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Potential Dermal and Inhalation Exposure to Chlorpyrifos in Australian Pesticide Workers

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Chlorpyrifos inhalation, dermal exposure and working practices of 28 pesticide applicators in Western Australia were assessed during a series of single property applications of a 0.5% (n=2) or 1% (n=26) concentration of active ingredient in water solution. Deposition on new cotton gloves worn beneath applicators' usual protective gloves was 2.4 (range 0.12–86.1) mg h^{-1}. Median deposition of chlorpyrifos onto a new cotton overall worn over other clothing (24 sections removed, corrected for body proportions) was 11.1 (range 0.2–41.9) mg h^{-1}. Deposition onto seven patches taped to the applicators' skin was 0.04 (range 0.01–4.7) mg h^{-1}. Inhalation concentration was 5.7 (range 0.7–219) μg m^{-3} time weighted average. In one group of 17 applicators' applying to existing properties, breathing zone air concentration correlated ($P<0.05$) with ambient air temperature (15–38°C). The questionnaire results (29 respondents) indicated applicators' practices led to increased exposure, in particular concerning poor usage and condition of protective equipment and a high frequency of splashes and spills onto the body. Prevention of deposition on clothing, in particular on the lower body is suggested, as well as improved working practices. **© 2001 British Occupational Hygiene Society. Published by Elsevier Science Ltd. All rights reserved**

Keywords: chlorpyrifos; inhalation exposure; dermal exposure; pesticide

INTRODUCTION

Australian worker exposure to pesticides is widespread and the factors contributing to exposure such as the predominantly hot and dry conditions, housing types, and worker behaviour may be different than reports of exposure from other countries. This paper presents results of a multiroute exposure study conducted in the summer (hot and arid) months in Western Australia.

Worker exposure assessment to organophosphate pesticides must account for the inhalation dose since vapours and aerosols can be breathed in, and the dermal dose as these compounds are capable of permeating the skin. Methods to assess inhalation, dermal absorption, and systemic doses are established (Anon, 1997; Curry *et al*., 1993) although in combination they may difficult to follow because of field practicality, worker acceptance and even lack of researcher understanding (Findlay, 1995). These issues may help explain the limited published exposure data and lack of exposure prediction models for substances with dermal absorption potential (Benford *et al*., 1999).

Other authors have indicated the contributing factors to the extent of exposure which include worker behaviour and use of personal protective equipment (Ohayo-Mitoko *et al*., 1999), and efficiency of dermal uptake (Fenske *et al*., 1990).

Recently a 'conceptual model' (Schneider *et al*., 1999) provided a framework and the terminology to standardise dermal exposure data and the explanation of transfer of contaminant mass between notional 'compartments'. Although the fieldwork for this study was completed before the 'conceptual model' was published, the present study will provide useful data for inclusion in a fuller description of dermal absorption.

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Industry background

Western Australian pesticide workers are provisionally licensed for one year after completing a pesticide safety course, and subsequent successful completion of a further course and 30 days on-the-job supervision by a fully licensed worker entitles them to apply for a full licence. The licence is renewed annually, however further training is not a requirement.

The organophosphate chlorpyrifos is applied manually by licensed workers to create a chemical barrier around a new property, or to eliminate and prevent termite infestation in existing properties. Termites consume cellulose including the structural timbers of properties resulting in millions of dollars of damage in Australia annually. Chlorpyrifos is moderately acutely toxic due to nervous system disruption caused by inhibition of cholinesterase enzymes (Fenske and Elkner, 1990). Due the presence of a more voracious species of termite, *Mastotermes*, a 2% solution may be used in the north of the Australia, whereas a 1% is used solution below the Tropic of Capricorn, the area of this survey. Other uses of chlorpyrifos are registered at a concentration of 0.5%, e.g. eradicating spiders and black ants.

