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Personal Exposure to Inhalable Dust and the Specific Latex Aero-Allergen, Hev b6.02, in Latex Glove Manufacturing in Thailand

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ABSTRACT

Objectives: Latex product manufacturing is an important industry in south-east Asia but has the potential for considerable occupational exposure of workers to latex allergens. Although exposure to latex allergens can result in adverse health reactions, few studies to characterize this exposure have been conducted to date. This study therefore aimed to characterize current airborne inhalable dust and the specific allergen, Hev b 6.02, exposures in this industry in Thailand.

Methods: Workers were recruited from three factories in the southern part of Thailand. Full-shift inhalable dust personal air sampling was conducted using IOM sampling heads equipped with polytetrafluoroethylene filters at a 2.0 l min^{-1} flowrate. After weighing to determine inhalable dust levels, filters were extracted and analysed for Hev b 6.02 using an enzyme immunometric assay.

Results: Two hundred and seventy-five workers agreed to participate, resulting in a total of 292 measurements. Geometric mean (GM) personal exposure to inhalable dust was 0.88 mg m^{-3}, but individual exposures up to 12.34 mg m^{-3} were measured. The pattern of exposure was similar across factories, with highest exposures in the stripping (GM 2.08–4.05 mg m^{-3} for the 3 factories) and tumbling departments (1.11–2.17 mg m^{-3}). Within-worker (day-to-day) variability contributed 92% to total variability. The Hev b 6.02 exposure pattern was similar with time-weighted average GM exposure levels in the oldest factory ranging from 8.7 mg m^{-3} in the laboratory to 30.2 mg m^{-3} in the stripping department. In contrast to inhalable dust exposure, total exposure variability was primary driven by variability between workers (67%).

Conclusions: Workers in these latex product factories get routinely exposed to measurable Hev b 6.02 levels, which may give rise to increased incidence of allergic symptoms and occupational asthma. Also, in this measurement campaign a 10 mg m^{-3}, but not 15 mg m^{-3}, occupational exposure limit for inhalable dust was occasionally exceeded. Highest Hev b 6.02 exposures were found in the stripping and tumbling departments, which would be natural targets for interventions aimed at reducing exposure.

KEYWORDS: allergens; allergy; glove manufacturing; hev b 6.02; inhalable dust; latex allergens; latex gloves; latex products; occupational asthma; occupational exposure; occupational hygiene

INTRODUCTION

Natural rubber latex (NRL) is a complex mixture of chemicals, and fresh NRL contains 2–3% proteins (Sri-akajunt *et al.*, 2000) which includes about 60 proteins considered to be allergens (Yeang *et al.*, 2002; Green-McKenzie and Hudes, 2005). Clinical manifestations of hypersensitivity reactions following latex allergen exposure include not only contact dermatitis, contact urticaria, and respiratory symptoms including rhinitis and asthma, but also life threatening anaphylaxis (Baur and Jäger, 1990; Zuskin *et al.*, 1998; Charous *et al.*, 2002; Kumar *et al.*, 2005).

The vast majority of studies on occupational exposures to latex allergens and the resulting health effects have been conducted in patients and healthcare workers (Vandenplas *et al.*, 1995; Liss *et al.*, 1997; Wrangsjö *et al.*, 2012). Other important industries, primarily concentrated in the developing world, with considerable potential exposure to latex allergens are latex tapping and the manufacturing of latex products. In particular few studies have been conducted to date in latex glove manufacturers. Four studies have reported latex sensitization prevalence rates in this industry as being 11% in Canada in the 1980s (Tarlo *et al.*, 1990), 5.9% in the early 1990s in Croatia (Zuskin *et al.*, 1998) and 1.7% prevalence in Thailand in the late 1990s (Chaiear *et al.*, 2001): these rates being much higher than those reported in the general population (<1%) (Liss and Sussman, 1999). More recently, no sensitized cases were reported in Iranian factories (although 50% of workers had symptoms of allergic disease (Moghtaderi *et al.*, 2012) and while these data may suggest that sensitization rates declined over time, the lack of recent studies suggests that these data should be interpreted with caution.

