Solvent Exposure Characterisation in the Collision Repair Industry in New Zealand.

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ABSTRACT

Background: Reviews of solvent exposure and neurotoxicity have identified the need for improved understanding of the characteristics of exposure in industries where workers are exposed to solvents (WHO 1985, Baker 1988, Mikkelson 1996, Meyer-Baron 2008).

Subjects and Methods: This exposure assessment study was conducted in 16 collision repair workshops in the Wellington region of New Zealand, and included 100 air samples from 77 workers in 16 workshops and 76 urine samples from 18 workers. Air was analysed using gas chromatography for solvents and urine was analysed for hippuric acid, metabolite of toluene. Regression analyses were performed and an exposure model was defined.

Results: The highly statistically significant multivariate exposure model with an R square value of .77 was able to explain almost 80% of the variance in the personal air exposure data. Significant associations between personal air solvent exposure and workshop ventilation characteristics were found: Gunwasher if placed in the workshop area without separate ventilation had a coefficient of 2.19 (1.34-3.59) and mixing room ventilation if floor level and away from the main mixing bench had a coefficient of 3.06 (1.51-6.19) compared with the reference category. Urine analysis did not show a statistically significant association with personal toluene or glove use.

Conclusions: Workshop ventilation characteristics have a significant impact on individual exposures. Recommendations can be given to industry to help lower exposures and results can feed into the neurobehavioural study to aid exposure characterisation in this population. This study has shown that exposure characterisation using statistical methods is a plausible and useful way to assess relative weight across a spectrum of exposure sources, and to identify areas for effective intervention.

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Contents

1.1	**Introduction**	1
1.2	**The solvents and spray painters study**	3
1.3	**Masters project**	3
1.4	**Rationale**	4
1.5	**Collision Repair in New Zealand**	4
2	**LITERATURE REVIEW**	6
2.1	**Industrial solvents**	6
2.2	**Solvent use in collision repair**	7
2.3	**Occupational solvent epidemiology – overview**	8
2.4	**Toxic Solvent Encephalopathy in New Zealand**	14
2.5	**Differences between clinical and epidemiological approaches to chronic solvent encephalopathy**	16
2.6	**Selection bias and the Healthy Worker Effect**	17
2.7	**Confounding**	21
2.8	**Solvents and other health effects**	22
2.9	**Exposure assessment – air monitoring**	24
2.10	**Biomonitoring for solvents using urine**	39
3	**METHODS**	43
3.1	**Recruitment**	43
3.2	**Workshop assessment**	44

3.3	**Air sampling**	44
3.3.1	**Switches**	45
3.3.2	**Canisters**	46
3.3.3	**Sample trains**	46
3.3.4	**Air sampling tubes**	47
3.3.5	**Sampling belts**	48
3.4	**Cleaning protocol**	48
3.4.1	**Cleaning canisters**	48
3.4.2	**Cleaning sample trains and sampling tubes**	49
3.5	**Air sample analysis**	49
3.5.1	**Solvent panel**	50
3.5.2	**Laboratory and field blanks**	38
3.6	**Urine sampling protocol**	51
3.7	**Urine analysis**	52
3.7.1	**Sample handling**	52
3.7.2	**Urine protein microassay**	53
3.7.3	**Hippuric acid microassay**	54
3.8	**Statistical analysis**	55
3.9	**Statistical analysis of urine results**	56
3.10	**Video exposure monitoring**	56
4	**RESULTS**	58
4.1	**Workshop and worker general characteristics**	58

4.2	**Personal Air Sample Population**	61
4.3	**Use of Personal Protective Equipment**	67
4.4	**Ambient Air**	69
4.5	**Video Exposure Monitoring**	71
4.6	**Statistical analysis of personal air exposure**	77
4.7	**Urine sampling results**	78
5	**DISCUSSION**	83
5.1	**Peak Exposures**	95
5.2	**Biological exposure assessment**	96
5.3	**Industry recommendations**	96
5.5	**Research recommendations**	97
5.6	**Conclusions**	99
6	**REFERENCES**	100
7	**APPENDICES**	110
7.1.1	**Contents as reported in Material Safety Data Sheets (PPG)**	110
7.1.2	**Contents as reported in Material Safety Data Sheets (Dupont)**	118
7.2	**Table 17 Univariate analyses of painters and apprentices & Table 18 Multivariate analysis of painters and apprentices**	134
7.3	**Participant information sheet**	137
7.4	**Workshop assessment record sheet**	139
7.5	**Air sampling record sheet**	142

List of tables and illustrations

Table 1	**List of solvents reported in collision repair workshops**	28
Table2	**Comparison of personal air solvents**	29
Table 3	**Neurobehavioural studies in collision repair workers**	33
Table 4	**Exposure assessment studies in collision repair workshops**	36
Table 5	**Workshop characteristics**	59
Table 6	**Personal air descriptive statistics**	61
Table 7	**Mean number of minutes spent on tasks**	63
Table 8	**Mean individual solvents and job title**	64
Table 9	**Exposure characteristics with mean summed personal solvents**	66
Table 10	**Use of protective equipment by task.**	69
Table 11	**Mean Ambient solvents**	70
Table 12	**Univariate analysis of summed solvents**	73
Table 13	**Multivariate model**	76
Table 14	**Urine results stratified by job title**	79
Table 15	**Mean personal toluene by hipppuric acid at 2-4pm**	80
Table 16	**Mean hippuric acid with glove use category**	81

Figure 1	**Toluene and Xylene measured in epidemiological studies of collision repair painters**	30
Figure 2	**Mean individual solvents and job title**	65
Figure 3	**Hippuric acid by job title and time**	79
Figure 4	**2-4pm hippuric acid against toluene with regression line fitted**	80
Figure 5	**Hippuric acid by glove use.**	81
Figure 6	**Comparative levels of toluene and xylene in epidemiological studies of collision repair workshops.**	90

1.1 Introduction

Evidence suggests that chronic exposure to solvents can lead to neurological damage which may become irreversible. (Dick 2006, WHO 1985, OSH 1992). Neurodegenerative illnesses, in general, are amongst the top ten causes of death in the US (Murphy 2013). In 2010 Neurodegenerative illnesses were estimated to cost the European Union 800 billion Euro, this figure includes direct healthcare costs and loss of productivity estimates (Gustavsson 2011). The aging population means that these costs will continue to rise in coming years. As yet there is no cure and no known etiology for many neurodegenerative illnesses (Brown 2005). One third of the chemicals recognised as toxic by the American Conference of Governmental Industrial Hygienists (ACGIH) affect neurological health (Anger 1984), and of those neurotoxic chemicals, one quarter are organic solvents (White and Proctor 1985). Solvent exposure has been linked with degenerative disorders of the nervous system including, Essential Tremor, Chronic Solvent Encephalopathy, Parkinson's Disease, Alzheimer's Disease, Motor Neurone Disease, Dementia and Multiple Sclerosis. However results in all these areas of research are conflicting (Dick 2006, Brown 2005). The difficulty of comparing studies of solvent exposed populations, because of a lack of detailed information about exposures has been raised by reviewers (WHO 1985, Meyer-Baron 2008) and the importance of accurate and complete exposure assessment has been identified as a priority in all

epidemiologic research into neurotoxic illness. (WHO 1985, Mikkelsen 1997, Brown 2006, Meyer-Baron 2008).

This master's thesis presents the background for, methods and results of this student's exposure measurement programme to assess solvent exposure in the collision repair industry. Section one gives the background and aims for the thesis. Section two reviews the literature on occupational solvents and chronic solvent neurotoxicity, giving an overview of the chronic occupational solvent and neurological effects epidemiology, followed by an analysis of problems and issues for study design, and finally an in depth investigation of epidemiological studies in collision repair workshops. Section three describes the materials, methods and participants. Section four presents results and section five is the discussion and conclusions, including recommendations. References are listed alphabetically in section six and appendices are in section seven.

1.2 The solvents and spray painters study

This master's project has been conducted as part of a larger Health Research Council funded cross-sectional study, looking at risk of neurological damage due to chronic solvent exposure. The larger study aims to conduct interviews with 400 spray painters and panel beaters in the New Zealand collision repair

industry and 400 carpenters and construction worker controls. The interviewing process includes a screening test for neurobehavioural deficits, the results of which will feed into a nested case-control study on the same risk and exposure. This case control part of the study will involve neurobehavioural testing of 70 collision repair painters with symptoms, and 70 controls.