METHODS

This study of workers in realistic conditions assessed their work practices and controls leading to chlorpyrifos exposure during one building treatment. A modified whole-body approach (WHO, 1986; Chester, 1995) was used to assess clothing deposition and permeation of chlorpyrifos. Cotton gloves were used to assess potential deposition of chlorpyrifos on the hands of workers. Patches attached to the skin were used to assess permeation of the pesticide through clothing. Surface wipes indicated contamination of surfaces in the workers vehicle and deposition on the workers' forehead. A questionnaire identified work practices and controls leading to exposure, and a checklist of symptoms of exposure.

Recruitment

Permission from all pest control companies in the Perth, Western Australia metropolitan area was sought to address licensed pesticide applicators that used chlorpyrifos. A consistent approach was used to supply information concerning the study and the role of participants.

Questionnaire

A questionnaire to collect personal information (questions 1–4), neuropsychological health information (questions 5–41), and work practices information (questions 42–70) was administered by the researcher before chlorpyrifos was used. Personal information recorded was date of birth, sex, time as a pest control operator, and grade of licence. The health section included indicators of well being including occurrence of hay fever, asthma, reaction to insect bites, and head injury; and secondly indicators of neuropsychological symptoms of organophosphate exposure, developed by Cassitto (University of Milan, unpublished), translated and piloted by one of the authors (see www.pesticide-research.curtin.edu.au).

Coverall and gloves

Before workers used chlorpyrifos they were supplied with a new cotton coverall and new cotton gloves. Due to worker imposed time constraints and acceptability most workers preferred to wear additional clothing under the new coverall, and their own protective gloves over the new cotton gloves. The details of additional clothing and gloves was recorded and a 'clo' value (Cena and Clark, 1981) calculated. Participants were briefed to leave the supplied cotton gloves on throughout the survey. Instances when the outer protective gloves were removed were noted.

Patches

Paper patches with an impermeable backing layer (Benchkote™) were attached to the skin at seven locations (Fig. 1) using medical tape (Chester, 1995).

Surface wipes

Three surfaces were wiped using dry cotton pads (5×6 cm), pressed firmly onto and moved over the whole surface; the worker's forehead, an area from immediately above the eyebrows to the hairline, the vehicle gear-stick knob, and the perimeter of the vehicle steering wheel.

Inhalation exposure assessment

A sorbent tube (SKC, Catalogue number 226-30-16; 'OVS' tube) contained in a protective holder was placed in the workers breathing zone and connected to a portable battery operated sampling pump, calibrated before and after use at a rate of 1–2 l. min^{-1}. Sampling time was the period from commencement of chlorpyrifos preparation and application, and finished at the end of the clean up. Samples were stored in an icebox following use then frozen until analysis at the laboratory. Samples were analysed using the method by Kennedy *et al.* (1994).

Sample preparation and analytical procedure

At the end of the exposure period each dosimeter was removed by the researcher wearing new disposable gloves and using scissor-tongs. Samples were sealed in a labelled plastic bag, stored in an icebox, and frozen at the laboratory until analysis. Twenty-four 100 cm^2 sections were cut from each coverall at locations shown in Fig. 1. Gloves, patches and wipes

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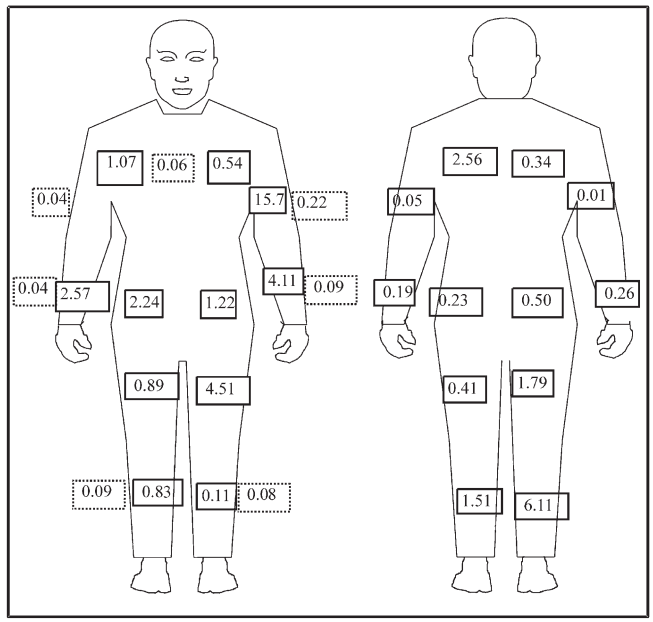

