

ORIGINAL ARTICLE

ASSESSMENT OF DERMAL EXPOSURE TO ORGANIC SOLVENTS AND POLYCYCLIC AROMATIC HYDROCARBONS (PAHs) AMONG MOTOR VEHICLE REPAIR (MVR) WORKERS: DREAM APPROACH

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ABSTRACT

Dermal exposure to used engine oil (UEO) and organic solvents during automobile repair, servicing, and painting is common among MVR workers. Limited studies were found on dermal assessment in Malaysia. This study focused on determining the total actual dermal exposure (ADE). A cross-sectional study was conducted on 247 MVR workers, consisting of mechanics and spray painters employed in micro and small automotive workshops located in Selangor, Malaysia. The groups completed a questionnaire to obtain socio-demographic, occupational, and health symptoms information and were observed during four specific tasks: spray painting, spray gun cleaning, flushing of UEO, and cleaning engine parts. Relevant data was gathered and an ADE assessment was conducted using the DREAM method. Overall, dermal exposure for the spray painters was found to be higher (76.01 ± 30.97 DREAM Units, DU) than for the mechanics (65.13 ± 5.02 DU). Spray painting tasks had moderate to high rankings with a mean ADE of 105.70 ± 11.92 DU ($p < 0.01$), the predominant routes being deposition followed by emission. Cleaning and oil flushing tasks resulted in moderate exposure. The ADE for UEO flushing was 61.93 ± 2.05 DU, for engine cleaning 69.11 ± 5.14 DU and for cleaning of spray guns 46.32 ± 1.93 DU ($p < 0.01$). The emission pathway was identified as the principal route of exposure and hands were the most exposed area. Clothing protection factors of hands and body parts scored minimally. The MVR workers faced significant susceptibility to occupational diseases as a result of exposure. Therefore, it is crucial to prioritise skin protection and to provide adequate training.

Keywords: DREAM, dermal exposure, mechanics, spray painters, motor vehicle repair (MVR), organic solvents, polycyclic aromatic hydrocarbons (PAHs).

INTRODUCTION

The automotive industry is one of the world's largest employers, and its significance is largely attributable to its intricate value chain which is tied to both domestic and international economies. Automobile maintenance and repair are substantial components of the automotive industry. Unlike vehicle manufacturing, repair and maintenance work typically occurs in small workshops or repair businesses¹. In automotive workshops, motor vehicle repair (MVR) workers such as mechanics, car painters, car repairers, vehicle maintenance personnel, panel beaters, and others are exposed to a variety of chemical substances. According to various studies, motor vehicle repair and maintenance workers are exposed to a wide range of hazards, including physical, chemical, and ergonomic hazards. Most spray painters work in small- to medium-sized workshops and do a variety of jobs, including sanding, degreasing, masking, mixing paint, primer spray painting, base coat painting, and clear-coat (topcoat) painting, as well as cleaning spray equipment. Mechanics also perform multiple tasks such as maintenance, cleaning, and servicing.

Organic solvents and polycyclic aromatic hydrocarbons (PAHs) are the most common chemicals used among MVR workers, especially when applying paint, removing oil, grime, and grease from work surfaces, using disposable aerosol spray cans, and performing maintenance on vehicles, especially changing lubricating oil²⁻⁴. In motor vehicle repair, dermal exposure is considered an important route of exposure as it involves contact with the skin and can result in the absorption of harmful chemicals present in automotive fluids and materials. Direct contact of solvents on the skin can cause the denaturation of lipids, leading to adverse effects such as dryness, irritation, cellular hyperplasia, and swelling. A notable example is the occurrence of dermatitis in these occupational settings, often resulting from the improper handling of solvents without the implementation of protective measures such as barrier creams and appropriate hand and arm protection. The impact of solvents on the lipid barrier in the skin has been investigated, revealing that the skin's permeability to solvents is dependent upon both the polarity of the solvent and the surface charge of the skin⁵. The most common modes of occupational exposure to PAHs are inhalation and skin contact. Meanwhile, skin

contact was also found to be a major route for PAH exposure among road pavers ⁶, automotive technicians ^{7,8}, and aluminium reduction workers ⁹.

Occupational skin diseases are common among car repair workers and can occur in different forms, for example, irritant and allergic contact dermatitis, skin cancer, skin infections, skin injuries, and others. Car repair workers are also at risk of developing occupational dermatoses as a result of their exposure to skin-irritating substances such as oils, greases, solvents, and detergents. In addition, some studies have also reported the adverse effects of solvents on the central and peripheral nervous systems, including neurobehavioral effects (visual impairment, memory deficit, and behavioural symptoms) in repairers and other workers in paint factories ¹⁰⁻¹².