1.3 Master's project

The exposure assessment conducted in this master's project will make a detailed assessment of exposure in a subset of those 400 collision repair subjects.

Aims

1. To assess exposure to solvents in employees of a sample of the collision repair industry using air and urine sampling.
2. To make detailed assessments of workshop facilities and practices, and quantify differences in order to identify risk factors for higher exposure.
3. To develop recommendations for the industry in how to minimise solvent exposure risks.

1.4 Rationale

When an association exists between an exposure and a health impact, steps need to be taken to identify specifically the factors leading to the extent of exposure so that preventative measures can be taken. Occupational hygeine methods can be used to this end, by identifying a spectrum of potential exposure pathways, and assessing the exposure environment for these pathways. Statistical analyses can be used to assess the strength of association for all the potential causal pathways, and from this a multivariate regression model can be used to "model" exposures and assess their relative importance. Previous research conducted by the author on house characteristics and dampness measurements used the described method to build an exposure model that accounted for between 18 and 42% of the variance in the exposures data, despite the fact that the data was not designed for this purpose, so a number of important exposure pathways were not available in the data (eg. number of inhabitants).

1.5 Collision repair in New Zealand

The New Zealand yellow pages lists 870 collision repair businesses and 1713 people listed their occupation as vehicle painter in the 2006 census, while a

further 3375 listed their occupation as panel beater. These individuals are all working in environments that manage solvent exposure in different ways, because of each workshop's different physical characteristics, and because of different work practices in workshops. New Zealand Health and Safety regulations on solvents in the workplace are not prescriptive, and are recommendations only with the legal requirements only to "take all practicable steps" to ensure the safety of workers (NZ Health and Safety in Employment Act 2002). This approach can lead to a wide array of approaches to managing hazardous chemicals in the atmosphere of the workplace. Further, while employers are required to provide personal protective equipment (PPE), workers are not legally required to wear it. Any information that can be gained into the specific pathways for exposure in such occupational settings will be a valuable tool for minimising toxic health effects caused by industrial chemicals, specifically solvents, in these workplaces.

2 LITERATURE REVIEW

2.1 Industrial solvents

The term solvent denotes any chemical which is liquid under the conditions of application and in which other substances can be dissolved without reacting chemically, allowing said substance to be recovered unchanged (Marcus 1998). This property makes solvents ideal for use in the application of paints and laquers; toluene, xylene, styrene and acetone being some of the most common. Typically solvents are highly volatile under normal atmospheric conditions, meaning they evaporate quickly. This capacity combined with their lipophilic nature also makes solvents ideal cleaners. A variety of solvents are used in domestic (ethanol, toluene, trichloroethylene) and commercial cleaning products (tetrachloroethylene,). These and other solvents are used to clean machinery and metal parts, hence their wide use in the motor mechanic trade (hexane, xylene, benzene) Many solvents are central nervous system (CNS) depressants at relatively low levels, hence the use of solvents as anaesthetics (ethyl ether, cyclopropane, halothane, trichloroethylene), in alcoholic beverages (ethanol) and as drugs of abuse, used for sniffing or “huffing” (toluene, acetone). Solvents are generally highly flammable, hence their use as fuels (methanol, gasoline). There are hundreds of solvents in everyday use in industry and in

domestic life, and solvents are ubiquitous in our environment. Toluene, for example, has been measured at levels of 1.3, 10.08 and 31.5 µg/m³ in rural, urban and domestic indoor ambient air respectively. (Agency for toxic substances and disease registry, 1994)

2.2 Solvent use in collision repair

Solvents are used in large quantities in the collision repair industry, primarily for thinning paint to a consistency ideal for spraying with a compressed air spray gun and for cleaning paint equipment. Solvents are invariably used as commercial products which include a mixture of solvents, therefore collision repair solvent exposure is always to mixed solvents. For examples of the contents of some products commonly used in New Zealand's collision repair industry, refer to Appendix 7.1.

In the New Zealand setting, each spray painter will typically use between half a litre and several litres of solvent per day for these purposes. The highly volatile nature of solvents is both what makes them so useful and potentially dangerous. Solvent evaporates rapidly out of paint, allowing several cars to be painted and dried consecutively each day. While water-based paints have been introduced by most of the larger paint producers, their use involves more work, time and cost to dry, and they do not eliminate the need for solvents altogether, as clear-

coats, the ubiquitous top-coat for every car painting job, have yet to be produced in water-based versions. Water-based paints do reduce the use of solvents by around 50% in workshops which use primarily water-based systems. However, this does not necessarily lead to a 50% reduction is exposure, as the solvent that is still present in the gunwashing and mixing equipment used of rthe solvent based lacquer coat often evaporates to a similar level of air saturation in the paint mixing room as is present in the typical workshop using a solvent-based paint system. Therefore, although the painter may be mixing water-based colour, they are still likely to be exposed to a significant level of solvent in the air throughout the process, and especially in the mixing room where open paint containers and gunwashing equipment provide constant point sources of solvent evaporation. Furthermore, it is possible that use of water-based systems may in some instances engender a complacency that could erode the benefit of less solvent use. Health risks of solvents include neurodegenerative illness, ocular degeneration, multiple chemical sensitivity and cancer.

2.3 Occupational solvent epidemiology – overview

The neurotoxic potential of solvents was first suspected in the mid nineteenth century, after Parisian physician, Auguste Delpech reported observations of workers in a rubber factory, using carbon disulphide to soften rubber for

spreading (Delpeche 1856). However, until the 1970s it was assumed that the effects were acute only, and there were no ongoing health effects once exposure to solvents was ended (Browning 1953). On the basis of this assumption; that solvents posed a health risk only for acute effects, the 1950s and 60s saw most industrial nations adopt regulations requiring workplaces to install air extraction in situations where solvent exposure was likely (Spurgeon 2006). This included the collision repair industry. New Zealand regulations for the installation of ventilation and the use of personal protective equipment (PPE) in the collision repair industry were introduced in 1962. (NZ Dept. Labour, 1962), these regulations have been reviewed in 1986, but remain essentially unchanged.

The association between chronic, low-level occupational solvent exposure and neurological health effects, was first put forward by Finnish researcher Helena Hanninnen (Hanninen 1971) who had conducted epidemiological research in a viscose factory where carbon disulphide was used. The study compared 50 unexposed workers, 50 exposed who had been diagnosed with carbon disulphide poisoning, and a further 50 exposed but healthy workers. Adapting highly sensitive clinical tests of psychological and psychomotor functioning, the team compared the three groups and found that the exposed but healthy workers showed symptoms of “neurasthenic syndrome accompanied by depression” characterised by depressive mood, fatigue, slight motor

disturbances and intellectual impairment which had not been previously identified in an epidemiological study. The authors concluded that this syndrome was likely to be common in solvent exposed populations.

Over the two decades following this report, cross sectional studies were conducted in various industries using high levels of solvents, such as collision repair (Hanninen 1976, Seppalainen 1978, Elofsson 1980, Daniell 1992), house painting (Hane 1977, Baker 1988, Hooisma 1993), industrial painters (Cherry 1985, Fidler 1987, Triebig 1992, Kishi 1993), floor laying (Ekberg 1986), printing factories (Maizlish 1985, Antti-Poika 1985) and paint manufacturing (Bolla 1990, Bleecker 1991, Wang 1993, Spurgeon 1994) with varied results. Some of these studies also found memory, nervous system or mood dysfunction (Hanninen 1976, Hane 1977, Seppalainen 1978, Elofsson 1980, Fidler 1987, Baker 1988, Bolla 1990, Bleeker 1991, Daniell 1992, Kishi 1993, Wang 1993). But many others found no neurobehavioural deficits which they could ascribe to chronic low-level exposure to solvents (Maizlish 1985, Antti-Poika 1985, Ekberg 1986, Triebig 1992, Hooisma 1993, Spurgeon 1994)

Case-control and retrospective cohort studies were conducted to assess the neurodegenerative effects of solvents in those who had left work involving solvent exposure (Axelson 1976, Husman 1980 Lindstrom 1984, Riise 1995, O'Flynn 1987, Mikkelson 1988, Cherry 1992, Rasmussen 1993). Again some of

these studies found increased rates of psychological disability in solvent exposed groups (Axelson 1976, Lindstrom 1984, Mikkelson 1988, Rasmusssen 1993, Riise 1995), while others found no association (O'Flynn 1987, Cherry 1992).