Inhalation	μg m^{-3}
Sample TWA	218.96
8 hour TWA	21.90
Extrapolated 8 hour TWA	191.59

Gloves	μg $hour^{-1}$
Left	4999.9
Right	2871.8

Surface wipes	μg
Forehead wipe	21.18
Steering wheel	2.80
Gear-stick	6.80

Coverall	
Mean deposition (μg cm^{-2} hr^{-1})	1.99
Weighted total (μg hr^{-1})	27291.4
Weighted total (μg 8 hr^{-1} TWA)	23879.9

Skin patches	
Mean deposition (μg cm^{-2} hr^{-1})	0.09
Weighted total (μg hr^{-1})	1003.4
Weighted total (μg 8 hr^{-1} TWA)	877.9

Intended chlorpyrifos conc^{n}.	1%
Application time (minutes)	48
Approximate litres used	100

TWA = Time Weighted Average

Fig. 1. Summary of personal exposure resulting from one application of chlorpyrifos; outline of worker annotated with chlorpyrifos deposition rate (μg cm^{-2} h^{-1}) on outer clothing (full squares) and on patches attached to the skin (dashed squares); and tables summarising coverall, skin patches, inhalation concentration, gloves deposition and surface wipes. This worker lay on his stomach with his head and shoulders through trap-doors in the wooden floor of a residential suspended floor property floor, and applied chlorpyrifos using jet nozzle to reach inaccessible areas.

were analysed whole. Chlorpyrifos was extracted from samples using a known volume of pesticide grade toluene and shaken for 1 h. Sample analysis was conducted using validated chromatography methods based on the Kennedy *et al*. (1994) procedure. No traces of chlorpyrifos were detected in control samples taken from identical coveralls, gloves, patches, skin patches or wipes, and therefore pre-washing was not deemed necessary. Recoveries of chlorpyrifos from laboratory spiked samples was 93% or greater. The analytical limit of detection was 1 ng ml^{-1}.

RESULTS

Recruitment

Two recruitment sessions were completed approximately one year apart. Each session indicated there were approximately 400 operators with a full licence and 100 with a provisional licence within the Perth metropolitan area. The rates of participation were similar for both years, 12% and 9% of contacted chlorpyrifos users. Two companies took part both years and one company contributed 10 surveys to the study, although variation in the application process and individuals were included. Twenty-eight individ-

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uals participated, four of which were surveyed twice (Table 1).

Application procedures and equipment

Three application procedures and associated equipment were identified:

(i) Pre-construction

Pesticide was applied onto the surface of a prepared building site with a sprinkling rose held in one hand and pointed towards and at approximately 45° to the ground and moved in sweeping arcs in front of the worker. An auto-dosing device installed in the workers vehicle continuously mixed mains water and the concentrate from a 20 l. drum to a predetermined concentration of 1%, at a rate enabling an application of diluted pesticide of 5 l. m^{-2}. The engineering control provided by the automatic dosing system effectively reduced chemical handling, although additional exposure may have occurred when renewing the concentrate drum.

(ii) Post-construction

Pesticide was sprayed onto the surface or injected into the ground around the perimeter of a recently constructed or established building. Injection at a depth of 100 mm into the ground was achieved using a trigger operated probe, and at 300 mm horizontal intervals around the building perimeter, at a rate of 100 l. m^{-3}. Where necessary injection entry 'ports' were drilled around the building perimeter.

Pesticide workers estimated the volume of pesticide required and made adequate volume for the individual job. Concentrate (e.g. 450 g $l.^{-1}$) was dispensed from the manufacturer's container, usually a 20 l. drum to a measuring vessel. The chlorpyrifos solution for the specific application was made up by pouring the concentrate to the 200–300 l. tank installed on the workers vehicle, and topping up with water. A petrol motor driven pump (typically a four stroke 3 hp model) transferred the pesticide via a hose to the worker who operated a pistol-grip trigger valve to commence spraying. The standard pump for this task is a centrifugal type pumping a maximum of 500 l. min^{-1} at a maximum pressure of 600 kPa.