The latex-glove-manufacturing industry is of further interest, as during the production of latex gloves exposure to aero-allergens is considered the dominant route of exposure (Chaiear *et al.*, 2001). In contrast, in the healthcare sector the most important exposure route is dermal, though inhalation exposure can also occur (Baur and Jäger, 1990; Wrangsjö *et al.*, 2012).

Rates of latex sensitization as well as of occupational asthma have been linked to the level of exposure to latex allergens that are released during the production of gloves (Tarlo *et al.*, 1990). Exposure to other chemicals, including accelerators also occurs and could contribute to the development of occupational asthma and other clinical outcomes (Chaiear *et al.*, 2001).

Therefore, we conducted an exposure assessment study in latex glove manufacturing companies in Thailand aimed at estimating personal exposure to inhalable dust and to latex-specific aero-allergens. Of the 60 allergens in NRL, 13 are considered the main allergens that stimulate allergic reactions in humans and 4 of these (Hev b 1, b 3, b 5 and b 6.02) in particular have been found in NRL gloves (Alenius *et al.*, 2002; Ahmed et al., 2003, 2004; Koh *et al.*, 2005). Of these, Hev b 5 and especially Hev b 6.02, a Hevein precursor have been shown to be the most important allergens in healthcare workers sensitized by latex gloves (Peixinho *et al.*, 2008; Yagami *et al.*, 2009), and therefore in this study we focussed on personal exposure to Hev b 6.02 specifically in addition to inhalable dust.

METHODS

Eighteen latex glove factories in the southern part of Thailand, registered in the database of the Department of Industrial Works, were contacted in 2009. Four of these, all classified as small- and medium-sized enterprises, agreed to participate and three located in Songkhla province were included in this study (the fourth factory was included in a pilot study to evaluate the methodology).

Workers employed at one of the three factories were invited to participate, which included an exposure assessment and a health assessment survey. This manuscript only describes the results of the exposure assessment survey. For the exposure survey all current workers were eligible for participation and no exclusion criteria were used. The study protocol was approved by the University of Manchester Research Ethics Committee (reference no 08184).

The production process in all factories was divided into 11 distinct departments in which workers were involved (i.e. not fully automated). These were compounding (where accelerators, stabilizers, and antioxidants are added to water and latex to facilitate the forming and curing process), and post-processing divided in stripping (where, after dipping and curing, latex gloves are stripped from formers), tumbling (in which latex gloves are further dried), chlorination (to remove proteins from the gloves), quality and control and assurance (QC/QA), packing (powdered gloves or non-powdered gloves), storage, and furthermore the laboratory, maintenance workers, and offices. Workers from each department were sampled randomly and on random working days. The measurement strategy aimed to obtain equal numbers of samples from each department, but because only eight sampling sets were available a maximum of 8 departments (depending on the agreement of workers) were sampled on any given day.

Personal air sampling was carried out for the duration of full shifts (4–10 h) during which ambient temperature and relative humidity in the factories were also measured. Inhalable dust was sampled using IOM sampling heads equipped with polytetrafluoroethylene filters. The sampling heads were connected to a personal air sampling pump calibrated, using a primary standard calibrator prior to each measurement, to a 2.0 ± 0.1 l min^{-1} flowrate. Preparation of the sampling media was done based on Methods for the Determination of Hazardous Substances 14/3(HSE, 2000). In short, filters were pre-conditioned in a desiccator for at least 24 h and then acclimatized for another 24 h prior to weighing. Pre-sampling weight was calculated as the mean of three stable readings. After sampling, the filters were similarly desiccated, acclimatized, and weighed. On each sampling day, one blank filter was prepared and handled similar to the actual sampling filters, except that they were not connected to a sampling pump. Values below the analytical limit of detection (LOD) (0.01 mg) were imputed by a randomly generated value between 0 and the LOD with its probability conditional on the lognormal distribution of the measurements >LOD (Lubin *et al.*, 2004).