The World Health Organisation with the Council of Nordic Ministers convened in 1985 to officially recognise, and present diagnostic criteria for Chronic Solvent Encephalopathy (WHO 1985). The New Zealand Government recognises this diagnosis of CSE set out by the WHO, which describes 3 stages of chronic toxic encephalopathy. It is accepted that at least 5-10 years of chronic exposure to industrial solvents precede the onset of symptoms for a diagnosis of chronic solvent encephalopathy (White 1997, WHO 1985).

Type 1 (diagnosis: Organic affective disorder) is characterised by memory impairment, fatigue, irritability and difficulty in concentrating (OSH 1992). This level of the illness may be associated with slightly slowed reaction times with normal EEG (electroencephalography), and is completely reversible on withdrawal from exposure. On continued exposure, this may develop into Type 2 (diagnosis: Mild toxic encephalopathy) involving sustained personality or mood change (Type 2a), and intellectual impairment (Type 2b). At this stage of the disease there may be abnormal (slowed) EEG readings, and the illness is reversible, to a varying degree, on withdrawal from exposure. The most severe level of this illness, Type 3, involves global deterioration of intellectual and

memory functions (dementia). (diagnosis: Chronic solvent encephalopathy). This stage will generally involve slow EEG readings, and is irreversible.

The 1985 World Health Organisation report emphasised the difficulty of comparing studies because of different definitions of syndromes and disorders and different methods of exposure assessment, while recognising that difficulty also lay in the fact that solvent effects are non-specific (present differently in different individuals). The meeting called for further epidemiological research to be conducted and set out diagnostic criteria to aid researchers and clinicians.

Several prospective cohort studies have aimed to assess changes in neurological and psychological functioning due to chronic solvent exposure (Gregerson 1988, Williamson 1992, Ihrig 2005, Dick 2010). Results of studies by Gregerson et al and Ihrig et al were affected by reported exposure decreasing over the follow-up period. The Gregerson et al study was questionnaire based and found increased memory and concentration impairment for the exposed group at 5.5 and 10.6 years of follow up and no such increase for unexposed. Ihrig et al who measured solvents twice, two years apart, found no deterioration of subjects' psychological functioning, however an increase in subjective symptoms was observed. Solvent exposure measurements reported by Ihrig et al, showed exposure at the second examination was approximately half of what had been measured the first time. Williamson & Winder 1992, recruited 200 apprentices

in their first year of study as collision repair spray painters, and took exposure measurements. Unfortunately no results after 3 years of follow-up were reported, so none of the participants achieved the accepted exposure period of 5 years to be considered as having had chronic exposure. More recently Dick et al 2010, conducted a retrospective analysis using a prospective cohort study on mental health which started in 1947. The participants were all 67 years of age and had their solvent exposure estimated by industrial hygienists who were blind to their psychological functioning. Dick et al found significantly poorer psychomotor and memory functioning in those assigned to the exposed group compared with the non exposed group.

Authors conducting literature reviews have come to different conclusions after reviewing the literature on solvents and neurotoxicity. Baker 1994 reviewed solvent induced neurological effects literature published after the WHO meeting of 1985 till 1993, concluding that the findings from cross-sectional studies were consistent in finding poorer psychological performance in exposed workers and that most studies showed dose-response relationships with exposure indexes. Most of these deficits were in memory function and attentional and behavioural aspects which were sometimes self-assessed using questionnaires. Juntunen 1993 also reviewed the literature and concluded that substantial evidence supported a diffuse spectrum of subclinical and clinical neurobehavioural effects for which susceptibility was an important factor. Mikkelson 1997 also reviewed

occupational solvent and CNS function literature reporting that the cumulative evidence suggested that neurobehavioral impairment was possible at exposure levels below accepted threshold limit values. Ridgeway et al 2003 reviewed only literature and results pertaining to quantitative neurobehavioural testing and brain imaging, and also reviewed literature from animal studies. They concluded that differences between exposed and unexposed were weak and inconsistent, and that animal studies did not support chronic effects on central or peripheral nervous system functioning. Meyer Baron et al 2008 conducted a meta-analysis of solvent related research and found significant negative effect measures in 12 areas of testing across attention, memory, psychomotor speed and perception. The authors noted inconsistent dose-response patterns and emphasized the difficulty of comparing populations with unknown differences in solvent exposure levels, calling for more detailed exposure assessment. This group also discussed confounding and suggested that poor reporting on important confounders such as age and alcohol intake meant that effect measures could not be validly assessed.

2.4 Toxic Solvent Encephalopathy in New Zealand

New Zealand's Occupational Health Service (OSH), currently a division of the Ministry for Business Innovation and Employment, distributed diagnostic criteria

for chronic solvent encephalopathy to medical practitioners throughout New Zealand in 1992, along with a standardised diagnostic test battery (Dryson & Ogden 1992)

Between 1993 and 1997, 193 cases of chronic solvent encephalopathy were notified to OSH, of which 76 were later verified (Dryson 1998) by a solvent neurotoxicity panel, consisting of an occupational physician, a neurologist and a neurosychologist. Of those 76 verified cases, 14 were classified as type 1 and 62 as type 2. There were no type 3 verified cases. Of the verified type 2 cases, 39% (25) were spray painters, 16% printers (10) and 9% boat builders (6 cases). The remainder of the cases came from a variety of occupations including 2 drycleaners, 2 furniture finishers, 2 house painters and 1 panel beater.

There is little other literature available on the subject of occupational neurotoxicity of solvents in New Zealand. The New Zealand disease notification system states that all diagnoses of "poisoning arising from chemical contamination of the environment" must be reported to the health authorities (Medical Officer of Health). However as CSE is a progressive illness which is not easily diagnosed (a diagnosis must be verified by a solvent panel as described above and CSE diagnosis is likely to be excluded if patient reports a history of head trauma, depression or alcoholism (van der Hoek et al 2000, van Valen

2012)), and CSE is likely even to be present in workers who are themselves unaware, (see below) there will undoubtedly be many unnotified cases.

2.5 Differences between clinical and epidemiological approaches to chronic solvent encephalopathy

Chronic solvent encephalopathy remains somewhat controversial. From the clinical perspective CSE is not straightforward. Firstly it is dissimilar to other neurological illnesses, which generally have much clearer disease progression and are more similar from one individual to another (Berent 2009). Secondly, in using psycological tests of neurological functioning, very few studies have shown that any one individual has undergone degenerative change, and animal studies do not support chronic low-level neurotoxicity (Ridgway 2003). Thirdly, brain imaging and EEG techniques in epidemiological research do not generally show significant differences between exposed and unexposed (Baker 1994, Mikkelson 1988). And fourthly, all of the symptoms used to diagnose CSE can be caused by other illnesses, such as depression, head trauma and alcoholism, and also by aging, or from acute exposure to solvents (Berent 2009, Ridgway 2003, Meyer-Baron 2008).

One difference between the clinical and epidemiological perspectives is in the definition of what a healthy range of behaviour is. Many of the results of epidemiological studies that have been used as evidence of functional deficit, would be considered within the normal range by a clinician (Juntunen 1993, Berent 2009).

While a clinical approach is designed to distinguish individuals in need of medical help from those who do not need medical intervention, the epidemiological approach is designed to assess whether any factors (such as occupational exposures) are having a negative effect on the population's health.

2.6 Selection bias and the Healthy Worker Effect

The healthy worker effect is a form of bias that has shown that working populations in general are more healthy overall than a random sample selected from the general population (Rothman 2012). Studies of solvent exposed workers have shown evidence of one form of bias which contributes to this effect; self-selection, whereby "sensitive" individuals leave solvent exposed jobs. Husman et al, 1980 explored the healthy worker effect and self selection in the collision repair industry in Finland. The group sent out questionnaires to 124 individuals who had left work as collision repair painters. Of the 124

questionnaires sent out, 39 (31%) had gone on to a job with no solvent exposure, 26 of those workers cited their health, or the hazardous nature of the job among their reasons for leaving. Subjective psychological symptoms in these ex-painters were found to be slightly higher than painters who had not left the job. When symptoms of current painters were grouped by duration of exposure, there was an initial higher rate of symptom frequency in the 1-4 year duration group, followed by a lower frequency, rising again to the highest frequencies after 20 years exposure. The authors conclude that these two outcomes may both reflect solvent sensitive individuals withdrawing themselves from exposure. Winder & Turner 1992 reported that 17% of painting apprentices who dropped out of their study left the trade for health reasons, while none of the electrical apprentices who dropped out of the study left for health reasons.

