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Exposure to wood dust and endotoxin in small-scale wood industries in Tanzania

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Workers in small-scale wood industries (SSWI) have increased risks of developing asthma and other respiratory diseases. Wood dust and microbial agents have both been suggested to play a role, but few studies have measured endotoxin exposure in SSWI in Africa. We assessed inhalable dust levels in 281 samples from 115 workers and bacterial endotoxins levels in 157 samples from 136 workers from SSWI in Dar es Salaam, Tanzania. The overall geometric mean of personal exposure was 3.3 mg/m^3; geometric standard deviation (GSD) 2.5; range 0.45–67.0 mg/m^3) and 91 EU/m^3 (GSD 3.7; range 9–4914.8 EU/m^3) for wood dust and endotoxins, respectively. Dust and endotoxin levels were weakly correlated ($r = 0.44$, $n = 157$, $P < 0.0001$). Between- and within-worker variances and percentages explained by the differences among job titles and seasons were 0.31 (9%) and 0.35 (30%), respectively, for wood dust exposure, and 0.35 (0%) and 0.35 (38%) for endotoxin exposure. Higher dust and endotoxin exposure levels were observed in the dry compared to the wet season, after correcting for differences in exposure between jobs. Carving and manual cleaning were associated with the highest dust exposures. Sewing seat covers and manual cleaning were associated with the highest endotoxin exposures. Dust and endotoxin exposure levels in SSWI are high and appropriate control measures are necessary.
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Introduction

Wood workers in well-established industries in developed countries have an increased risk for asthma and other respiratory diseases (Demers et al., 1997). Similar observations have been made in a recent study in Africa (Rongo et al., 2002). Wood dust and microbial agents have been suggested to play a role, but few studies have measured microbial exposure. Data are completely absent for small-scale wood industries (SSWI) in Africa. Pulmonary diseases associated with inhalation of organic dust have been reported in many industrial sectors (Jacobs, 1997a, b). The sources of these dusts causing the diseases are different in individual circumstances, yet the symptoms, regardless of the environment, are strikingly similar. Bacterial endotoxins are one of the potential causative agents for these diseases (Jacobs, 1997a, b), since they have been associated with the development of respiratory diseases and symptoms in various occupational environments. Wood dust can be contaminated by naturally occurring microorganisms like moulds and bacteria that produce toxins or release toxins after lysis in case of endotoxins. Endotoxins originate from Gram-negative bacteria and are part of the cell wall. If found in wood dust, this is due to contamination by Gram negatives, but elevated endotoxins usually also indicate that mould or fungi are present as well. This observation is supported by studies recently performed in the US and Canada.

Determinants of wood dust exposure include machining and other processes involving wood and wood-containing materials (chipboard and fiberboard) (HSE, 1999). Operations such as sawing and cutting produce relatively coarse dust, while sanding and assembly generate fine dust. Recent studies have reported airborne endotoxins exposures in saw mills (7–588 EU/m^3) (Douwes et al., 2000), in fiberboard factories (193.1–1974.0 EU/m^3) (Dutkiewicz et al., 2001), chipboard factories (2.2-217.4 EU/m^3) (Dutkiewicz et al., 2001), and at different woodworking sites–logging sites, sawmills, wood chipping sites, and joineries (Alwis et al., 1999). Differences between studies and/or countries in the level of endotoxin exposures may depend on climate and type

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of wood treatment/storage of wood, as well as machinery, tasks, and layout of factories. So far, no such studies have been conducted in Africa.

We have conducted a study in SSWI in Africa to (a) measure wood dust and endotoxins exposure among workers, (b) assess seasonal differences in exposure levels, and (c) identify jobs associated with elevated exposure levels.