After weighing, the filters were cut into small pieces, suspended in 1.5 ml phosphate buffered saline containing 0.02% sodium azide and vortexed for approximately 10 s before being placed on a rotatory mixer for 4 h. The tube was then vortexed again and the small pieces of filter removed by clean tweezers. The remaining solution was centrifuged at 2000g for 15 min at 4°C. The clear supernatant was collected, aliquoted, and stored at −20°C until analysed. Hev b 6.02 analyses were carried out using a FitKit® (Icosagen, Tartu, Estonia) enzyme immunometric assay (EIA) according to the manufacturer's instructions. The FitKit® EIA has been previously used in studies examining specific latex allergen content (including Hev b6.02) in gloves used by healthcare workers (Koh *et al.*, 2005; Peixinho *et al.*, 2008). Hev b 6.02 was quantified from the derived standard curve. The laboratory LOD was 5 μg l^{-1} and similarly, values <LOD were replaced by a single value using the same method as for inhalable dust.

All descriptive analyses and regression modelling was done using R version 2.13.1 (R Development Core Team, 2005). Statistical analyses were done using linear mixed-effects modelling using the R 'lme4' package (Bates *et al.*, 2013) to account for repeated measurements of workers. Multivariate model selection was done based on Akaike's Information Criterion. The final multivariate mixed-effects models included factory and department as fixed effects and worker as random effects. Other factors (worker ethnicity and gender, temperature, relative humidity, sampling duration, and day of the week) were not significantly ($P < 0.05$) associated with measured concentrations and therefore not included in the final models.

RESULTS

Factory 1 employed just over 300 workers at the time of the study. It produced powdered latex gloves, chlorinated latex gloves, and polymer coated latex gloves. Factory 2 employed just over 500 workers and primarily manufactured chlorinated latex gloves (powder-free latex gloves) but powdered latex gloves and nitrile gloves were also produced. The largest factory (Factory 3) employed just over 600 workers and produced powdered latex gloves and polymer coated gloves. This factory was the only one in this study that did not manufacture chlorinated latex gloves.

A total of 275 workers were included in the exposure assessment survey and a total of 292 personal shift measurements were collected; 96 in Factory 1, 98 in Factory 2 and 98 in Factory 3, respectively (Table 1). The total number of measurements per department ranged from 2 to 29. Most workers collected 1 sample, but if repeated samples could be taken, 2–4 were collected per worker.

An overview of the study population and characteristics of the measurements is provided in Table 2 and shows that the participants made up 19% of the total workforce. About 40% (range 35–50% between factories) of the participating workers were male. The percentages of participating non-Thai workers ranged from 1% in Factory 1 to 54% in Factory 2 (mean 24%) and the duration of employment of workers ranged from 1 month to 17 years (mean 3 years). On average, measurements lasted 474 min (7.9 h) and ranged from

Table 1. Overview of measurement programme

Department	Pooled		Factory 1		Factory 2		Factory 3	
	***N*(s)**	***N*(w)**	***N*(s)**	***N*(w)**	***N*(s)**	***N*(w)**	***N*(s)**	***N*(w)**
Compounding	25	17	7	4	9	5	9	8
Laboratory	24	21	8	8	8	6	8	7
Stripping	39	37	10	9	10	9	19	19
Tumbling	19	19	2	2	8	8	9	9
Chlorine	18	18	9	9	9	9	0	0
QA/QC	30	30	15	15	8	8	7	7
Packing	58	58	19	19	29	19	20	20
Storage	26	23	8	8	9	7	8	8
Maintenance	27	26	9	9	9	9	9	8
Office/admin	26	26	8	8	9	9	9	9
Total	292	275	96	91	98	89	98	95

N(s)/N(w): Number of sample/workers.