Another source of selection bias is a poor response rate. An illustration of such bias is seen in the British study by Spurgeon and colleagues at a paint factory (Spurgeon 1994). The response rate for the paint makers was 43%. A questionnaire was given to non-participants, 50% of whom replied. Of that group 30% cited having no health concerns as a reason for non-participation in the study, and the researchers concluded that this "gave support to the view that any bias in the exposed population was likely to be of over representation of less healthy members thus increasing the likelihood of finding a positive relation between exposure to solvents and outcome methods" (which this study

did not find). However this conclusion disregards the fact that this type of occupational study is designed to pick up health effects in workers who are not obviously ill (White 1997). It is therefore questionable to attach any conclusion to the individual's self-report of health effects. Most importantly, a response rate this low means that any bias in the non-responders could impact effect measures calculated from this sample.

A further source of bias, that can affect the interpretation of epidemiological studies using neurobehavioural testing, is any difference in initial intelligence between the exposed and unexposed groups. Studies using other blue-collar trades have often found significant differences between exposed and unexposed groups in education level (Williamson 1993) or verbal intelligence (Hanninen 1978, Elofsson 1980, Spurgeon 1994, Bockelmann 2002)

These differences mean the findings need to be adjusted, but questions remain about suitable parameters for adjustment. Michelson & Lundberg 1996 showed that verbal intelligence, frequently used to adjust for differences in initial intelligence (Spurgeon 1994, Cherry 1985, Bockelmann 2002) can change over time and with exposure to solvents.

Epidemiological studies of the neurobehavioural effects of chronic solvent exposure have sometimes found high rates of self-reported and neurological

symptoms in the reference group (Hanninen 1976, Triebig 1989) when blue collar workers from other industries are used, which diminish the ability to draw conclusions from the results of the study. Hanninen used railway workers and Triebig used construction workers, electricians and mechanics. To address this effect, other studies have used reference groups from non-exposed workers from the same industry (Daniell 1992, Bleeker 1991)

One study attempting to address this issue of systematic bias due to differences between the exposed and unexposed populations was published by Hanninen et al in 1991. This study examined differences between 21 pairs of monozygotic twins – one twin exposed to lower occupational solvents (median lifetime exposure 20% of Finnish exposure limit values at the time of study), and the other exposed to higher lifetime exposure to solvents (median 40% of the same limit values). This study found poorer performance in psychiatric tests of memory and visuospatial intelligence and a dose-response pattern was shown for those twins with higher cumulative exposure. The effects were subtle and not statistically significant, however the mean difference (-1.6 for lower exposed and -2.2 for the higher exposed) between the pairs was large enough to suggest a real effect.

2.7 Confounding

Confounding, in epidemiological studies, occurs when exposed and unexposed populations differ in some variable that is unaccounted for in the data, but that is related to disease outcome (Pearce 2005). Any variable that is associated with the illness in question such as, in the case of neurodegenerative illness, age, head trauma, depression, and alcohol, could represent background differences in the exposed population that will become associated with exposure in analysis. Therefore these confounders must be measured along with exposures and outcomes so that they can be accounted for in analysis.

As alcohol is a solvent, it is possible that high levels of alcohol consumption could be causing the affects ascribed in studies to chronic occupational solvent exposure, as has been suggested by some researchers (Guberan 1989, Spurgeon 2001). Some studies have found solvent exposed populations to consume more alcohol than other blue-collar workers (Antti-Poika 1985, Fidler 1987).

Another possibility, however, is that the interaction between alcohol and solvent exposure causes higher rates of alcoholism or alcohol related illness without higher consumption rates. This idea was explored in a retrospective cohort study (Lundberg 1992) which found higher rates of alcoholism despite no evidence of higher consumption in a subset of the study population. A case-

control study, also published in 1992 by Cherry et al, likewise found an excess of solvent exposed individuals with organic brain disorder compared with other psychiatric disorders, this was particularly strong for exposed individuals with an associated diagnosis of alcoholism, while drinking habits were found to be similar in exposed and unexposed groups.

Depression can also cause many of the same symptoms as chronic solvent encephalopathy, such as poor concentration, slowed perceptual awareness and emotional lability (Berent 2009, Spurgeon 2006). Spurgeon 1994 measured job satisfaction as a potential confounder, but this issue has not been extensively explored.

2.8 Solvents and other health effects

There is no doubt that exposure to solvents including toluene and xylene at high levels can cause neurological damage and in particularly severe cases, death. (Berent and Albers 2009). N-hexane is established to have a causal link with peripheral neuropathy causing tremor and loss of motor control (Berent and Albers 2009). A number of specific solvents are established as cancer causing, including benzene and trichloroethylene. Occupation as painter, or occupational solvent exposure has also been associated with excess cancer, including lung

and bladder or kidney cancer, (Guberan, Rushton 2012), non-Hodgkins lymphoma and leukaemia (Cocco 2010) and multiple myeloma (Bethwaite 1990). Bethwaite et al, also found that car painters in New Zealand were particularly at risk of multiple myeloma compared with construction or house painters.

More recently epidemiological research has started to discover more health effects of solvents at relatively low levels including, toxic hepatitis which has been linked with exposure to toluene and xylene (Malaguearnera 2012), and cirrosis of the liver (Guberan 1989).

A prospective study of women occupationally exposed (79 exposed and 580 controls) to solvents during pregnancy found increased rates of birth defects, especially cleft palette and urinary tract or genital deformation, associated with exposure to glycol ethers and chlorinated solvents (Cordier 2012). Solvent exposure has also been linked to infertility and miscarriage (Attarchi 2012).

Occupational exposure to solvents has also been linked with colour vision degeneration (Costa 2012, Lee 2013) and evidence is building for a causal link to hearing loss (Fuente 2013).

2.9 Exposure assessment – air monitoring

In a study from Denmark, Olsen and Seedorf 1990, surveyed the industrial workforce to assess which industries were associated with solvent exposure. The survey identified 372 industrial processes with likely solvent exposure, and undertook quantitative measurements at a business representing each of these processes. The group found 48 individual solvents in their measurements. Ninety four percent of the processes involved solvent mixtures. Fifty percent of the measurements were 25% or less of the additive time-weighted exposure limits, (this is where each solvent measured is calculated as a proportion of the exposure limit for that solvent and all components of the mixture are summed, as advised by ACGIH) while 25% were above 1, meaning that exposure limits had been exceeded in those workplaces (Olsen & Seedorf 1990). Thirty three percent of spray painting processes measured were above 1, so exceeded the limit value, and 38% were 25% or less.

Calculating exposure indices is an important way for epidemiological studies to quantify exposures retrospectively, or to calculate cumulative exposure (Mikkelsen 1988, Meyer-Baron 2008). However solvents are generally used industrially in mixtures of three or more different solvents, (Olsen & Seedorf) and the profiles of these solvents may differ significantly from one industry to

another, or from one process to another. Elofsson et al 1980, showed that the exposure profile of solvent mixtures differed significantly for collision repair painters compared with industrial painters who painted machinery and industrial products. The investigators found higher levels of toluene and xylene in personal air of collision repair painters, but more trichloroethylene and trichloroethane in industrial painters' personal air. The industrial painters in their study spent a larger proportion of their time on tasks directly related to painting than the collision repair painters, however the collision repair painters had consistently higher total solvent exposure.

Elofsson et al, 1980, also recreated a car body repair workshop setting to simulate the spray painting workshop environment of 1955, and took exposure measurements in this simulated setting as well as in currently operating collision repair and industrial painting workshops. Exposures in the simulated 1955 workshop were still generally well below exposure limits of 1980, and exposure to solvents did not vary greatly from measurements taken in a functioning workshop, with mean total solvents reaching 0.4 of additive time weighted exposure limits during spray painting in the 1955 workshop, compared with 0.3 in the 1970s workshop and 0.25 of time weighted exposure limit during colour mixing, degreasing and cleaning compared with 0.27 for the same tasks in the 1970s.

Jayjock and Levin 1984, conducted repeat exposure measurements in a collision repair workshop over a one year period and concluded that the collision repair environment was characterized by relatively high, short-term exposures, meaning that although limit values based on a full shift were seldom exceeded, short-term limits frequently were. These authors also observed poor use of personal protective equipment, concluding that exposures could be significantly reduced by improved use of PPE.

