demers *et al.*, 2000) as expected, because sawing tends to rupture wood cells and therefore releases the cell contents, including abietic acid and terpenes. Previous studies in sawmills concluded that wood trimmers exposed to inhalable dust, organic dust (molds), terpenes and endotoxins may develop airway symptoms (Hedenstierna *et al.*, 1983, 1986; Dahlqvist *et al.*, 1992). Formaldehyde levels were lower than those measured before in plywood mills (Malaka and Kodama, 1990). Sawmill workers are not exposed to formaldehyde and thermal decomposition products.

Although the numbers of samples analyzed for bacterial endotoxin, abietic acid and formaldehyde were too few to show a clear pattern of exposure for the different job titles in the plywood mill, this study has shown that employees in a plywood mill are exposed to significant levels of these compounds.

Exposure to terpenes was significantly higher for job titles involving work before and during the veneer drying, which suggests that terpenes are mainly emitted during the veneer production and veneer drying processes. Levels of terpenes were similar to those measured in plywood mills by the US National Institute for Occupational Safety and Health (1981, 1982) and these studies also showed a similar pattern of higher terpene exposure in those areas of the process up to and including the veneer drying. Studies in Swedish sawmills and joinery shops (Eriksson *et al.*, 1996, 1997) showed much higher levels of terpenes (range 10–214 mg/m^3). The lower levels of terpenes found in Canadian sawmills (range <LOD–6.5 mg/m^3) (Teschke *et al.*, 1999; Demers *et al.*, 2000) may be due to species and process differences.

In this study we found an increased prevalence of asthma symptoms in plywood mill workers, when compared with the general population. The findings should be interpreted with caution since we examined seven different asthma symptom measures and it is therefore possible (albeit unlikely) that some findings are due to chance. Nevertheless, our findings are consistent with previous studies (National Institute of Safety and Health, 1981, 1982; Malaka and Kodama, 1990) in that they indicate that working in a plywood mill is associated with an increased prevalence of respiratory symptoms and eye and nose symptoms. These findings are similar to those of a recent study in sawmill workers in the same geographical area using the same questionnaire (Douwes *et al.*, 2001) and, with the exception of 'shortness of breath with wheezing', there was little indication that plywood mill workers experienced more respiratory symptoms than sawmill workers. However, both groups showed more respiratory symptoms than the general population.

Misclassification of exposure might have occurred in this study as workers were classified as to high or low exposure based on a small number of measurements. Furthermore, measurements for the classification of exposure were taken in the same period as the questionnaire survey, whereas any work-related asthma symptoms are more likely to result from exposures in the past. Although we do not think that the exposures have changed due to changes in the process over recent years, workers may have shifted to different areas and job titles in the mill and therefore misclassification may have biased the results.

Although the relatively low response rate (66%) may have biased the results, the prevalences of asthma symptoms were similar to those found in sawmill workers, with a similar process and exposure levels to the plywood mill. Therefore, it is not likely that the results in this study were biased.

Plywood mill workers reported that a high percentage of their respiratory symptoms (range 53–83%) lessened or disappeared during holidays or days off. This is higher than we have previously observed in sawmill workers (Douwes *et al.*, 2001). Furthermore, workers with a long duration of employment reported more asthma symptoms than short-term employees, and a relationship of symptoms with exposure to formaldehyde was observed. However, symptom prevalence did not show a very strong relationship with any of the other measured exposures (inhalable dust, abietic acid, endotoxin and terpenes), which may be due to the relatively small number of study participants and exposure measurements. Alternatively, other exposures, such as fungi and fungal β(1,3)-glucans, may have played a role (Alwis *et al.*, 1999; Mandryk *et al.*, 2000). In any case, our data suggest that respiratory symptoms are work related.

Symptoms appear to occur at levels well below the current occupational exposure limit for softwood dust (5 mg/m^3), used in New Zealand and other countries including the USA, since the majority of the exposure measurements did not exceed 1 mg/m^3 and none of the samples exceeded 5 mg/m^3. This provides support for the recommendation by Demers *et al.* (1997) to lower the current standard for softwood dust exposure to 1 mg/m^3.

The inhalable dust levels in the plywood mill probably consist of a mixture of (wood) dust, dirt and exhaust fumes and are unlikely to be only wood dust. The proportion of wood dust in the inhalable dust fraction is not known and might vary between the different sections in the plywood mill. A comparison with the exposure standard for wood dust might therefore not be justified.

Furthermore, symptoms seem to appear well below the occupational exposure limit for formaldehyde (1.25 mg/m^3). For the other compounds, no occupational exposure limits have been set in New Zealand. However, seven out of the 20 endotoxin measurements exceeded 50 EU/m^3, an exposure limit recommended by the Dutch Expert Committee on Occupational Standards (Heederik and Douwes, 1997; Dutch Expert Committee on Occupational Standards, 1998). None of the terpene measurements exceeded the present Swedish occupational exposure limit of 150 mg/m^3.

In conclusion, plywood mill workers are exposed to significant levels of inhalable dust, bacterial endotoxin, abietic acid, terpenes (α-pinene, β-pinene and Δ^3-carene) and formaldehyde, and they appear to have an increased risk of developing work-related respiratory symptoms. The results show an association between formaldehyde exposure and asthma symptoms. However, no strong association with any of the other measured exposures was found. Workers with long-term exposure have a higher respiratory symptom prevalence than workers exposed for shorter periods, and a high proportion of symptoms were reported to be work related.

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