In two cases a 0.5% chlorpyrifos solution (Empire™) was prepared instead of a 1% solution. A known volume of the product was dispensed into a hand-held sprayer and topped up with water. The tank was pressurised by hand pump and sprayed by depressing a trigger on the application lance.

(iii) Under-floor

Buildings constructed on brick or concrete piers, i.e. with suspended floors, require the pesticide to be applied to the ground surface, necessitating access to the void below the floor. The restricted height of under-floor voids may require the worker to crawl on hands-and-knees or flat on his stomach to reach all areas. Since the perimeter of these buildings from ground level to at least floor level is usually bricked or boarded up, underfloor is usually devoid of light and has restricted ventilation.

Termite treatment consisted of three tasks; *preparation* included drilling of injection ports or cutting access holes to the underfloor void, but not the direct use of pesticides (although contact with contaminated surfaces was possible); *application* included donning of personal protective equipment, dilution of the concentrate, unraveling of hoses, and the application itself; *clean-up* occurred when application equipment was stored and included removing spills, filling injection ports with bungs or concrete.

Sampling and exposure time

The study comprised a series of separate surveys, each a fraction of the workers' day (median 1.3, range 0.3–5.1 h), the remainder of the day an uninvestigated number of applications was conducted, although an estimate of the number of hours spent applying pesticide was obtained (median 4, range 1–11.5 h).

Table 1. Summary of recruitment of workers to each assessment technique[a]

Assessment technique	Sample (n)[b]	Application technique		
		Pre-construction	Post-construction	Under-floor
Questionnaire	30[c]	4	18	6
Work practices	29	5	17	6
Air sample	30	5	18	6 (5)
Skin patches	30	5	18 (17)	6
Surface wipes	30	5	18 (16)	6
Gloves	30	5	18 (16)	6
Coverall	30	5 (4)	18 (16)	6

[a]In cases of samples missing the number in brackets indicates the actual number analysed.
[b]28 surveys included all assessment techniques during one application, including 4 workers surveyed twice.
[c]Two workers; one a manager, the other a newly provisionally licenced worker observed the application at a distance, and completed a questionnaire only.

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Ambient air temperature

The ambient air temperature during surveys was between 15° and 38°C. During nine surveys the temperature was equal to or more than 30°C and in six surveys less than or equal to 20°C. Seasonal variation in the termite treatment industry may occur in summer due to an increase the building industry activity, and termites are more active in the warmer months. Generally pesticide workers work at other times of the year as well, conducting routine inspections and treatments for a range of pests.

Chlorpyrifos deposition on coveralls

Chlorpyrifos deposition (μg cm^{-2}) was calculated proportional to body areas (Spear *et al*., 1977) giving a total weight per body section and per coverall, and as a deposition rate (μg cm^{-2} h^{-1}). The daily chlorpyrifos deposition was calculated from the workers estimated application hours per day.

The leg sections had the highest chlorpyrifos deposition accounting for approximately half of the chlorpyrifos on the coverall (Table 2). Approximately two thirds of leg area deposition occurred on the lower leg section indicating a priority for action to reduce exposure. Deposition on arms accounted for (approximately) 15, 17 and 26% in preconstruction, post construction and under floor jobs respectively. Workers abdomen areas received 25, 17 and 21%, whilst chest areas 8, 6 and 8% in preconstruction, post construction and under floor jobs respectively. As, for example, approximately 75% of deposition occurred on the leg and abdomen areas of pre-construction workers efforts to prevent dermal absorption in these areas would have a significant effect on total absorption. Contaminated clothing may also lead to contamination of other surfaces. Although workers were not observed to change their practice in higher temperatures, some indicated they wore less clothing, for example just shorts and a T-shirt without a coverall, potentially increasing their dermal exposure.