Triebig et al, 1992, found significant differences in solvent measurements in collision repair workshops compared with other spray painting industries including wood and metal painting and container painting. The four container painting workshops in their exposure assessment survey had nil toluene, but high levels of ethyltoluene which was not detected in any of the other six workshops. Also xylene was measured at high levels in the container spraying group, exceeding the collision repair workshop levels by around 50 times.

Bratveit et al 2004, conducted a collision repair exposure assessment study in which their aim was to assess the difference in exposure to solvents between collision repair workshops using water-based paint systems, compared with the traditional solvent-based systems. Eight car repair workshops and 27 painters were assessed for exposure. Each painter was sampled for the full shift on 3 consecutive days (Monday-Wednesday) resulting in a total of 79 personal

samples. A statistically significant association between solvent paint and additive factor was seen in multiple regression analysis adjusting for number of spray painters per booth and time spent on job. The number of blood samples with toluene below detection limits of .005mg/l on Wednesday was 6 out of nine in water-based paint shops, and geometric mean toluene in blood was .007mg/l. In solvent-based paint shops the number of Wednesday post-shift samples below detection limits for toluene were 0 out of 17, and geometric mean of toluene in blood was 0.044mg/l.

Table 1 shows a comparison of different solvents measured in the collision repair industry

Table 1 List of solvents reported in collision repair workshops

Solvent	*Number of studies*	*Mean level (range)ppm*	*studies*
Toluene (methylbenzene)	11	6.6 (0.1-38.2)	all
Xylenes	11	3.1 (0.1-18.1)	all
Butyl acetate (isobutyl acetate, n-butyl acetate)	10	2.4 (0.006-11)	1, 2, 3, 5, 6, 7, 8, 9, 10,11
Ethyl benzene	6	2 (0.1-7.3)	3, 6, 7, 8, 9, 10, 11
Acetone (propanone)	6	5.7 (0.1-14.4)	1, 3, 5, 7, 8, 9
Methyl isobutyl ketone (Methyl n-butyl ketone, isobutyl methyl ketone)	6	1.3 (0.46-2)	1, 2, 5, 7, 9, 11
Ethyl acetate	6	1.4 (0.1-4.7)	1, 3, 5, 7, 8, 11
Ethanol (2-ethoxyethyl acetate)	5	4.5 (0.5-10)	1, 2, 5, 7, 10
Benzene	5	1 (0.003-4.1)	5, 6, 7, 10, 11
White spirit (turpentine, stoddart solvent) -Mix of aliphatic and aromatic C7-12, hydrocarbons, hexane and benzene)	4	6.2 (0.0004-17.9)	1, 2, 5, 8
Trimethylbenzene (mesitylene)	4	0 .9 (0.1-3.2)	5, 7, 9, 11
Methyl ethyl ketone (butanone)	4	4.2 (0.1-9)	2, 5, 7, 11
Styrene	3	1.3 (0.0005-3.8)	2, 8, 11
Methylene chloride (Dichloromethane)	3	5 (0.7-7.9)	2
Isopropanol (isopropyl alcohol)	3	1.3 (0.01-3.7)	1, 8, 9
Butanol (n-butanol, Butylalcohol)	3	1.3 (0.5-2)	2, 5, 7
Propyl acetate (isopropyl acetate)	2	1.1 (0.01-4.1)	7, 11
Aliphatics C4-7	2	6.1 (1.3-10.9)	5, 8
Trichloroethylene	2	0.5 (0.0004-1)	2, 11
Hexane	2	1 (0.9-1.1)	5, 7
Alpha pinene	1	0.001	6
2-Butoxyethanol	1	0.4	5
Ethylene chloride	1	3.5	7
Methyl acetate	1	14.2	7
2-Methoxyacetate (cellosolve acetate)	1	14.3	7
Diisobutyl ketone	1	0.01	9
Napthalene	1	0.5	11
Propyl benzene (cumene)	1	4.6	11
Propylene Glycol (1-Methoxy-2-propyl acetate)	1	1	11
Methyl tert-butyl ether	1	0.5	11

1-Hanninen; 2-Eloffson; 3-Triebig; 4-Daniell; 5-Williamson & Winder; 6-Bocklemann; 7-de Espigares & Medinilla 8-Moen & Hollund; 9-Bratveit; 10-Vitali; 11-Caro & Gallego

10 individual solvents have been measured by only one study group.

Looking at the means and ranges for those compounds measured by only 1 or 2 of the studies, we see the levels are not insignificant.

Table 2. Comparison of personal air solvents

		Number of solvents measured	Mean total solvents (ppm)
Hanninen et al 1976	(n=54)	9	61.3
Elofsson et al 1980 (painting)	(n=106)	12	62.3
de Medinilla & Espigares 1984	(n=11)	18	117
Daniell et al 1992	(n=137)	2	16.4
Winder and Turner 1992	(n=70)	15	52.3
Moen & Hollund 2000	(n=30)	12	13.7
Bocklemann et al 2002	(n=unknown)	6	4.6
Bratveit et al 2004 (solvent shop)	(n=51)	10	2.3
Bratveit et al 2004 (water-based shop)	(n=28)	10	0.84
Vitali et al 2006	(n=8)	5	22.5
Caro & Gallego 2009 (painting)	(n=6)	18	20.2

Table 2 explores the relationship between number of solvents measured and total summed solvents found

Figure 1. Mean exposure to Toluene and by study (collision repair painters)

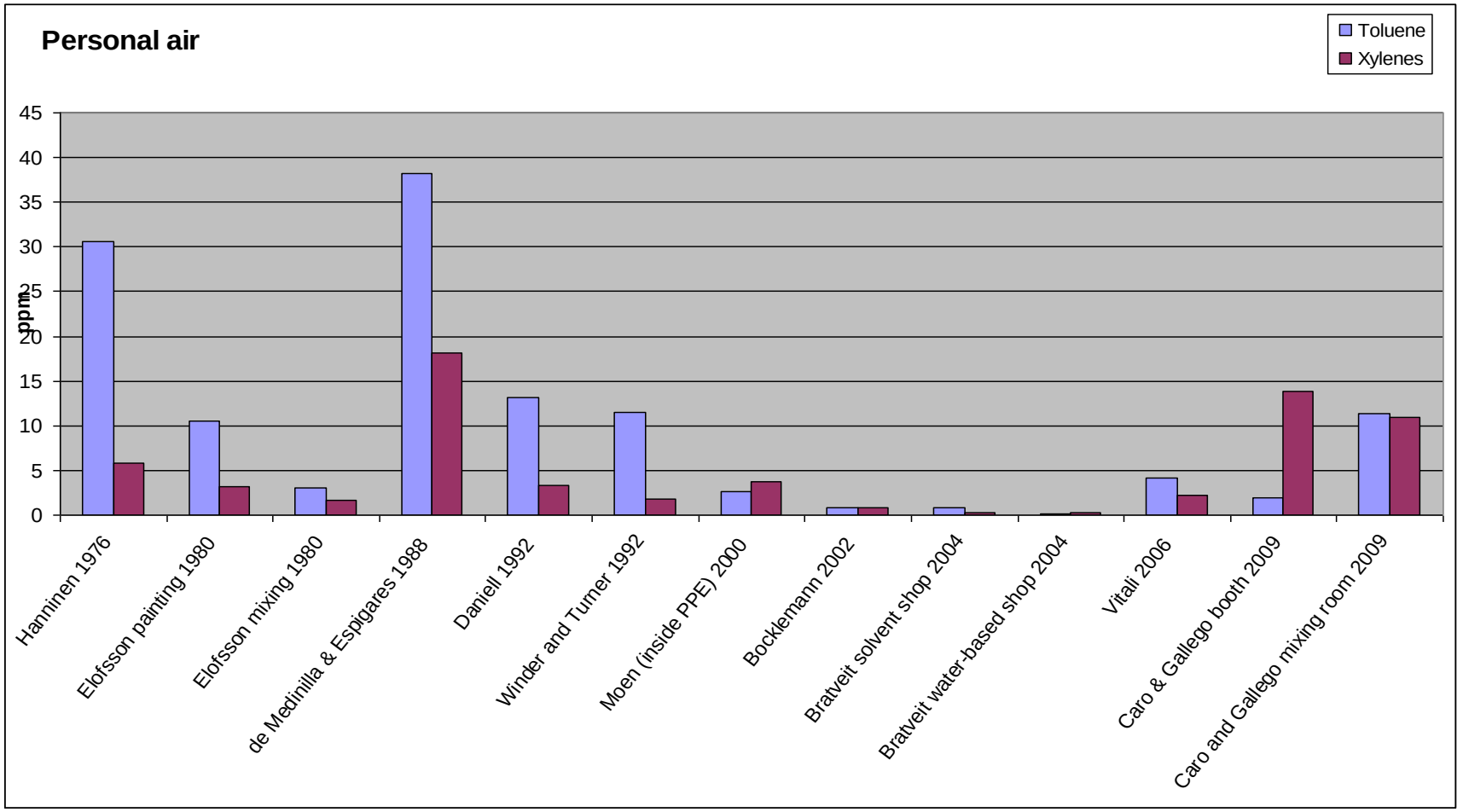


Figure 1 graphically illustrates levels of toluene and xylene, measured using personal sampling, in epidemiological studies over the last three decades.