246 to 609 min. Differences in average sampling duration between factories were marginal (<1 h). Similarly, differences between factories with respect to relative humidity (range 50.9–59.8%) and temperature (range 32.5–33.1°C) during the measurement periods were minimal.

Average time-weighted geometric mean (GM) personal exposure to inhalable dust in these factories was 0.9 mg m^{-3}, but individual time-weighted average (TWA) exposures up to 12.3 mg m^{-3} were found (Table 3). The highest GM exposure was found for workers in the stripping departments (3.0 mg m^{-3}; range 0.7–12.3), followed by the tumbling (GM 1.7 mg m^{-3}) and packing (GM 1.3 mg m^{-3}) departments, while maintenance workers also had relatively high TWA exposures ranging from 0.3 to 10.3 mg m^{-3} (GM 1.1 mg m^{-3}).

Multivariate results indicated that the pattern of inhalable dust exposure was similar in all factories, with the highest exposures found for workers in the stripping departments (GM 2.1, 2.5 and 4.1 mg m^{-3} for Factories 1,2, and 3, respectively), following by tumbling (1.1, 1.3, and 2.2 mg m^{-3}) and packing departments (1.0, 1.2 and 1.9 mg m^{-3}). GM exposure levels were about two times higher in all departments in Factory 3 than in the other 2 factories. The between-worker variance was only ~8% while the within-worker, day-to-day variability contributed 92% to total variability in personal exposure levels.

Table 4 shows results of similar analyses for personal Hev b 6.02 exposure. Overall, a large proportion of samples were below the LOD (63%), but this differed greatly between departments with most samples above the LOD in the stripping and tumbling departments (67 and 74%, respectively) and only 4% of samples with measurable Hev b 6.02 levels in the compounding and laboratory departments. GM Hev b 6.02 exposure was 8.9 mg m^{-3}, with individual TWA measurements ranging from 1.0 to 345.5 mg m^{-3}. The exposure pattern of Hev b 6.02 was similar to that observed for inhalable dust exposure, with highest exposures found in the stripping (GM 18.9 mg m^{-3}; range 1.4–192.9), tumbling (GM 12.4 mg m^{-3}; range 5.5–60.9), and packing (GM 12.1 mg/m^{-3}; range 1.0–345.5) departments, and the lowest exposure measured in the laboratory (GM 4.9 mg m^{-3}; range 1.7–23.4). TWA GM exposure levels in Factory 3 were ~2-fold higher than those found in factories 1 and 2. GM personal exposure in Factory 3 ranged from 8.7 mg m^{-3} in the laboratory to 30.2 mg m^{-3} in the stripping department. In contrast to inhalable dust exposure, total exposure variability was primarily made up

Table 2. Overview of study population and sampling characteristics

	Pooled, *N* (%)	**Factory 1, *N* (%)**	**Factory 2, *N* (%)**	**Factory 3, *N* (%)**
Population				
Workers	275 (19)	91 (28)	89 (17)	95 (15)
Gender (male)	111 (40)	32 (35)	45 (51)	34 (36)
Ethnicity (non-Thai)	66 (24)	1 (1)	48 (54)	17 (18)
Duration of employment (yrs)[a]	3.0 (4)	2.4 (2)	2.5 (2)	3.9 (5)
Range	0.1–17.4	0.1–4.7	0.1–9.5	0.1–17.4
Measurement programme				
Sampling duration (min)[a]	474 (62)	442 (71)	504 (42)	476 (54)
Range	246–609	246–584	262–560	372–609
Relative humidity (%)[a]	56.0 (9)	50.9 (8)	57.1 (9)	59.8 (8)
Range	33.0–80.0	38.3–80.0	33.0–76.4	37.4–76.8
Temperature (°C)[a]	32.7 (3.8)	33.1 (3.8)	32.6 (3.4)	32.5 (4.0)
Range	23.7–42.5	23.7–42.5	24.4–40.4	23.9–41.2

[a] Mean (standard deviation).

of variability between workers (67%) with within-worker, day-to-day variability only contributing 33%.