Consumers in Malaysia rely on motor vehicle maintenance and servicing on a regular basis, and the demand is constantly increasing due to the annual rise in the number of motor vehicles in the country. In Malaysia, there are numerous options for vehicle maintenance and repair, such as official service centres, general workshops, self-maintenance, or a combination of these ¹³. In their study on consumers' preference for car repair and maintenance, Wahab et al. ¹⁴ found that the majority of Malaysians preferred authorised service centres, also known as franchise workshops, as well as general workshops (also known as independent workshops).

For many years, the field of occupational hygiene has focused on the inhalation exposure pathway, since it was thought to be the most significant route of exposure ¹⁵. Dermal exposure may occur when the skin comes into contact with liquids, solids, and contaminated work clothes or surfaces. However, skin exposure can contribute to the total body burden even when inhalation exposure is well-controlled ¹⁶. Therefore, dermal contact is also seen as an important route of exposure, and several studies have been conducted on dermal contact with chemicals in the same sector through various methods, such as patch testing ¹⁷⁻²¹ and clinical or dermatological examination ²²⁻²⁵. There are established quantitative methods for measuring dermal exposure, such as surrogate skin, wipe-sampling procedures, or biological monitoring. However, these methods are costly and time-consuming, requiring a high level of expertise and complex chemical analysis ^{26,27}. Non-measurement-based approaches such as the DREAM tool ²⁸ or similar techniques such as the RISKOFDERM toolkit ²⁹ are likely to require simpler processing of information. Therefore, this study aims to conduct dermal exposure assessment through the DREAM method among MVR workers who are exposed to organic solvents and PAHs.

MATERIALS AND METHODS

Sample size

This non-comparative cross-sectional study was conducted on 247 volunteer MVR workers, including mechanics and spray painters, employed in 20 micro and small automotive workshops (also known as independent workshops) located in Selangor, Malaysia. A sample size of 260 MVR workers has been calculated based on the prevalence of hand dermatitis among car repair workers in a similar socio-demographic population based on a study conducted in Iran ³⁰. The sample size was determined using the formula for descriptive studies³¹ for the hypothesis of one sample situation with an estimated margin of error of 5% and a confidence range of 95%. The previous study indicated that the prevalence of hand dermatitis among car repair workers in a similar socio-demographic study was 19% ³⁰. The sample size for determining the prevalence of skin problems among MVR workers exposed to chemicals was estimated taking into account an anticipated non-response rate of 10%.

Sampling method

Prior to conducting the study, permission was obtained from the relevant associations connected with vehicle painting and maintenance. Subsequently, the sampling frame was obtained by specifying the list of spray painters and mechanics from each workshop situated in Selangor. To execute this form of sampling, a numerical identifier was allocated to a roster of spray painters and mechanics, and a simple random procedure was employed. A total of 247 MVR workers consisting of 162 spray painters and 85 mechanics agreed to participate in this study and completed the self-report questionnaire. Spray painters were observed when they were spray painting and cleaning the spray guns, while mechanics were observed when they were flushing used engine oil (UEO) and cleaning engine parts using the dermal exposure assessment method (DREAM).

The inclusion criteria for respondent selection were male mechanics and spray painters using organic solvents and PAHs during four specific activities, namely used engine oil (UEO) flushing, engine parts cleaning, spray painting, and spray gun cleaning. Another inclusion factor considered was having an employment duration of more than six months to determine their health condition. The Ethical Committee for Research Involving Human Subjects at Universiti Putra Malaysia approved the study's methods, approaches, and respondents' participation. All individuals involved had provided their informed consent prior to the conduct of the interviews, where they had been briefed about the study objectives, procedures, and data handling privacy.

Questionnaire

A self-administered questionnaire was developed to ascertain the primary study's research questions and objectives. The questionnaire consisted of six parts: socio-demographics (Part A), occupational information (Part B), chemical exposure (Part C), PPE usage (Part D), skin symptoms (Part E), and general health (Part F). Part E (skin symptoms) was curated based on the Guidelines on Occupational Health Services 2005 and Part D of the Guidelines on Basic Occupational Health Services (BOHS) (unpublished) 2014³². Part F (general health/neurological symptoms) was outlined based on literature review findings^{5,33}. The self-report questionnaire was adapted for the MVR working scenario. The mechanics and spray painters completed the self-reported questionnaire at the automobile workshops. Similar method (self-administered questionnaire) has been utilised in small and medium enterprises (SME) manufacturing³⁴.