Methods

SSWI and Job Category Descriptions

We randomly selected 70 SSWI out of 400 in Dar es Salaam. Each enterprise employed on average five persons. Most industries consisted of a temporary shelter with four poles supporting a roof thatched with old corrugated iron sheets or palm leaves. Most of the tasks were performed manually. Only SSWI with permanent shelters were fitted with wood machinery (5%). No exposure controls (such as exhaust ventilation) were present in any of the workshops. For the workshops with permanent shelters, the effect of outside air does affect the ventilation inside the workshops only to a limited extent since the workshops had only one entrance and no windows. Therefore, the effect of wind in dry and wet season as far as workshops are concerned is negligible. No measurements for wind speed were taken. The meteorological conditions during the measurements were relatively stable. The dry season was windier than the wet season. The wood machine operators receive tasks from other SSWI using hardwood, which is difficult to process manually. The tasks commonly carried out in workshops with wood machines are planing, sawing, carving, and drilling hard hardwoods (teak, mahogany, camphour, mtanga (*albizia* ssp) and softwoods (cedar, podo, pine, and cypress). Manual woodworking includes all manual jobs that involve sawing, planing, joinery, drilling, and polishing. On average, three operators and one casual labour operate one wood-processing machine.

Dust Sampling and Endotoxins Analyses

A random sample of 115 exposed workers participated in the study. Inhalable dust measurements at three occasions maximally were taken from each individual on different days. In all, 281 full shift (8 h) personal inhalable dust samples were collected over a broad range of job titles. Included were woodwork machine operators (planing, sawing, drilling, carving and joinery, and servicing); workers in carpentry (planing, sawing, drilling, joinery, polishing/varnishing and sanding manually); and during manual cleaning of the workshops. Measurements were taken from 0800 to 1700 hours from Monday to Saturday. We used a so-called PAS-6 sampling head with one hole in a cone attached to the workers lapel close to the breathing zone. The PAS-6 sampling head has been developed in the 1980 in the Netherlands and samples the inhalable dust fraction. This sampler has been used in large-scale hygiene and epidemiological studies performed over the last decades, and has recently been compared with the inhalable dust convention curve and other inhalable dust samplers common in Europe like the IOM sampler (UK) and the GSP sampler (Germany) (Kenny et al., 1997). Wood dust was sampled on glass fibre filters at flow rate of 2.0 l/min using portable pumps (Casella) and PAS-6 inhalable dust sampling heads attached to the workers lapel close to the breathing zone. PAS-6 sampling heads have been developed in the Netherlands and have been applied in several large-scale epidemiological studies (Boleij et al., 1995). One field blank was taken on each measurement day. The filters were pre- and post- weighed on an analytical balance (0.01 mg sensitivity). Filters were equilibrated to 22°C centigrade and 65% relative humidity before weighing. The weight of the sample filters was corrected by the average weight change of the field blanks. The detection limit was calculated by adding three times the standard deviation to the average weight change of blanks. Concentrations below this limit were assigned a value of two-thirds the detection limit in statistical analyses.

Dust samples were stored in the freezer and after transport to the Netherlands, thawed and immediately extracted in 5 ml Tween 20 and frozen again until analysis. Endotoxins were analysed in a chromogenic kinetic Limulus Amebocyte Lysate Assay as described in details elsewhere (Douwes et al., 1995).

Statistical Analysis

Data were analysed using SAS statistical software (SAS 6.12; SAS Institute, Cary, NC, USA). Pearson's correlation coefficients were calculated using natural log-transformed data. Comparisons were made with exposure standards for wood dust methods. The current recommended standard levels for 8 h of wood dust exposure, proposed by the American Conference of Government Industrial Hygienists (ACGIH) threshold limit value (TLV), are 1 mg/m^3 for hardwood and 5 mg/m^3 for softwood (ACGIH-TLV, 2002). In this study, a mixture of softwood and hardwood was used, for which no standard exist. We also do not have information on the proportion of softwood and hardwood in our dust samples, precluding application of the proposed TLVs. The Tanzania Bureau of Standards (TBS) has not proposed a standard for wood dust exposure, because no wood dust exposure data were available. The effect of jobs performed and season during sampling (fixed effects) on exposure to inhalable dust and endotoxins were estimated using mixed effects models (PROC MIXED), while correcting for systematic between-worker differences and correlation between repeated measurements. A compound symmetry covariance structure was assumed, because data were too limited to explore alternative covariance structures. The restricted maximum likelihood algorithm was used to