DISCUSSION

This is the first study to investigate personal exposure to inhalable dust and Hev b 6.02 in among workers in the latex-glove-manufacturing industry in Thailand. No measurements exceeded the Thai Occupational Safety and Health regulation limit value of 15 mg m^{-3} (Ministry of the Interior, 1977). Though inhalable dust has not previously been measured in the Thai glove manufacturing industry, a number of other studies have been carried out in other countries. In the Canadian industry in the late 1980s personal exposure ranged from 0.4 to 5.5 mg m^{-3} (Tarlo *et al.*, 1990) whereas in a 1998 Croatian study (Zuskin *et al.*, 1998) the reported mean total dust concentration from area sampling was 7.7 mg m^{-3}. Exposure in this study seems comparable, but the effects of the different sampling devices, filters and measurement strategies used are unclear.

There are no occupational exposure limits specifically for latex allergen Hev b 6.02, and no studies to date have been conducted to specifically measure personal exposure to this allergen in the latex-glove-manufacturing industry. Personal exposure to total latex aero-allergens in three latex-glove-manufacturing companies in Thailand has previously been reported (Sri-akajunt *et al.* 2000; Chaiear *et al.*, 2001): GM level was 15.4 µg ml^{-1} [geometric standard deviation (GSD) 2.5] for the *a priori* defined 'high exposure group', which included glove stripping, inspection, powdered glove packaging, turning gloves inside out, and curing. Corresponding GM exposure levels in the 'moderate' (packaging of non-powdered NRL gloves, machine operation and maintenance, compound mixing, chlorination, glove weighing and quality control) and 'low' (mould cleaning, administration, warehouse assistants, drivers and office cleaners) exposure groups were 2.3 (GSD 3.1) and 1.0 (GSD 4.2) µg ml^{-1}, respectively. Although not directly comparable to the results from this study as Hev b 6.02 levels were measured, this study showed the same division of departments into 'high exposure', 'moderate exposure' and 'low exposure' (although we did not classify departments as such) with the highest personal exposure levels being found in the glove stripping departments. However, we analysed total protein and Hev b 6.02 in the gloves produced in

Table 3. Summary data inhalable dust measurements

Department	Measured (mg m^{-3})			Modelled geometric mean (GM)[a]		
	Arithmetic mean	GM	range	Factory 1	Factory 2	Factory 3
Compounding	0.7	0.3	0.0–3.9	0.2	0.3	0.5
Laboratory	0.7	0.4	0.1–2.2	0.3	0.4	0.7
Stripping	3.9	3.0	0.7–12.3	2.1	2.5	4.1
Tumbling	1.9	1.7	0.4–4.5	1.1	1.3	2.2
Chlorine	1.1	0.7	0.3–8.4	0.6	0.8	n/a
QA/QC	1.4	1.0	0.2–9.5	0.8	1.0	1.6
Packing	2.0	1.3	0.2–9.3	1.0	1.2	1.9
Storage	1.7	1.2	0.2–6.5	0.9	1.1	1.7
Maintenance	1.9	1.1	0.3–10.3	0.9	1.0	1.7
Office/admin	0.2	0.1	0.0–0.9	0.1	0.1	0.2
Total	**1.7**	**0.9**	**0.0–12.3**			
S_{bw}[b]					**0.1**	
S_{ww}[c]					**0.8**	

[a] Mixed effects model to account for repeated measurements amongst workers.

[b] S_{bw} = estimated between-worker variance.