Chlorpyrifos on skin patches

The deposition rate of chlorpyrifos on patches attached to the workers skin was highest during preconstruction applications (Table 3), the largest proportion on the lower legs. The relationship between the clothing deposition rates and the skin patch deposition rates indicates the penetration of chlorpyrifos through clothing.

Gloves

Eighty-six percent of workers wore protective gloves over the supplied cotton gloves, most frequently PVC (60%), but also rubber (10%), cloth and leather (10%), and latex surgical. Only one worker used latex surgical gloves and chlorpyrifos was not detected on the cotton gloves beneath them, possibly, as this worker was particularly careful to minimise his exposure. Chlorpyrifos was detected on all other cotton gloves. The total (left and right gloves combined) chlorpyrifos on gloves, excluding none detected, was between 0.2 and 73 mg (median 2.5 mg). Deposition of chlorpyrifos on cotton gloves (total of left and right) below rubber gloves 2.3 mg h^{-1}, below PVC gloves was 1.9 mg h^{-1}, and below riggers or leather gloves was 12.5 mg h^{-1}. Workers who did not wear protective gloves over the cotton gloves had a total (combined left and right glove) deposition rate of 6.3 mg h^{-1}. The rate of deposition to cotton gloves was higher in under-floor applications (median of 8.0, range of 1.1–46.7 mg h^{-1}) than post construction (median of 2.4, range of 0.1–86.1 mg h^{-1}) and pre-construction (median of 2.1, range of 1.9–29.3 mg h^{-1}) applications.

Surface wipes

Deposition of chlorpyrifos on the forehead of workers was between 0.1 and 93 μg (median of 2.3 μg). On the steering wheel of "the workers' vehicle" chlorpyrifos ranged from none detected to 11 μg, with a median of 2.7 μg. The workers' vehicle gear stick

Table 2. Deposition rate (μg cm^{-2} h^{-1}) of chlorpyrifos on workers coveralls sections, patches attached to the skin of workers and cotton gloves worn under protective gloves (if any)

Clothing	Application type	Samples (*n*)	*n*>0[a]	Range[b]	Median	75th percentile	95th percentile
Coverall	Pre-construction	3	3	0.1–1.6	0.8	1.2	1.5
	Post construction	18	17	0.1–2.8	0.7	1.1	2.6
	Under floor	6	6	0.2–2.3	1.5	1.9	2.2
Patches	Pre-construction	28	28	0.01–4.68	0.17	0.42	1.37
	Post construction	121	84	0.01–2.65	0.03	0.12	0.53
	Under floor	41	35	0.01–4.36	0.06	0.15	3.11
Gloves	Pre-construction	4	4	1.9–29.3	2.1	9.0	25.2
	Post construction	17	16	0.12–86.1	2.4	4.8	32.9
	Under floor	6	6	1.1–46.7	8.0	11.4	38.2

[a]*n*>0 column indicates the number of samples with a result greater than zero.
[b]Range (minimum–maximum) of samples with results greater than zero or none detected.

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Table 3. Comparison of total deposition (mg h^{-1}) on coveralls and patches attached to the skin[a]

Application type	Samples (*n*)	*n*>0[b]	Range[c]	Median	75th percentile	95th percentile
Pre-construction						
Coverall	3	3	2.0–22.9	12.0	17.5	
Skin patches	4	4	0.5–14.5	3.7	8.4	
Post construction						
Coverall	18	18	0.2–41.9	8.8	15.5	35.7
Skin patches	18	14	0.2–8.3	0.4	1.3	3.8
Under floor						
Coverall	6	6	3.2–32.8	19.3	25.3	31.4
Skin patches	6	5	0.3–7.0	0.8	4.3	6.6

[a]Proportional body part calculation were performed after Spear *et al.* (1977).
[b]*n*>0 column indicates the number of samples with a result great than zero.
[c]Range (minimum–maximum) of samples with results greater than zero or none detected.

knob had a 1 μg median deposition of chlorpyrifos (range from zero to 38.8 μg).