Dermal Exposure Assessment Method (DREAM)

DREAM is a semi-quantitative assessment and the DREAM questionnaire is a checklist containing inventory and evaluation information for the assessment of dermal exposure to chemicals in occupational settings²⁸. Each part comprises hierarchically structured questionnaires and assessments completed by observing each MVR worker perform four specific tasks, namely spray painting, spray gun cleaning, UEO flushing, and cleaning engine parts. Each answer has an assigned value of the dermal exposure which is calculated using a mathematical formula as shown in Table 1. The DREAM method gathers relevant information such as physicochemical data, dermal exposure route (emission, deposition, and transfer), protective clothing, and exposure estimate for each task.

Potential dermal exposure is concerned with exposure to clothing and uncovered skin, whereas actual dermal exposure is defined as exposure to skin. In the DREAM model, potential dermal exposure ($Skin-P_{BP}$) was first obtained by determining the route of exposure estimates for nine different body parts: head, upper arms, lower arms, hands, torso front, torso back, lower body parts, lower legs, and feet. Then, actual dermal exposure ($Skin-A_{BP}$) for each body part was determined by considering protective clothing estimates (hands and other body parts). The summation of actual dermal exposure ($Skin_W-A_{TASK}$) of the nine body parts produced the total actual dermal exposure in DREAM units (DU) and the score was categorised according to six different rankings³⁵. The DREAM study was conducted through the systematic observation of spray painters and mechanics engaged in four distinct jobs. A checklist was used to record the actions of each participant, and subsequently, the collected data was entered into Microsoft Excel

for the purpose of calculating potential and actual dermal exposure.

Statistical analysis

All of the MVR workers were subjected to descriptive statistics based on their demographic and occupational characteristics. The Shapiro-Wilk test was used to analyse the distribution of continuous variables and inferential statistics, such as the chi-squared test for qualitative data, and the independent *t*-test and one-way ANOVA for quantitative data. The significance level was less than 0.05 in this study and SPSS software was used for conducting statistical analysis.

RESULTS

Socio-demographic characteristics

The socio-demographic characteristics of the automotive repairers are shown in Table 2, comprising 162 spray painters and 85 mechanics. All the spray painters and mechanics were men (100%). The median age of the spray painters was 33 years (IQR = 16), with almost all (82.7%) of them falling between the ages of 15 and 44. Meanwhile, the median age of the mechanics was 25 years (IQR = 14), with 65.3% falling between the ages of 15 and 34. Although the majority of respondents were Malaysian citizens, 18.5% of the spray painters and 7.1% of the mechanics were foreign nationals. In terms of ethnicity, the majority of the spray painters (77.8%) and mechanics (89.0%) were Malay. More than half of the mechanics (56.6%) but less than half of the spray painters (48.1%) had completed their postsecondary education. Most of the spray painters (43.2%) and mechanics (64.7%) had held their current positions for less than five years. Active smokers made up 53.1% of spray painters and 45.5% of mechanics. A total of 62% of the spray painters and 59.5% of the mechanics had smoked for between 5 and 15 years, with medians of 9 (IQR = 8) and 5 (IQR = 4.5) years, respectively.

Actual dermal exposure according to tasks, position, and routes

A histogram, using an eyeball test for a bell-shaped curve and z-value, was used to observe the Shapiro-Wilk test, which was used to determine the normality of ADE of the spray painters and mechanics with their respective responsibilities. The Shapiro-Wilk test indicated that, overall, the ADEs for spray gun cleaning and UEO flushing jobs were normally distributed ($p > 0.05$). However, the numerical approach of skewness and kurtosis was examined for normality due to the limitations of the eyeball test for the ADE of other tasks. The study used medium-sized samples ($50 \leq n < 300$), inferred a normal sample distribution at absolute z-value ± 3.29 , and accepted the null hypothesis³⁶. The mean actual dermal exposure for the spray painters of 76.01 ± 30.97 DU was higher than for Adapted²⁸ the mechanics (65.13 ± 5.02 DU). The dermal exposure estimates of individuals engaged in spray painting activities were shown to be

elevated due to exposure through three distinct pathways: emission, deposition, and transfer. This was observed during both the actual spray painting work and the subsequent cleaning of spray guns, when exposure primarily occurred through the emission and transfer routes. When

compared with the mechanics, it was evident that there were only two pathways that were noticed during the process of executing UEO flushing and cleaning of engine parts.