[c] S_{ww} = estimated within-worker variance.

these factories and these could be directly compared to similar results for gloves used by healthcare workers in Singapore (Koh *et al.*, 2005). For powdered examination gloves we found (n = 3) an average Hev b 6.02 content of 4.69 µg per g glove (range 0.26–13.33 µg g^{-1}) and for non-powdered gloves (n = 3) 0.24 µg g^{-1} (range 0–0.66 µg g^{-1}), which is comparable to those reported by Koh *et al.* (2005); 3.77 µg g^{-1} (range 0–27.62 µg g^{-1}) and 0.47 µg g^{-1} (range 0.19–1.31 µg g^{-1}), respectively. In addition to showing that Hev b 6.02 content of gloves can be extremely variable and depends on the brand, type, and batch, both studies further showed that the contribution of Hev b 6.02 to total protein (our data) or a screen of the most important allergens (Hev b 1,3,5, 6.02) (Koh *et al.*, 2005) was also extremely variable and ranged from 2–80%. The study by Chaiear *et al.* (2001) and Sri-Akajunt *et al.* (2000) further indicated that latex aero-allergen levels found in Thai glove manufacturing were about 3-fold higher than in Thai rubber plantations and 16 times higher than those measured in a UK hospital at the same time.

Inhalable dust and Hev b 6.02 had similar exposure patterns and were highest in the glove stripping departments. This was expected since workers used compressed air to blow the finished latex glove out of the formers. In addition, the stripping area was located near the main oven and industrial fans, which may have increased the dispersion of airborne dust. High exposure in the tumbling department was likely from transfer of the latex gloves in and out of the tumble dryer, while in the packing department workers' wages depended upon the number of boxes packed, which will likely have resulted in increased exposure.

Exposure in Factory 3 was about twice as high as that in the other two factories. Factory 3 was the largest and also oldest factory of the three, used older equipment in the manufacturing process and likely also had the highest production. In addition, Factory 3 also almost exclusive manufactured powdered latex gloves while Factories 1 and 2 also had a sizeable production of nitrile and chlorinated gloves.

Table 4. Summary data Hev b 6.02 measurements

Department	**Samples > LOD[a] (%)**	**Pooled dataset**			**Modelled geometric mean (GM)[b]**		
		Measured Hev b 6.02 (mg m^{-3})					
		Arithmetic mean	**GM**	**range**	**Factory 1**	**Factory 2**	**Factory 3**
Compounding	4	6.0	5.7	2.0–10.5	3.9	4.0	9.2
Laboratory	4	5.8	4.9	1.7–23.4	3.7	3.7	8.7
Stripping	67	40.3	18.9	1.4–192.9	12.8	13.0	30.2
Tumbling	74	16.1	12.4	5.5–60.9	8.2	8.4	19.4
Chlorine	6	6.1	5.6	2.2–11.2	5.6	5.7	n/a
QA/QC	43	16.6	10.6	3.5–102.0	8.7	9.5	19.9
Packing	57	28.1	12.1	1.0–345.5	8.9	9.1	21.1
Storage	31	9.1	6.2	1.7–41.1	4.8	4.9	11.4
Maintenance	30	12.5	7.7	2.6–79.0	6.0	6.8	14.1
Office/admin	12	6.2	5.8	2.3–14.6	4.3	4.5	10.0
Total	**37**	**17.6**	**8.9**	**1.0–345.5**			
S_{bw}[c]						**0.4**	
S_{ww}[d]						**0.2**	

[a] Percentage of samples above the LOD.
[b] Mixed effects model to account for repeated measurements amongst workers.
[c] S_{bw} = estimated between-worker variance.
[d] S_{ww} = estimated within-worker variance.

Interestingly, analysis of between- and within-worker variability indicated that exposure to inhalable dust was fairly homogeneous throughout the factory (small between-worker variability) but differed significantly between days (large within-worker, day-to-day variability), while the opposite was observed for Hev b 6.02. This may indicate that whereas exposure to inhalable dust is primarily related to the volume of product produced on each day, exposure to allergens is primarily determined by the specific task each worker routinely performs and how he or she conducts this.

There are a number of limitations to the study design used. The possibility of systematic bias in the selection of the factories cannot be completely excluded. The participating factories might have higher hygiene standards with cleaner working conditions compared to other factories. Although data obtained from the Department of Industrial Work indicated that participating factories were comparable in size to other medium size factories, it was not possible to compare non-participating companies by conducting a field visit.