Table 1. Dust exposure by job category among workers in SSWI in Dar es Salaam

Job category	N^a	AM[b] (mg/m^3)	GM[c] (mg/m^3)	GSD[d]	Range (mg/m^3) Min–max
Overall	281	5.7	3.32	2.47	0.45–67
Dry season	188	5.16	3.25	2.37	0.45–49
Wet season	93	6.8	3.43	2.68	0.5–66.7
Carving machine	14	25	15	3.05	2.72–67
Cleaning manually	6	16	10	3.22	2.23–49
Joinery manually	22	5	3	2.49	0.50–45
Planing machine	45	3	2	1.82	0.55–11
Planing manually	81	5	3	2.20	0.45–27
Planing/sawing machine	16	7	3	2.37	1.49–60
Planing/sawing manually	19	5	4	2.33	0.67–18
Resting	18	3	3	1.88	0.6–9
Sawing machine	9	12	4	4.20	1.22–60
Sawing manually	18	4	3	2.58	0.55–15
Sanding manually	27	4	3	2.07	0.9–11
Sewing seat covers machine	11	4	3	1.63	1.10–7

[a] Number of samples taken.
[b] Arithmetic mean.
[c] Geometric mean.
[d] Geometric standard deviation.

estimate models. Jobs with similar exposures were combined in the final models. Residual plots were examined to test for deviation from assumption of homoscedasticity.

The full mixed effects models that we used had the following general form:

$$Y_{ij} = \mu + S + JC_1 + \cdots + JC_n + \chi_i + \varepsilon_{ij}$$

Y_{ij} is the natural logarithm of the exposure concentration measured on the *j*th day of the *i*th worker, μ the common mean of log-transformed exposure, S the fixed effects of season, coded as indicator variables (1 = dry; 0 = wet), $JC_1 \cdots JC_n$ the fixed effects of job categories 1 to *n*, coded as indicator variable (1 = present; 0 = absent), χ_i the random effect of the *i*th worker, ε_{ij} the random within-worker variation.

Proportions of between-worker (S^2_{BW}) and within-worker (S^2_{WW}) variances explained by each model were estimated as:

BW variance explained $= (S^2_{\text{BW}}$ (worker only) $- S^2_{\text{BW}}$ (full model))/S^2_{BW} (worker only) and WW variance explained $= (S^2_{\text{WW}}$ (worker only) $- S^2_{\text{WW}}$ (full model))/S^2_{WW} (worker only), where (worker only) refers to variance component from the model that has only random worker effects.

Results

Dust Exposure Levels and Determinants

In all, 281 samples were analysed for dust levels and 157 samples out of 281 samples for endotoxin levels. None of the dust samples was below the detection limit of 0.3 mg/m^3. Exposure levels followed a skewed frequency distribution that resembled a lognormal distribution; therefore further calculations were carried out using log-transformed data.

All production circumstances had some samples with dust concentration above 1 mg/m^3 for hardwood, and 7% of all samples were above the TLV of 5 mg/m^3 for softwood. Table 1 shows that the geometric mean (GM) dust exposure was 3.32 mg/m^3 with a geometric standard deviation (GSD) 2.47. The highest dust exposures were found in carving (GM = 15 mg/m^3) and cleaning operations (GM = 10 mg/m^3) and the lowest in machine planing (2 mg/m^3).

Table 2 shows determinants of exposure to dust among workers in SSWI. The job categories (manual joinery, machine planing, manual planing/sawing, resting, machine sawing and manual sanding) were grouped as reference category. On average, the exposures to dust during the dry season were 1.69 times (= exp(0.53) higher than during the wet season. Exposure to dust during machine carving was 5.93 times (= exp(1.78) higher and manual cleaning was 1.89 time higher (= exp(0.64) than the reference. The results of the mixed model for dust exposure with only a random worker effect yielded a between-worker variance estimate of 0.343, with a standard error (SE) of 0.073 (*P* (variance estimate is zero) of 0.0001) and a within-worker variance estimate of 0.473, and SE of 0.051 (*P* = 0.0001). The percents explained of the between- and within-workers variances by the model for wood dust were, respectively, 0.31 (7%) and 0.35 (30%).