Table 1: Mathematical Algorithm for Potential and Dermal Exposure Estimates and Total Actual Dermal Exposure at Task Level

Step	Variables	Formula
1	Calculate potential exposure estimate for each body part, and for each exposure route to all 9 body parts, Skin-P _{BP}	$Skin-P_{BP} = E_{BP} + D_{BP} + T_{BP}$
	Emission, E _{BP}	$E_{BP} = P_{E,BP} \cdot I_{E,BP} \cdot E_I \cdot E_{RE}$
	Deposition, D _{BP}	$D_{BP} = P_{D,BP} \cdot I_{D,BP} \cdot E_I \cdot E_{RD}$
	Transfer, T _{BP}	$T_{BP} = P_{T,BP} \cdot I_{T,BP} \cdot E_I \cdot E_{RT}$
	Intrinsic Emission, E _I	$E_I (SOLIDS) = PS \cdot C \cdot F \cdot DU \cdot SS$
		$E_I (LIQUIDS) = PS \cdot C \cdot F \cdot EV$
		$E_I (VAPOURS) = PS \cdot C \cdot$
	Exposure route factors	$E_{RE} = 3$
		$E_{RD} = 1$
		$E_{RT} = 1$
2	Calculate actual dermal exposure for each body part	$Skin-A_{BP} = Skin-P_{BP} \cdot O_{HA}/O_{BP}$
	Clothing protection factors of hands, O _{HA}	$O_{HA} = M \cdot PFM_{HA} \cdot RF \cdot GC \cdot GD \cdot UG \cdot URF \cdot BC$
	Clothing protection factors of other body parts, O _{BP}	$O_{BP} = M \cdot PFM_{BP} \cdot RF$
	Note: O _{HA} /O _{BP} indicates 1 when no protective clothing is worn	
3	Calculate total actual exposure estimate at task level	$Skin_W-A_{TASK} = \sum_{BP=1-9} [Skin-A_{BP} \cdot Body \text{ Surface Factor } (BS_{BP})]$

For task-based exposure, the average actual dermal exposures for spray painting and spray gun cleaning were 105.70 ± 11.92 DU and 46.32 ± 1.93 DU, respectively. Meanwhile, spray painting tasks were ranked as high actual dermal exposure (74.1%), while the others were ranked as moderate. In contrast, all spray gun cleaning tasks were ranked as moderate. The average dermal exposures for flushing used engine oil and cleaning engine parts were 69.11 ± 5.14 DU and 61.93 ± 2.05 DU, respectively. According to the actual dermal exposure ranking, both tasks were ranked as moderate. Refer to Tables 3 and 4.

According to Tables 3 and 4, in spray painting tasks, deposition (248.46 ± 19.49 DU) was

recorded as the most common route and was ranked high, followed by emission (89.63 ± 11.89 DU). For spray gun cleaning, the highest dermal exposure was through emission (114.40 ± 42.24 DU), due to the immersion of the workers' hands in the vessels containing petrol to soak the spray gun, and cleaning the gun using a sponge. Meanwhile, the mechanics' main route of exposure was through emission during UEO flushing (97.97 ± 3.26 DU) and engine parts cleaning (89.33 ± 7.03 DU), followed by the transfer route. However, for the transfer route, the exposure during engine parts cleaning (75.10 ± 11.01 DU) was higher than that of UEO flushing (38.36 ± 0.81 DU).

Table 2: Socio-Demographic Characteristics among Respondents

Variables	Spray Painters (n=162)		Mechanics (n=85)	
	Median (IQR)	n (%)	Median (IQR)	n (%)
Age (years)	33 (16.0)	162 (100)	25 (14.0)	85 (100)
15-24		44 (27.2)		41 (48.2)
25-34		48 (29.6)		23 (27.1)
35-44		42 (25.9)		18 (21.1)
45-54		22 (13.6)		3 (3.5)
Above 55		6 (3.7)		-
Gender				
Male		162 (100)		85 (100)
Nationality				
Malaysian		132 (81.5)		79 (92.9)
Non-Malaysian		30 (18.5)		6 (7.1)
Ethnicity				
Malay		126 (77.8)		76 (89.4)
India		-		3 (3.5)
Bumiputra		6 (3.7)		-
Others		30 (18.5)		6 (7.1)
Education Level				
No Formal Education		12 (7.4)		3 (3.5)
Primary		24 (14.9)		3 (3.5)
Secondary		48 (29.6)		31 (36.5)
Tertiary		78 (48.1)		48 (56.5)
Duration of Employment (years)	5.0 (12.0)	162 (100)	3.0 (5.8)	85 (100)
Below 5 years		70 (43.2)		55 (64.7)
5-10 years		28 (17.3)		19 (22.4)
11-15 years		30 (18.5)		7 (8.2)
16-20 years		18 (11.1)		4 (4.7)
Smoking Status				
Yes		100 (61.7)		37 (43.5)
No		62 (38.23)		48 (56.5)
Duration of Smoking (years)	9.0 (8.0)	162 (100)	5.0 (4.5)	37 (100)
Below 5 years		32 (32.0)		15 (40.5)
5-15 years		62 (62.0)		22 (59.5)
Above 15 years		6 (6.0)		-