This study further employed a cross-sectional study, and although this provided insights in current exposure levels and working practices in Thailand, no information is available as to whether the measurement period was representative of exposure in other months or years.

Due to a limited budget, only Hev b 6.02 was analysed as an indicator of allergic potential. Although Hev b 6.02 is considered the most important one in relation to health effects (Peixinho *et al.*, 2008), it is only one out of 13 specific latex allergens (IUIS-WHO, 2008) and hence the true exposure to allergic latex aero-allergens will have been underestimated. The extent of this underestimation may have been limited as previous work has shown that Hev b 5 and 6.02 contributed ~70 to ~100% of the total content of four specific latex allergens (Hev b 1, 3, 5 and 6.02) (Koh *et al.,* 2005). Our method to analyse inhalable dust may also have resulted in an underestimation of true exposure because any exposure in the form of liquid droplets would have evaporated off the filters. The impact of this may have differed between factories and departments but the magnitude of bias resulting from this is unknown. For Hev b 6.02, however, this would not have resulted in biased results since after evaporation these would remain on the filters for analysis.

Furthermore, while only 4 inhalable dust measurements were below the LOD, a relatively high number of Hev b 6.02 measurements were below the LOD and were replaced by a single conditional expected value. This method can result in biased estimates (Lubin *et al.,* 2004; Helsel, 2006). Nonetheless, we used this method because it has been shown to be preferable over deletion of nondetects (Helsel, 2006) and does not result in multiple datasets. Additional analyses (not shown) using LOD/$\sqrt{2}$ (Hornung and Reed, 1990) as single imputation values showed minimal differences to the means and variability estimates. This is in agreement with studies using different imputation methods to evaluate their impact, such as for example a study on welding fumes (Lehnert *et al.,* 2012), which indicated that the actual estimates are similar. Nonetheless, this choice may have resulted in biased individual estimates and standard errors (Lubin *et al.,* 2004).

Finally, the factories produced different brands of gloves and it has been demonstrated that levels of dust and Hev b 6.02 vary with glove type (Koh *et al.,* 2005), while also associations with airborne dust concentrations and total NRL aero-allergen concentrations are not straightforward (Kujala *et al.,* 2002). No data are available about the exact types and quantities of gloves produced during the measurement days, and this may explain some of the observed differences.

The study had several strengths. Importantly, we collected full-shift personal measurements that do not require extrapolation from 4-h sampling strategies and from stationary or source-oriented measurements. Furthermore, a group-based sampling strategy was utilized, based on the assumption that workers who carried out the same task in the same department were likely to have similar exposures (Tielemans *et al.,* 1998). This seemed a reasonable assumption based on factory visits prior to the start of the measurement programme. Alternatively, an individual-based exposure assessment strategy may have resulted in missing data for certain, small, departments thereby missing exposure estimations for specific tasks in the production process.

Finally, we incorporated a repeated measurement sampling design enabling estimation of between- and within-worker variability, which provides additional information on how and where exposure occurs in these factories and will further provide important information for targeted exposure reduction strategies (Heederik *et al.,* 2012; Wrangsjö *et al.,* 2012).

CONCLUSIONS

In conclusion, this was the first study evaluating occupational exposure to inhalable dust and Hev b 6.02 of workers in the contemporary latex-glove-manufacturing industry in Thailand. This study indicated that workers are routinely exposed to measurable levels of latex aero-allergens in especially the stripping, tumbling, and packing departments, which may give rise to an increased incidence of allergic symptoms and occupational asthma. These departments therefore would be natural targets for interventions aimed at reducing exposure. However, complete prevention of sensitization may necessitate total avoidance of exposure, which would entail continuing exposure measurement surveys coupled with medical surveillance and/or specific immunologic testing latex (Zuskin *et al.,* 1998).

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