Endotoxin Exposure Levels and Determinants

None of the samples had endotoxin levels below the limit of detection (0.5 EU/m^3). Table 3 shows personal endotoxin

Table 2. Determinants of exposure to dust (fixed effects) among workers in SSWI results of mixed effects models with worker as random effect and compound symmetry covariance structure

Determinants of exposure	Ln(mg/m^3 wood dust) ($N=281$, $k=114$)[a]			
	No of filters	β[b]	SE[c]	$P(\text{ß}=0)$[d]
Intercept	-	1.17[e]	0.10	0.0001
Carving	14	1.78	0.21	0.0001
Sawing manually	27	0.16	0.17	0.032
Sewing seat cover	11	0.41	0.27	0.13
Cleaning manually	6	0.64	0.31	0.04
Planing manually	81	0.37	0.11	0.0008
Planing/sawing machine	17	0.29	0.21	0.17
Planing/sawing manually	19	0.47	0.20	0.02
Dry season	188	0.53	0.11	0.0001
Covariance components		Estimate (% explained by model[f])	SE[c]	P[h]
Between worker[i]		0.31 (9%)	0.07	0.0001
Within-worker[j]		0.35 (30%)	0.04	0.0001

[a] N = number of measurements; k = number of workers.
[b] Regression coefficient of fixed effect.
[c] standard error of β or estimate of covariance component.
[d] P-value for t-test for fixed effect.
[e] Reference exposure in wet season.
[f] Percent of covariance component explained, relative to model with only random effects.
[h] P-value of Wald test for covariance component being equal to zero.
[i] % BW variance explained = (S^2_{BW} (worker only)- S^2_{BW} (worker + fixed effects))/S^2_{BW} (worker only).
[j] % WW variance explained = (S^2 $_{\text{WW}}$ (worker only)- S^2_{WW} (worker + fixed effects))/S^2_{WW} (worker only).

Table 3. Descriptive statistics of personal endotoxin concentrations (EU/m^3) in 12 job categories of SSWI in Dar es Salaam

Job category	N[a]	AM[b] (mg/m^3)	GM[c] (EU/m^3)	GSD[d]	Range (EU/m^3) Min–Max
Overall	157	288.00	91.00	3.74	9–4914.8
Dry season	65	545.83	188.29	4.21	14.9–4914.8
Wet season	92	105.40	54.60	2.57	9.0–1808.0
Carving machine	5	243	181	2.36	81–602
Cleaning manually	5	406	276	2.75	67–1095
Joinery manually	9	896	219	6.45	33–3294
Planing machine	40	84	40	2.36	9–1636
Planing manually	37	354	118	3.60	20–4915
Planing/sawing machine	13	213	81	3.28	13–1808
Planing/sawing manually	8	414	245	3.22	33–1480
Resting	6	193	105	3.57	15–602
Sanding manually	4	156	102	2.82	49–446
Sawing machine	12	59	48	1.93	16–181
Sawing manually	14	418	99	4.84	30–2241
Sewing seat cover	4	750	384	4.43	55–2000

[a] Number of samples taken.
[b] Arithmetic mean.
[c] Geometric mean.
[d] Geometric SD.

concentrations in 12 job categories in SSWI. The overall GM of endotoxin exposure was 91 EU/m^3 (GSD = 3.7). Approximately 67% of the 157 measured samples indicated endotoxin exposure higher than 50 EU/m^3, a standard recently suggested to protect workers from developing adverse respiratory health effects (Douwes and Heederik, 1997; DECOS, 1998). The highest endotoxin exposure appeared to occur when workers were sewing seat covers, geometric mean 384 EU/m^3, (GSD = 4.43).

Table 4 shows determinants of exposure to endotoxin among workers in SSWI. The reference category consists of the following job categories (machine planing, machine

Table 4. Determinants of exposure to endotoxins (fixed effects) among workers in SSWI: results of mixed effects models with worker as random effect and compound symmetry covariance structure

Determinant of exposure	Ln (EU/m^3 endotoxin) (N = 157, k = 48)[a]			
	Filter samples	β[b]	SE[c]	$P(\beta=0)$[d]
Intercept	-	3.66[e]	0.16	0.0001
Cleaning manually	5	1.08	0.53	0.04
Joinery manually	9	1.03	0.42	0.02
Planing/sawing machine	13	0.53	0.35	0.14
Sewing seat cover	4	1.34	0.62	0.033
Dry season	65	0.97	0.20	0.0001
Covariance components		Estimate (% explained by model[f])	SE[c]	P[h]
Between worker[i]		0.35 (<0)[j]	0.22	0.0518
Within worker[k]		0.93 (38%)	0.19	0.0001

[a] N = number of measurements. k = number of workers.