Actual dermal exposure according to body parts

During spray painting, all body parts are exposed to organic solvents because painting is usually carried out in a spray booth or an enclosed system. Over-spraying and deposition of the paint mist were clearly visible during the observations. Figure 1 shows the highest actual dermal exposures of body parts reported were on the upper body, i.e., head (24.85 ± 4.12 DU), hands (24.12 ± 9.77 DU) and lower arms (20.19 ± 0.00 DU). Feet record an actual dermal exposure of 13.39 ± 8.01 DU. For the spray gun cleaning task, hands had the highest exposure (49.59 ± 4.19 DU), due to the immersion of hands into solvents for cleaning purposes. The flushing engine oil task usually caused oil to dribble onto the mechanic's hands or arms. Meanwhile, for the engine cleaning task, hands were always used in cleaning, washing, sponging, and brushing engine parts. Therefore, the findings showed that hands had the highest values of actual dermal exposures for both UEO flushing (52.51 ± 0.48 DU) and engine parts cleaning (56.26 ± 0.88 DU). Other body parts of the mechanics were also exposed to chemicals while they performed UEO flushing. This was due to the position of the mechanics lying on contaminated floors to perform this task.

Figures 2A and 2B depict the patterns and pathways of dermal exposure in the context of repair and maintenance of vehicles tasks. The analysis of actual dermal exposure between the hands and the rest of the body revealed that the hands exhibited a higher level of exposure compared with other body parts. This heightened exposure was mostly attributed to the immersion of hands during cleaning and UEO flushing which was identified as the most significant pathway (see Figure 2A).

Only 14.8% of spray painters wore latex gloves and 4.7% of mechanics wore woven gloves. These types of gloves and their effectiveness were such that protection was scored as minimal in the DREAM method ($O_{HA} = 0.86 - 1$, see 2A). Neither spray painters nor mechanics wore full protective clothing (long coveralls or a Tyvek suit) while performing the task since they typically wore short-sleeved cotton shirts and long trousers for their day jobs. Therefore, clothing and protective clothing eliminated 60% of the dermal exposure ($O_{BP} = 0.40 - 0.41$, see Figure 2B).

For spraying, the main route of exposure for the hands and rest of the body appeared to be deposition followed by emission exposure. Different patterns were seen for dermal exposure during the cleaning of spray guns, engine parts, and UEO flushing. Emission was the most important route of exposure for the hands, but a considerable contribution through transfer was also noted.

DISCUSSION

Socio-demographic characteristics

Mechanics and spray painters were found to be male-dominated occupations. All (100%) of the 247 MVR workers were men. This finding can be expected since most of the studies conducted in the motor vehicle repair sector indicate that the large majority of respondents were males. This was not surprising considering the physically demanding and strenuous nature of the job, which discourages female participation^{30,37,38}. The majority of these men were young; in this study, 63.2% of the MVR workers were below the age of 34 years³⁹. More than 80% of them were Malaysian. This differed substantially from previous research in Saudi Arabia, which reported that more than 65% of its respondents were expatriates from other countries such as Pakistan, India, Bangladesh, Yemen, and Turkey^{40,41}.

In terms of education level, most spray painters and mechanics had completed their tertiary education, possessing either a technical certificate or a diploma. Malaysia has introduced Technical and Vocational Education and Training (TVET) to provide highly skilled human resources, and practical abilities are viewed as an important aspect of a technician's profile in the automotive sector^{42,43}. This situation differs from that found in a study in Nigeria, where more than 50% of the mechanics had secondary education; and 49.4% of car repair workers in Egypt were primary school educated^{17,39}. This study included 247 independent workshops that represented small and medium enterprises (SMEs). This was consistent with the work undertaken in the United States⁴⁴, Saudi Arabia⁴⁵ and Thailand⁴⁶, where the focus of their research for this industry was on small-scale businesses.

Actual dermal exposure

MVR workers working in automobile workshops are at risk of having skin contact with organic solvents, oils, and greases during maintenance and repair activities⁴⁷. Although there are various substances that this occupation group are exposed to via inhalation, the skin, and ingestion, the dermal route has been proven to be the route for the uptake of solvents and PAHs^{7,9,48-52}. The results of this study showed a high to moderate ranking of actual dermal exposure for both organic solvents and PAHs during maintenance and repair tasks.