Tables 3 and 4 show a catalogue of studies which have undertaken measurements of solvents in collision repair workshops, including the type of measurements made, solvents assessed and mean levels. Studies were included in this table only if they reported results in collision repair separately to results measured in different industries. Table 3 is of studies of neurobehavioural effects, while table 4 shows studies of exposure assessment only. Note that although Jaycock and Levin 1984 reported solvent levels measured in collision repair workshops, they are not easily comparable to those of the studies included in tables 3 and 4 and are therefore not included`.

Of the six studies in table 3, assessing neurobehavioural effects in collision repair workers, only Triebig et al and Williamson and Winder did not find evidence of neurodegenerative health effects associated with exposure to solvents. Triebig et al however did not stratify results for collision repair workers separately to workers in the other industries in their study (furniture sprayers and industrial spray painters), therefore results for collision repair workers are unclear.

Williamson and Winder's study population had only three years of exposure, and therefore do not qualify as chronically exposed.

Toluene and xylene are the two solvents most consistently measured in these studies. There is little consistency either in terms of the levels of solvents found or in the type of solvents measured.

Table 3 Neurobehavioural studies in collision repair workers

study	no. sampled workshops/painters	length of sample time	reference group	solvents assessed	solvent levels			results
1976 Haninnen et al Cross-sectional survey	6 collision repair workshops 40 painters	1 hour	Railway workers	**PERSONAL AIR** ppm Toluene Xylene Butyl acetate White spirit Methyl isobutyl ketone Isopropanol Ethyl acetate Acetone Ethanol	Mean (range) **(n=54)** 30.6 (5-249) 5.8 (<1-36) 6.8 (<1-128) 4.9 (<1-150) 1.7 (<1-39) 2.9 (<1-85) 2.6 (<1-14) 3.1 (<1-25) 2.9 (<1-27)			Poorer neurobehavioural function in exposed group.
1980 Elofsson et al Cross-sectional survey	20 Collision repair/industrial painting workshops 80 painters	not reported	industrial electronics workers	**PERSONAL AIR** (car painters) Toluene ppm Xylene Styrene Ethanol Butanol Butyl acetate Trichloroethylene Methylene chloride White spirit Methyl-isobutyl-ketone Methyl-ethyl-ketone Methyl-n-butyl-	**Painting (n=106)** 10.5 3.2 1.6 10 2 1.5 1 7.9 13.9 .5 9 1.2	**Grinding (n=218)** 4 .8 .8 10 .5 6.5 17.9 2 1.5	**Mixing (n=137)** 3 1.6 3.1 10 1.5 1.5 .8 5 13 .5 7.5	Poorer neurobehavioural functioning exposed group

				ketone				
1992 **Treibig et al.** Cross-sectional study	3 collision repair workshops 3 furniture spray workshops 4 container spray workshops 14 collision repair painters	between .5 and 6 hours	mechanics, construction workers, electricians.	**AMBIENT AIR** Toluene ppm xylene Ethylbenzene Acetone Ethyl acetate Butyl acetate **URINE** Cadmium µg/L Chromium Hippuric acid mg/L Methyl hippuric acid	Mean collision repair workshop **(n=22)** 5.8 1.4 4.6 2.3 2 4.9 Mean (range) painters **(n=83)** .8 (.1-7.1) .9 (0.1-28.8) 250 80	Mean (range) controls **(n=42)** .7 (.1-3.4) .5 (0.1-2.6) 450 20		Similar neurobehavioural function between exposed and unexposed groups Similar age-related increased complaints in exposed and control groups
1992 **Daniell et al** Cross-sectional study	25 collision repair workshops 34 collision repair painters	full-shift	lower exposed groups in same workshops	**PERSONAL AIR** mean(±SD) ppm Toluene xylene **URINE** mg/L Hippuric acid Methyl hippuric acid	**painters (n=34)** 13.1(±8.9) 3.3(±2.4) (n=97) 776(±527) 81(±55)	**combination (n=21)** 5.8(±6.3) 1 (±1) (n=97) 516(±47) 26(±27)	**non-painters (n=42)** 2.8(±2.6) .7(± .7) (n=97) 776(±52) 33(±36)	Age related poorer neurobehavioural performance in higher exposure groups

1992 Williamson and Winder Prospective cohort study Winder and Turner 1993 exposure assessment	46 workshops 56 apprentices 14 experienced spray painters	4-7hrs	Electrical apprentices metal fabrication apprentices	**PERSONAL AIR** Toluene ppm Xylenes Trimethyl benzene Methyl ethyl ketone C3-C7 aliphatics Acetone Butanols 2-Butoxyethanol High boiling hydrocarbons (C7 and higher) Butyl acetate n-Hexane Methyl isobutyl ketone Ethanol Benzene Ethyl acetate	Mean(±SD) **(n=70)** 11.5(±1.9) 1.8 (±.2) .8 (± .2) 4.1 (± .5) 14.4 (±3.5) 1.5(± .4) .4(± .1) 3.7(±1.8) 2.5(± .6) 1.1(± .4) 1.7(± .6) 4 .1(± .3) 0.3 4.7	Range 1.9- 85.7 .8 – 5.5 .2 - 3.1 1 - 7.3 5.1 - 32.4 .7 - 4 .2 - .6 .9 - 16 .4 - 4.8 .6 - 2.8 .5 - 3.2	frequency % 94% 60% 31% 29% 14% 13% 11% 11% 10% 9% 6% 4% 1%	No significant decrease in neurobehavioural performance over the study period of 3 years.
2002 Bocklemann et al Cross-sectional survey	5 collision repair workshops 6 ambient samples per workshop	3-5 hours	all industries in same 50km radius	Toluene ppm Xylene Benzene Alpha pinene Ethyl benzene Butyl acetate	**PERSONAL AIR** (n not reported) .9 .9 .006 .001 1.3 1.5	**AMBIENT AIR** **(n=30)** 1.1 1 .003 .002 1.3 1.5		Poorer neurobehavioural functioning exposed group

Table 4 Exposure assessment studies in collision repair workshops

study	no. sampled workshops/painters	length of sample time	solvents assessed	solvent levels	
1988 de Medenilla and Espigares	11 collision repair painters	30 min		**PERSONAL AIR (n=11)**	**frequency**
	11 workshops		Toluene	38.2	11
			Xylene	18.1	11
			Acetone	14.3	1
			Isopropyl acetate	3.3	4
			Isobutyl acetate	2.2	2
			Propyl acetate	.8	1
			2-Methoxyethyl acetate	3.6	2
			Benzene	.3	3
			Ethylbenzene	7.3	11
			Dichloromethane	.7	1
			Dichloroethane	.6	2
			n-hexane	.9	4
			Isopropanool	3.7	4
			Isobutanol	.8	1
			methyl acetate	5.2	4
			Ethyl acetate	.3	1
			n-butyl acetate	9.8	4
			Trimethylbenzene	1.2	5
			Methyl ethyl ketone	6	3
			Methyl isobutyl ketone	.7	1

2000 **Moen and Hollund**	6 collision repair workshops 28 painters (cases) 18 admin/panel beaters (controls)	16-450 min	Mean ppm Acetone Ethylacetate Isopropanol Ethanol Isobutyl acetate Butyl acetate Toluene Ethylbenzene Xylenes Styrene Aliphatics C4-C7 Aliphatics C7-C12	**PERSONAL AIR (n=30)** painting specific, inside respirator .9 .4 1.7 1.7 .1 .6 2.6 .1 3.8 1.3 .5	**AMBIENT AIR (n=24)** (mixing room) .8 .4 .6 .6 .2 1 2.8 1.5 .5 .8 .3 .1