Air concentration

The air concentrations in the worker breathing zone (Table 4) were generally less than the health based limit, however in one instance the Occupational Exposure Standard (Anon, 1995) of 0.2 mg m^{-3} was equaled.

Questionnaire results

The work practices questionnaire was completed by 29 workers; 76% held a full licence the remainder a 'provisional'. Forty eight percent were current smokers, 28% were ex-smokers, 24% never smoked, 41% responded that they sometimes smoke in the vehicle cabin, and one worker stored chemicals in the vehicle cabin. Meals were sometimes eaten in the vehicle cabin by over 80% of workers. The combination of smoking, eating and handling pesticides may result in an increased risk of ingestion and dermal absorbtion.

Spills which required medical attention were not reported by any worker, however in the 'past six months' 10% reported they had to change their socks because of a spill, and 7% had a spill of the concentrate, 70% had a spill of the dilute solution in their eyes and 90% on their boots (Table 5). Boots were cleaned daily by 30% of workers, weekly by 40%, and less than once a month by 25%. Two workers indicated their boots were not required to be cleaned. All workers reported to use a respirator, 90% reported they had sufficient training in using it, 40% changed their respirator weekly, 50% monthly and 10% every three months. Gloves were reported to be routinely worn by 90% of workers. Reusable gloves were used by 75% of workers, and were washed weekly by 60%, monthly by nearly 30%, and one worker never washed his gloves. Coveralls were worn routinely by over 90% of workers, 75% had a spare pair in their vehicle, and 55% of workers changed into normal clothing at the end of a job. Protective clothing was washed weekly by 55% of workers, at the end of the day by 20% of workers and less frequently than weekly by the remainder. No workers reported their employers provided for washing of their protective clothing.

Table 4. Pesticide applicators breathing-zone chlorpyrifos concentrations during application (μg m^{-3})

Application type	Samples (*n*)	*n*>0[a]	Range[b]	Median	75th percentile	95th percentile
Pre-construction						
Sample TWA[c]	4	4	5.8–41.5	21.6	38.1	40.8
8 h TWA	4	4	0.2–1.2	0.8	0.9	1.1
Daily exposure[d]	4	4	2.3–25.9	13.0	23.8	25.5
Post construction						
Sample time	17	17	0.7–58.3	3.3	5.7	49.4
8 h TWA	17	17	0.1–16.9	0.9	1.5	8.7
Daily exposure[d]	17	17	0.2–18.2	1.3	2.2	13.1
Under floor						
Sample time	5	5	17.1-219	40.0	205.9	216.4
8 h TWA	5	5	0.9–32.6	8.9	21.9	30.5
Daily exposure[d]	5	5	6.4–191.6	57.6	77.2	168.7

[a]*n*>0 column indicates the number of samples with a result greater than zero.
[b]Range (minimum–maximum) of samples with results greater than zero or none detected.
[c]TWA=time weighted average.
[d]Total atmospheric exposure to chlorpyrifos based on workers estimated hours spent applying pesticide per day.

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Table 5. Results from a sample of questions from the health status, neuropsychological symptoms and work practices questionnaire for 7 provisionally licensed and 22 fully licensed pesticide applicators related to work practices

Question	Provisionally licensed		Fully licensed	
	Positive response	Negative response	Positive response	Negative response
In the past six months, have you ever had a splash of the *dilute* solution in your eyes or in your face?	4 (57%)	3 (43%)	16 (73%)	6 (27%)
In the past six months, have you ever had to change your socks because of a spill or contamination?	0 (0%)	7 (100%)	3 (14%)	18 (86%)
Do you use a respirator?	7 (100%)	0 (0%)	22 (100%)	0 (0%)
If 'yes', have you had sufficient training on the use of respirators?	5 (74%)	2 (26%)	22 (100%)	0 (0%)
Do you sometimes have meals in the vehicle cabin?	5 (74%)	2 (26%)	19 (86%)	3 (14%)
Do you store chemicals in the vehicle cabin?	0 (0%)	7 (100%)	1 (5%)	21 (95%)