In this study, the mechanics who performed UEO flushing and engine parts cleaning recorded a moderate ranking of actual dermal exposure. The findings are consistent with a study in Iran where dermal exposure of car mechanics (44.64 ± 31.81 DU), transmission technicians (44.85 ± 24.53 DU), and motorcycle mechanics (36.10 ± 27.39 DU) to PAHs were found to be of moderate ranking⁵³. Another country conducted similar studies to measure dermal exposure to PAHs in bitumen

production, which also recorded moderate rankings among the caldron users and building material workers, at 44.04 ± 20.82 DU and 39.97 ± 23.10 DU, respectively ⁵⁴. However, a study conducted to estimate dermal exposure to heavy fuel oils (HFO) in oil refineries and power stations

that also contain PAHs revealed relatively low rankings of actual dermal exposure ($0.1 - 0.5$ DU/cm²) ⁵⁵. The low dermal exposure levels to HFO are most likely related to the nature of the HFO, which needs to be heated during storage, transport, and usage.

Table 3: Actual Dermal Exposure According to Tasks among Spray Painters

DREAM Category (DU) (Spray Painters)	Spray Painting (n = 81)	Spray Gun Cleaning (n = 81)	p-value
	SkinW-A _{Task} n, (%)	SkinW-A _{Task} n, (%)	
Very Low (0 - 0.99)	-	-	
Low (10 - 29.99)	-	-	
Moderate (30 - 99.99)	21 (25.9)	81 (100)	
High (100 - 299.99)	60 (74.1)	-	
Very High (300 - 999.99)	-	-	
Extremely High (> 1000)	-	-	
Actual Dermal Exposure (SkinW-A _{Task}) DU, Mean $\pm$ SD	105.70 $\pm$ 11.92	46.32 $\pm$ 1.93	< 0.01 ^a
Emission DU, Mean $\pm$ SD	89.63 $\pm$ 11.89	114.40 $\pm$ 42.24	
Deposition DU, Mean $\pm$ SD	248.46 $\pm$ 19.49	0.00 $\pm$ 0.01	< 0.01 ^a
Transfer DU, Mean $\pm$ SD	8.49 $\pm$ 0.66	13.80 $\pm$ 2.24	
Position: Spray painters	76.01 $\pm$ 30.97		< 0.01 ^b

^aOne-Way ANOVA test

^bIndependent t-test

Table 4: Actual Dermal Exposure According to Tasks among Mechanics

DREAM Category (DU) (Mechanics)	Used Engine Oil Flushing (n = 41)	Engine Parts Cleaning (n = 44)	p-value
	SkinW-A _{Task} n, (%)	SkinW-A _{Task} n, (%)	
Very Low (0 - 0.99)	-	-	
Low (10 - 29.99)	-	-	
Moderate (30 - 99.99)	41 (100)	44 (100)	
High (100 - 299.99)	-	-	
Very High (300 - 999.99)	-	-	
Extremely High (> 1000)	-	-	
Actual Dermal Exposure (SkinW-A _{Task}) DU, Mean $\pm$ SD	61.93 $\pm$ 2.05	69.11 $\pm$ 5.14	< 0.01 ^a
Emission DU, Mean $\pm$ SD	97.97 $\pm$ 3.26	89.33 $\pm$ 7.03	
Deposition DU, Mean $\pm$ SD	0.00 $\pm$ 0.01	0.00 $\pm$ 0.01	< 0.01 ^a
Transfer DU, Mean $\pm$ SD	38.36 $\pm$ 0.81	75.10 $\pm$ 11.01	
Position: Mechanics	65.13 $\pm$ 5.02		< 0.01 ^b