[b] Regression coefficient of fixed effect.

[c] standard error of ß or estimate of covariance component.

[d] P-value for t-test for fixed effect.

[e] Reference exposure in wet season.

[f] Percent of covariance component explained, relative to model with only random effects.

[h] P value of Wald test for covariance component being equal to zero.

[i] % BW variance explained = (S^2_{BW} (worker only)- S^2_{BW} (worker + fixed effects))/S^2_{BW} (worker only).

[j] Explained variance < 0, due to imprecision of between-worker variance in worker only.

[k] % WW variance explained = (S^2_{WW} (worker only) - S^2_{WW} (worker + fixed effects))/ S^2_{WW} (worker only).

carving, machine planing/sawing, resting, machine sawing, and manual sawing). Exposures to endotoxin during the dry season were 2.6 times (= exp(0.97)) higher than during the wet season. Endotoxin exposures during sewing seat covers and manual cleaning were, respectively, 3.9 times (= exp(1.34)) and 2.9 times (= exp(1.08) higher than the reference.

The results of the mixed model for endotoxin exposure with only worker as a random effect yielded a between-worker variance estimate of 0.262 (SE = 0.245, $P = 0.142$), and within-worker variance estimate of 1.488 (SE = 0.223, $P = 0.0001$).

Between- and within-worker endotoxins variances (and % explained by model) were 0.35 (<0) and 0.92 (38%), respectively. We did not explain between-worker variance, and therefore endotoxin exposure among workers cannot be distinguished using our models. However, we could explain day-to-day variation in exposure due to tasks and season.

Correlation Between Endotoxin and Dust Exposure

Figure 1 shows the correlation between dust and endotoxin exposure by season. The correlation between dust and endotoxins exposure was positive and weak with a Pearson correlation coefficient of $r = 0.44$ ($P = 0.001$; $n = 159$). The regression lines are almost parallel but the correlation coefficient r is higher in the dry season ($r = 0.63$) compared to the wet season ($r = 0.48$).

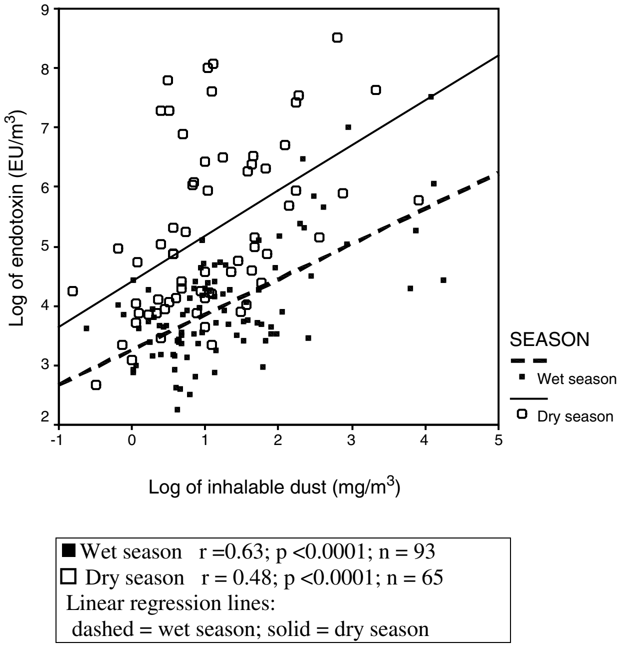

Figure 1. Correlation between dust and endotoxin exposure in wet and dry seasons.

Discussion

Summary of the Findings

In this study, the overall GMs dust and endotoxin exposures were 3.32 mg/m^3 (GSD 2.57) and 91 EU/m^3 (GSD 3.7), respectively. Endotoxin levels were clearly elevated with 67% of the samples measured above the proposed health-based limit. Exposures to dust and endotoxin during the dry season were higher than during the wet season. The mean dust exposure levels varied significantly between jobs and dust levels were significantly correlated with endotoxin levels. The most significant jobs related to increased dust exposures were machine carving and manual cleaning. Significant jobs related to increased endotoxins exposures were sewing seat covers, manual cleaning, manual planing and sawing, and manual joinery. For both dust and endotoxin, differences in jobs and seasons tended to explain day-to-day variability in exposure within-worker, rather than between-worker variability in exposure levels.