2004 **Bratveit et al**	8 collision repair workshops 27 painters	full-shift (median:432min water based, 440 solvent based)	Mean ppm Toluene Xylene Ethyl benzene Trimethyl benzene Isopropanol Acetone Butyl acetate Isopropylacetate methyl isobutyl ketone diisobutyl ketone **BLOOD** mg/L Toluene (post-shift)	**PERSONAL AIR (n=51)** solvent shop .8 (±9.5) .3 (±4) .1 (±7.9) .1 (±5.1) .3 (±11.9) .1 (±22.2) .6 (±4.6) .02 (±7) (n=17) .044 (±3.41)	**PERSONAL AIR (n=28)** water-based shop .1 (±4.2) .3 (±3.1) .1 (±7.9) .1 (±4.1) .01 (±3.2) .01 (±4.2) .2 (±4.5) .02 (±7.2) (n=9) .007 (±5.28)	**AMBIENT AIR (n=2)** solvent shop booth .2 (±4.96) .2 (±15.8) .8 (±10.6) .1 (±22.3) .01 (±11)

2006 **Vitali et al**	8 car repair workshops 8 collision repair painters (1 per workshop) Only non-smokers were included to minimize confounding of benzene exposure assessment.	277-323 min		**PERSONAL AIR** ppm **(n=8)**	**AMBIENT AIR** ppm **(n=8)**	**URINE** µg/L **(n=8)**	
			Benzene	1.2 (40.0)	.6 (38.2)		
			Toluene	4.2 (58.7)	1.4 (18.0)	.5 (20.3) 8.2 (21.3) 3.3	
			n-Butyl acetate	9.3 (100.2)	2.2 (26.5)	(4.2)	
			Xylenes	2.2 (73.8)	.7 (14.3)	2.9 (4.4)	
			Ethylbenzene	5.6 (16.6)	.5 (3.4)	.9 (0.3)	

2009 **Caro J & Gallego M**	6 car painters 1 personal air and 1 alveolar air each	10 min	Mean (±SD) ppm	**PERSONAL AIR (n=6)** Booth	**ALVEOLAR AIR (n=6)** Booth	**PERSONAL AIR (n=6)** Mixing room	**ALVEOLAR AIR (n=6)** Mixing room
			Toluene	2	.23	11.4	6.6
			Xylenes	13.9	1.03	10.91	3.9
			Styrene	.02	.001	.2	.03
			Benzene	0	.003	0	0
			Ethyl benzene	.3	.03	2	.4
			Propyl benzene	.04	.006	.3	.06
			Trimethyl benzenes	.2	.02	3.2	1.2
			Napthalene	.0004	0	.006	.001
			Trichloroethylene	0	0	.002	.001
			Methyl isobutyl ketone	.46	.05	1.8	.3
			2-Butanone	.1	.01	.5	.1
			Ethyl acetate	.2	.08	1.1	.2
			n-Butyl acetate	2.1	.3	9.9	1.5
			Isobutyl acetate	.008	.0008	.08	.02
			Isopropyl acetate	.01	.007	.1	.02
			propylene glycol	.3	.03	1.6	.3
			ethanol	.5	.05	2.9	.7
			Methyl tert-butyl ether	.08	.008	.4	.1

2.10 Biomonitoring for solvent exposure using urine

Hippuric acid is the most commonly measured biomarker for toluene exposure in occupational settings (Lauwerys & Hoet 2001). Toluene is the most abundant and commonly measured solvent in the collision repair setting (see tables 3 and 4). Although there are a number of factors which can affect the accuracy of hippuric acid as a biomarker for toluene exposure, its relative ease of handling and analysis make it a common and valid choice for occupational hygiene purposes (NIOSH 1994, Lauwerys & Hoet 2001). In the case of this study, the Centre for Public Health Research laboratory had equipment capable of colorimetric analysis, meaning that urine analysis for hippuric acid could be added into the study without significant extra cost to the study.

The half-life of toluene in the blood is 2-3 hours (Lauwerys & Hoet 2001), meaning that within this time from exposure half the toluene in the blood will have been metabolized into another chemical form, and or excreted from the blood. The half life of hippuric acid in urine is around 42 hours (Nise, 1992). Metabolism rates for toluene and other industrial solvents have been shown to differ significantly according to sex, smoking and drinking habits, as well as by ethnicity and genotype. For example, Waldron et al, 1983, found moderate alcohol consumption was associated with a significant increase in the rate of

toluene metabolism and excretion, while others found the opposite effect of drinkers having a slower toluene metabolic rate than non-drinkers (Inoue et al 1993). Increased adipose fat storage of toluene relates to a decreased rate of metabolism (Nise 1989) This means that for some individuals, who are metabolizing toluene more quickly, hippuric acid may be fully excreted within 18 hours and there may be no significant difference between Monday and Friday pre-work samples, showing no accumulation of exposure over the course of the week, while other individuals metabolizing toluene more slowly may in fact suffer a significant weekly accumulation of urinary hippuric acid (Lauwerys & Hoet 2001).

Daniell et al, 1992, attempted to assess the contribution of dermal exposure to total solvent exposure in collision repair workshops. They took workplace air measurements as well as collecting post-shift urine samples which they analysed for hippuric acid, metabolite of toluene, and methyl hippuric acid, metabolite of xylene. This group found significant correlations between xylene measured in personal air and methyl hippuric acid, but no relationship between hippuric acid and personal air toluene samples. The team concluded that dermal exposure could be a significant contributor to solvent body load, and air sampling only , in moderate or high levels exposure settings, may significantly underestimate exposures.

Huang et al, 1994, assessed hippuric acid and methyl hippuric acid among painters and workers in printing or plastic production to assess the biological interaction between metabolism of toluene (hippuric acid) and xylene (methyl hippuric acid), two solvents that are commonly found together in solvent mixtures in occupational settings. The team took air samples and collected urine samples in the 5^{th} to 6^{th} hour of an eight hour workshift. Huang et al concluded that there was no evidence of biological interaction between toluene and xylene affecting metabolism rates, as both metabolites were found to have similar linear relationships with personal air concentrations of the two solvents. They also concluded that metabolism of toluene was significantly reduced among smokers and drinkers, compared with non-smokers and non-drinkers, however this relationship was not totally clear, as the non-smoking drinkers had the least reduction in metabolism rate of all the groups.

Chang et al 2007, assessed urinary metabolites of ethylbenzene (mandelic acid) and xylene (methyl hippuric acid) along with personal air samples to assess the effectiveness of gloves and protective suits in protecting workers from solvents. Fifteen spray painters at a ship painting factory were studied over two weeks. On the first week the workers wore no PPE during work, and in the second week the workers all wore gloves and protective suits. Pre and post-shift urine samples were collected and showed a decrease in 69% for mandelic acid and 49% decrease for methyl hippuric acid compared with the first week. The

authors concluded that without dermal protection dermal absorption can become the major contributor to total body load of solvents.

Kawai et al 2008 conducted surveys at 16 workplaces to assess the relative validity of various biomarkers for toluene exposure. The group concluded that hippuric acid was a valid biomarker at relatively high exposures, ie; ≥8ppm as a time weighted exposure, but was less useful for assessing lower levels of exposure, when urinary toluene became the biomarker of choice.

Kawai et al 2010, conducted a validation study of urine density correction in hippuric acid. They concluded that correlations between toluene in air and hippuric acid in urine were similar regardless of whether correction for urinary protein or specific gravity was used or not.

Ukai et al 2007 compared urinary biomarkers for toluene at various levels of air exposure and found that for levels up to 10ppm unmetabolised toluene was the most reliable marker for exposure. Between 10- and 40ppm unmetabolised toluene was also very closely correlated with exposure. Above air concentrations of 40ppm hippuric acid in urine became the more reliable biomarker for toluene exposure.

3 METHODS

3.1 Recruitment

Collision repair workshops were identified through the yellow pages and contacted via mail with an information sheet (see appendix 7.2) detailing the proposed study on neurobehavioural effects. This was followed up with phone calls and or site visits. 26 workshops in the Wellington region were contacted initially and invited to participate in the neurobehavioural effect of solvent exposure study. Of those workshops ten (37%) declined involvement in the study; three cited disinterest, six (22%), scheduling difficulties and one did not give a reason for non-participation, The exposure assessment programme is phase two of the study, and interviews had been conducted in 90% of those workshops prior to participating in sampling. Of those workshops contacted to conduct sampling, only one workshop declined to participate in this aspect of the study. The owner cited staff shortages and scheduling difficulty. It is noted that this workshop was one of two workshops approached who did not use a commercial extraction booth. Final participation rate in the exposure assessment part of the neurobehavioural effects study was 59%.