^aOne-Way ANOVA test

^bIndependent t-test

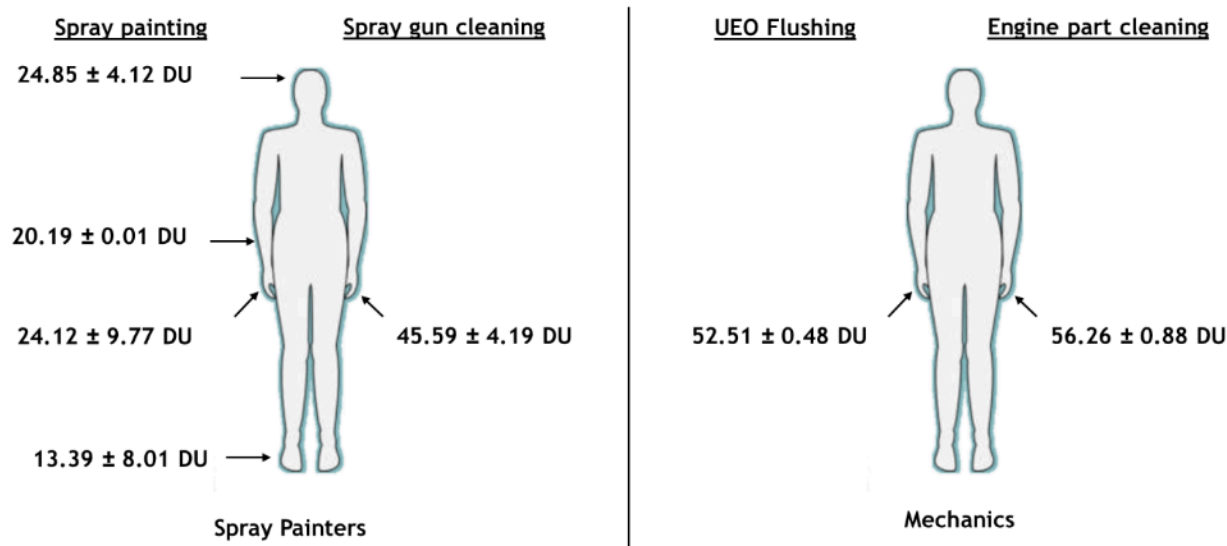


Figure 1: Actual dermal exposure for body parts

In addition, spray painting tasks in this study were found to have high to moderate rankings. Spray painters in the automobile industry in the United States have recorded potential dermal exposures of 17.0 ± 1.4 DU for the hands, and 19.0 ± 1.4 DU for the upper legs. Meanwhile, the actual dermal exposure was 0.06 ± 9.9 DU for the hands and 0.04 ± 17.6 DU for the upper legs⁵⁶. However, the results did not reflect the original DREAM estimates because modification of the DREAM algorithm has been tailored for comparison with quantitative assessment, and more specific DREAM estimates by using the actual concentration of active ingredient expressed as a percentage of weight-weight. Therefore, studies on the spraying of pesticides have been referred to. Likewise, the findings revealed moderate to high DREAM rankings among manual pesticide sprayers³⁵.

This study also estimated actual dermal exposure for nine body parts. The findings from this study revealed that the hands and wrists were the most exposed body parts in spray gun cleaning, UEO flushing, and engine parts cleaning. These findings were similar to those of a study conducted in Iran, which found that gearbox mechanics had the highest potential and actual exposure in the hands region⁵³. However, a study conducted in Taiwan among shipyard painters carried out dermal exposure assessments using a charcoal cloth patch to measure xylene and ethylbenzene, with the highest concentrations found on the upper legs⁵⁷. This was contrary to the findings in this study, where the hands and upper body of spray painters were the most exposed body parts. This is possibly due to the overspray generated by the spray painting process, where the overspray creates an opportunity for dermal exposure to the neck and face^{26,44}. Spray painting in an enclosed area such as in a spray booth also increases overspray conditions. This situation has been confirmed,

where the mean concentration of dermal exposure to xylene and ethylbenzene across the different body regions inside the ship blocks was significantly higher than those outside the ship blocks ($p < 0.05$)⁵⁷.

Previous studies have been conducted to model dermal exposure among spray painters, taking into account the factors that may influence deposition^{26,58}. In terms of exposure routes, deposition has been identified as the main route among spray painters. This was similar to a study conducted among shipyard painters, where they did not wash their skin with solvents and the source of the dermal contact was discovered to be the accumulation of paint aerosol on the skin and the uptake of solvent vapour⁵⁷. Other studies in the agricultural sector, which looked at Malaysia's pesticide spraying in rice fields also revealed the highest levels of pesticide exposure were by deposition (144.31 ± 30.23 DU), especially on the upper body⁵⁹. Meanwhile, cleaning tasks and UEO flushing recorded the highest emission through the dermal exposure route. This was because these tasks involved the handling of objects immersed in liquid which could splash onto body parts. Similar studies in Iran revealed the highest was emission exposure (31.97 ± 27.28 DU) followed by transfer (8.79 ± 6.3 DU) observed in gearbox mechanics⁶⁰.

Overall, this study has found that actual dermal exposures were higher for spray painters compared with mechanics, with the presence of three exposure routes: emission, deposition, and transfer. Mechanics were observed not to have any deposition exposure routes. Hands were identified to be the most exposed body part among the nine body parts. However, both occupation groups were still at risk of exposure to chemicals that could adversely affect their health if no proper control measures were taken.