Explanation and Interpretation of the Findings

Endotoxin exposure was significantly higher during the dry season, because there was probably less natural dust suppression by rain in the dry season, leading to higher background dust exposure during the dry season. In the dry season, temperatures range from 20–35°C, but with low humidity. In the wet season, the temperatures were low and humidity was high. The dry season was windier than the wet season. This makes it difficult to conclude how microbial growth and resulting endotoxin exposures will be influenced, and therefore a further study is needed. The levels of endotoxin in wood dust at the source could be increased because of the changes in climate. During the dry season, high temperatures and low humidity encourage more growth of endotoxin-containing bacteria, and therefore increase endotoxin levels at source. Most of the wood workshops were outdoor and near main roads (Rongo et al., 2002).

The variability overtime is considerable, but could be attributed to certain tasks and a seasonal effect. Some tasks like sewing seat covers and manual cleaning were associated with very high endotoxin exposure but low dust exposures.

The between-worker variance was not easily explained by determinants of exposure. The main explanation is the strong job rotation observed and the absence of different task patterns between workers. As a result, we could not form uniformly exposed groups based on work similarities, such as work tasks/jobs titles. Development of exposure groups for epidemiological studies of chronic health effects in the study's population is likely to be very difficult on the basis of our models.

Comparison to the Studies

With the exception of carving, cleaning, and sewing seat covers, dust exposure in our study is twice that in planing and sawing in Eastern Canadian saw mills (Duchaine et al., 2000). The sawmills were processing pine, birch, cedar, and oak and demonstrated lower endotoxin contamination in planing sites than in debarking and sawing (Duchaine et al., 2000). In our study, endotoxin analysis showed that machine planing had lower contamination than sawing seat cover, manual cleaning, and manual planing, and sawing. Our results are similar to those of Duchaine et al. (2000) where machine planing, had the lowest endotoxin levels compared to other jobs. In our study, cleaning operations showed high contamination of endotoxins. Other studies have shown similar findings in that clean-up and maintenance operations result in high mean endotoxin concentrations compared to other operations (Dennekamp et al., 1999).

A study by Scheeper et al. (1995) emphasized that sanding leads to the highest exposures and planing to the lowest, but the actual exposure level can be highly influenced by other factors, such as cleaning methods, local exhaust ventilation, layout of the production, and cleanliness of the work environment (Scheeper et al., 1995). Another study also reported recently that one of the determinants of exposure in the Danish furniture industry is manual sanding (Mikkelsen et al., 2002). In our study, carving using wood machine yielded the highest dust exposure. The findings on cleaning operations were the second in dust exposure and were higher than dust exposures reported during sweeping operations (Scheeper et al., 1995).

The measured endotoxin concentrations in our study are higher than those found in studies where adverse health effects have been observed. A study by Douwes et al. (2000) showed that endotoxin exposures range in New Zealand saw mills as from 7 to 588 EU/m^3 (Douwes et al., 2000). Recently, Dutkiewcz et al. (2001) reported concentration of endotoxin to range from 103.1 to 197.0 EU/m^3 in fibreboard factories and from 3.2 to 217.4 EU/m^3 in chipboard factories (Dutkiewicz et al., 2001). These two studies were performed in industries, where occupational health and safety is better than in SSWI in Tanzania. A detailed comparison is not possible because of the type of industries we have in Tanzania and the seasonality difference in temperature and humidity. Our study shows the highest endotoxin exposure levels because no exposure controls were taken in the SSWI workshops to protect the workers from the exposures. In this study, the observed exposure levels are higher than the exposure levels that are known to cause adverse health effects because another study in SSWI workers showed a higher prevalence of respiratory symptoms than the control group (Rongo et al., 2002). The high endotoxin levels might play a role in these elevated respiratory prevalence symptoms.

Conclusions

In conclusion, dust and endotoxin exposure levels in SSWI in Tanzania are elevated and appropriate reduction measures are recommended.

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