	Provisionally licensed		Fully licensed	
	End of day or every second day	Twice a week or once a week	End of day or every second day	Twice a week or once a week
How often is protective clothing washed?	3 (43%)	4 (57%)	6 (27%)	16 (73%)

	Provisionally licensed			Fully licensed		
	Once a week	Once a month	Once every three months	Once a week	Once a month	Once every three months
How often do you change your respirator cartridge?	5 (74%)	2 (26%)	0 (0%)	8 (36%)	11 (50%)	3 (14%)

	Provisionally licensed				Fully licensed			
	Mop	Rag	Hose it	Other	Mop	Rag	Hose it	Other
If you have a spill or leak, what do you mainly use to clean it up?	0 (0%)	2 (29%)	2 (29%)	3 (43%)	0 (0%)	11 (50%)	4 (18%)	7 (32%)

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DISCUSSION

The pest control industry in Western Australia comprises around two hundred companies; however, only five employ more than ten pesticide applicators. The majority of companies are therefore smaller businesses such as self-employed owner-operators, who often employ their spouse for administrative duties. The extent of compliance and integration of occupational health and safety is well known to be poorer in small businesses, often because of constraints on expenditure. Further research of exposures of workers in small businesses is suggested.

Generally employers were reluctant to be involved in a survey which reduced production time by more than a few minutes, or which could highlight irregularities in their practices. A recent governmental review (Department of Local Government, 1999) of the quality of workmanship in the industry may have contributed to this concern. The possibility chlorpyrifos would be banned following the results of the present study was a concern of several individuals prompting a negative attitude towards the study. The recent action in the United States (US EPA, 2000) to phase out chlorpyrifos by 2004 is also likely to effect the Western Australian industry, in the meantime the effect on workers exposure is difficult to predict.

The pesticide applicators themselves were generally interested in taking part, using their experience in the industry and lack of symptoms as a justification of their work practices, whether satisfactory or not. Workers declining participation in the study occasionally indicated they did not require further health and safety information, in some cases this was also a reason to participate i.e. 'I've got nothing to hide'. Since the study indicates frequent poor control of exposure, suggestions for improvement outlined in this paper are also likely to be applicable for those that did not take part. Further research of the contribution of behavioural factors of pesticide exposure is therefore suggested.

The issue of infrequent maintenance and cleaning of protective equipment was particularly relevant since the dermal assessment in this study was based on one application whereas clothing may not be clean, either by replacement or laundering for several applications. Therefore the levels reported here may be an underestimate of the chlorpyrifos on clothing. The accumulation of chlorpyrifos on clothing is potentially a significant source for dermal absorption and further work to assess the levels of chlorpyrifos on workers usual clothing should be considered.

The concentration of substance on the skin has been shown (Cherrie and Robertson, 1995) to be of greater influence on dermal dose than mass of the substance. Workers in this study used both concentrated and dilute chlorpyrifos. Anecdotally, workers appeared to increase control of exposure whilst handling the concentrate, but further work to assess risk perception and techniques of handling concentrated and diluted chlorpyrifos would be useful. Control of exposure to the concentrate has been achieved by introduction of small pumps and auto-dosing equipment, however control during application of the dilute solution is often poor. Poor practice was observed during most surveys, including placing a contaminated nozzle in the mouth to blow-out a blockage, and handling equipment without protective gloves. A provisionally licensed worker was observed to carefully control his exposure, including an assessment of the wind direction to ensure he remained upwind. In addition he proposed installing remote central locking on his vehicle to eliminate direct contact with the vehicle whilst he had contaminated hands. This worker was the only individual with undetectable levels of chlorpyrifos on the cotton gloves. He had recently completed the pesticide applicator training and had also supplemented his knowledge. Provisionally licensed operators indicated, in the questionnaire, increased hazard and control measure awareness (Table 5), possibly due to the shorter time since training.