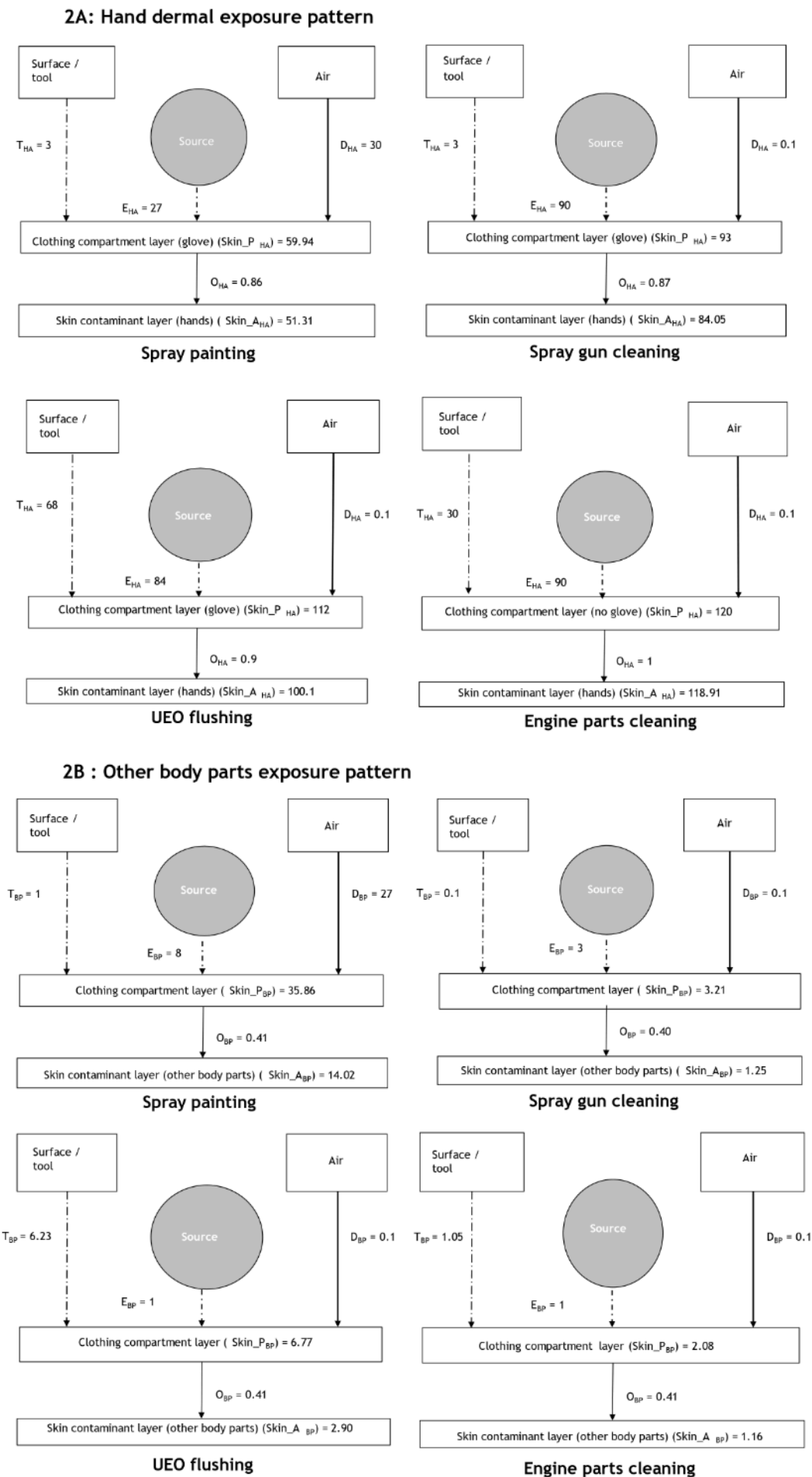


Figure 2: Hands and other body parts dermal exposure patterns

Limitations

The study used a modified self-report questionnaire, which may introduce bias or underestimation. To obtain more comprehensive data, clinical examination, inhalation exposure assessment, and biological monitoring of exposure are recommended in future studies. In addition, limited data were available for this occupation group in Malaysia. This study focused on spray painting without considering additional variables such as painting activities, paint-solvent combinations, spray gun design, engineering control measures, and employee posture. Therefore, the DREAM method did not incorporate these components in its assessment. The sample was primarily Malay, limiting the scope for further investigation. The inclusion of individuals from diverse racial backgrounds as respondents allows for the observation of distinct practices, technologies, and prevalence studies. The lack of a control group may also contribute to uncertainties. Hence the scope of further investigation and comparison has been constrained.

CONCLUSION

This study aimed to conduct dermal exposure assessments through DREAM among MVR workers exposed to organic solvents and PAHs. In conclusion, dermal exposure was higher among spray painters than among mechanics. Deposition was the main route of exposure among spray painters, followed by emission and transfer. Meanwhile, for mechanics, the main route of exposure was emission, followed by transfer. Deposition did not occur in UEO flushing and cleaning of engine parts. The main route of exposure for the hands was emission for cleaning and motor oil changing tasks. Meanwhile, the main route for other body parts was deposition in spray painting, followed by transfer in UEO flushing. Clothing protection factors for hands and body parts scored minimally. Therefore, the findings of this study add to the comprehension and awareness of exposure assessment, allowing for the development of intervention strategies that prioritise exposure route reductions.

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Conflict of interest

The authors declare no potential conflict of interest.

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