This study has shown similar air concentrations as Fenske and Elkner's (1990) study. Additionally, there was potential for under-floor air concentrations to approach health based exposure limits and an association between the ambient air temperature and the type of exposure (post-construction application). The control of inhalation exposure using respiratory protective equipment was not as effective as possible, as respirator cartridges were often out of date, contradicting 93% of workers who responded they had sufficient respirator training. The majority of workers were therefore unaware of the limitations of their respiratory protective equipment.

It may be possible workers become desensitised to the characteristic chlorpyrifos smell since at times the researchers found the smell quite uncomfortable but the workers denied being able to detect it. Although the odour level at which a health effect may occur is likely to be well above the odour threshold in unexposed individuals a reduction in sensitivity to chlorpyrifos odour may effect the workers action to control exposure.

In standardised tests the transfer of chlorpyrifos from a surface to a hand resulted in approximately 2% being transferred (Clothier, 2000), although higher levels may be transferred from a surface to skin. The results of surface wipes in this study indicated chlorpyrifos had accumulated on surfaces in regular contact with workers skin; the steering wheel and gear stick. These 'secondary sources' of chlorpyrifos provide contaminant for re-deposition to other surfaces, including skin, food, cigarettes, and protective equipment. As over 80% of workers reported eating meals in their vehicle cabins, it is probable that a transfer of chlorpyrifos from contaminated surfaces to food or skin, and subsequently ingestion or skin

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permeation, occurred in these workers. Almost all workers who smoked (nearly 50%), at some time did so in their vehicle, possibly resulting in a transfer of chlorpyrifos from contaminated surfaces to cigarettes, and subsequently to skin and the mouth. Most workers spilt chlorpyrifos on their boots, which are likely to have accumulated chlorpyrifos because only one third cleaned them daily. Boots and clothing are removed by hand at the end of the day possibly without skin protection leading to re-deposition. Following an application only 55% of workers changed into other clothing, possibly contaminating the vehicle and other surfaces contacted. It could be assumed that as employers did not provide laundering facilities, protective clothing is taken home for laundering, possibly contaminating surfaces there too. The frequency which coveralls are laundered indicated there was at least a weekly accumulation of chlorpyrifos on around 80% of workers protective clothing, acting as source for re-deposition or skin permeation on subsequent days. All workers, except one, had chlorpyrifos in their gloves, trapped next to their skin, possibly for the majority of the day, and day after day, until the gloves were laundered or replaced. Domestic laundering can be effective to decontaminate clothing, however it is reliant on factors including the temperature of the wash, mechanical agitation, volume of water and numbers of other clothing in the wash (Department of Textiles, 1993).

Increased effectiveness of exposure control should include a reduction of the quantity of chlorpyrifos vapour and mist by examining the application equipment and its method of use. The methods used to prepare and apply chlorpyrifos in particular under-floor were not conducive to the elimination of worker exposure, reliance frequently being placed on administrative control and protective equipment. These results demonstrate a requirement to control contamination of surfaces and for an increase in workers' awareness of the importance of personal hygiene during and following their use of chlorpyrifos.

CONCLUSIONS

1. Australian worker dermal exposure assessments to chlorpyrifos indicated deposition rates of 11.1 mg h^{-1} on overalls, and 2.4 mg h^{-1} on gloves. Chlorpyrifos permeated the clothing of workers resulting in a deposition rate on skin patches of 0.3 $\mu g\ cm^{-2}\ h^{-1}$.
2. Inhalation of chlorpyrifos vapour was influenced by the ambient air temperature. Exposure assessment indicated workers were exposed to less than the health based limit of exposure, unless they applied the chlorpyrifos under-floor when the levels may approach the exposure limit.
3. Workers often did not select, use or maintain their protective equipment effectively; the likely cause of increased level of dermal absorption in some individuals.
4. Contamination of clothing and infrequent laundering led to an accumulation of chlorpyrifos on protective clothing. The re-deposition of chlorpyrifos to other surfaces was confirmed by the detection of chlorpyrifos in the workers vehicles.
5. Efforts to reduce exposure should concentrate on the prevention of chlorpyrifos deposition on clothing, in particular on lower body where the majority was detected.
6. Workers awareness of the hazards and routes of entry of the substance should be increased by adequate training.

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