At each workshop all the painters were encouraged to participate in sampling by wearing the sampling equipment for one work shift. Participation from painters

in the sampling was 90% (43 out of 48). Panel beaters and office staff were also recruited to wear sampling equipment, and the participation rate was lower at 65% for panel beaters and 50% for office staff.

3.2 Workshop assessment

Workshop procedures were observed in detail, and after the first five workshops had been assessed, a workshop assessment protocol was developed which included; type of booth ventilation, type of mixing room ventilation, type of gun washing equipment ventilation, number of employees, workshop volume, roller door area, solvent contaminated rubbish in workshop and mixing room, number of open paint containers in workshop and mixing room. An ambient sample was also taken in each mixing room, with the sampling tube placed at head height above the main mixing bench. For the full workshop assessment protocol see appendix 7.4.

3.3 Air sampling

Equipment available for sampling solvent concentration in air was Restek brand whole air stainless steel vacuum canisters and sample trains. This sampling

method is simpler than traditional charcoal patches or tubes used with pumps as the canister takes a whole air sample, so there is no need to calculate a per minute sample rate as the canister absorbs clean air in the same proportion with contaminants as the air from which the sample is taken. Therefore the actual level found in each canister represents the mean solvents in the air over the sample period. The equipment is also relatively inexpensive as the canisters can be cleaned and reused many times and for many different chemical exposures. Painters, panel beaters, office staff, groomers and labourers participated in air sampling. Canister pressure and start time were recorded after participants were fitted with sampling equipment when the canister was connected to the sampling train for monitoring purposes. After canister pressure had reached 5 inches of mercury vacuum pressure the canisters were disconnected from the sample trains. The time and pressure were again recorded, and the participant was asked about the tasks they had performed, and the products they had used over the sampling period. See Appendix 7.3 for the full air sampling record sheet.

3.3.1 Switches

Five remote-controlled switch controllers were constructed which opened and closed a valve that fitted perfectly into the breathing tubes used with the

sampling system (see below). This allowed the operator to remotely close the air inlet of the sampling train of a participant under observation. A small LED light was connected to the switch to aid operator control. The switches were turned off (valves closed) every time a painter was observed to don a face-mask, and switched back on when the face-mask was removed.

3.3.2 Canisters

Canisters used are 400cc volume stainless steel canisters designed to hold vacuum to a pressure of 40psig. Canisters were attached to the sample train using Restek quick connect valves. Quick connect valves enable canisters to be connected and disconnected with minimal loss of vacuum.

3.3.3 Sample trains

Sample trains are stainless steel Restek brand sample trains and components designed to be used with the Restek canisters. Sample train flow-rates are adjustable within a range of 0.5-2.5ml/min. Canisters were set at a flow rate of 2ml/min , allowing an average sample time of 6 hours.

The sampling train is fitted with a flow controller which works to maintain a constant flow despite pressure differentials in the canister and the outside atmosphere, as the diaphragm maintains the pressure differential between the critical orifice and the atmospheric reference.

The flow controller can maintain a constant flow down to 5 inches of mercury vacuum, as displayed on the field gauge. For this reason sampling canisters were disconnected from the sampling trains as close as possible to 5 inches of mercury vacuum.

3.3.4 Air sampling tubes

Polytetrafluoroethylene plastic tubes of 2mm internal diameter were selected for use with the air sampling equipment as these were the most inert of the sampling tubes available. Sample tubes were clipped to the participant's collar area, with a second clip holding the tubing onto the back of the clothing to minimise tubes being caught on items while the participant carried out their normal duties, which often included lying down on the ground, or wedging their bodies into tight spaces. The equipment performed very well under these circumstances.

3.3.5 Sampling belts

The sampling equipment weighed 0.9kg. It was decided to use a commercial brand of belt bags to house the equipment as this allowed for some cushioning for the wearer along with easy maneuverability and handling.

3.4 Cleaning protocol

3.4.1 Cleaning canisters

Canisters were cleaned by first evacuating them, leaving them for 1 hour to equalise, then filling them to 105psi with humidified nitrogen and heating for 2 hours at 70°C. Canisters were immediately evacuated after taking them out of the oven and left to equalise for a further hour before repeating the process by refilling them again with humidified nitrogen, evacuating and filling them 3 times consecutively, each time leaving them evacuated for 1 hour before refilling with humidified nitrogen. The final cycle involved heating them once again for 2 hours at 70°C, then immediately evacuating them and storing. This cleaning protocol was an adaptation of the Restek recommended cleaning protocol.

Adaptations included heating the canister to only 70°C instead of the recommended 120°C. This was in order to maintain the integrity of the silicon lining of the canisters. Instead the filling and emptying cycle was repeated 3 extra times, and the bake time was extended from 1 to 2 hours to ensure solvents had been fully ejected.

3.4.2 Cleaning sample trains and sampling tubes

Sample trains and tubes were not heated during cleaning. Instead they were attached, fully open, to a continuous flow of humidified nitrogen for two hours.

3.5 Air sample analysis

All samples were couriered to an independent laboratory in Christchurch, Syft Technologies, where they were analysed within 48 hours of sampling, using gas chromatography. The limits of detection using this process were 5ppb for all solvents. The laboratory analysed the canisters only for the 16 solvents under investigation.

3.5.1 Solvent panel

Solvents for analysis were chosen after reviewing the literature and the MSDS (Material Safety Data Sheets) for the major brands of the paints, laquers, thinners and degreasers and fillers available in New Zealand. The full panel of solvents included: 1,2 dimethoxyethane (ethylene glycol), all isomers of trimethyl benzene, all isomers of butanol, all isomers of propanol, 2-methoxyethanol (propylene glycol), acetone, benzene, butanone (methyl ethyl ketone), butyl acetate, ethanol, all isomers of hexane, methyl isobutyl ketone, all isomers of xylene, propyl acetate, styrene and toluene.

3.5.2 Lab and Field blanks

The cleaning protocol was tested by sending 1 blank (unused canister) per 20 samples. Blanks were prepared by releasing the vacuum in the laboratory by pressing the release valve. On two occasions field blanks were prepared by taking them on field work, carrying them into the workshop, but not using them, then pressing the release valve once back at the lab, prior to couriering them overnight to Christchurch. The lab was blind to the status of the blank canisters.

3.6 Urine sampling protocol

Urine sampling was not part of the original funding and ethics applications so ethics approval was sought and gained from the multi-regions ethics committee. Participants in the air sampling protocol were encouraged to participate in urine sampling on the same day they were being sampled for air exposure to solvents. Ethics approval was not gained until the air sampling was underway, but after this, approximately 50% of those workers wearing air sampling equipment also gave urine samples. Participants were encouraged to give a before-shift and end of shift sample, and mid-shift samples also, so that the change in hippuric acid over the course of the workday could be evaluated. Although the importance of being able to compare pre and post shift samples was explained to the workers involved, many of those in this group failed to produce a pre-shift sample within the first hour of starting work. Urine samples were taken back to the Massey Public Health lab immediately after sampling finished (around 4-5pm the same day), placed in freezers and kept frozen at -20°C, until analysis.

3.7 Urine analysis

3.7.1 Sample handling

All urine sample analysis was undertaken by the author at the Centre for Public Health laboratory, Massey University. Urine was taken out of the freezer the day before analysis (approximately 16 hours prior). It was first mixed in its original polyethylene containers on a vortex mixer for 45 minutes, then aliquoted into duplicate 1.6ml micro-centrifuge tubes. One aliquot was kept refrigerated at 4°C for immediate use, while the other aliquot was returned to the freezer at -20°C. The effect of the freeze/thaw cycles was assessed using a high and low control that had been frozen alongside duplicate aliquots that had remained unfrozen, but refrigerated for 2 days. Urine was analysed for hippuric acid, the primary metabolite of toluene, and also for protein content, to adjust for urine density. All urine assays were analysed in a Bio-Tek ELx808 microtier plate spectrophotometer, operated via a PC running Bio-Tek's KC4 software, as recommended by Bio-Tek.

3.7.2 Urine protein microassay

The urine protein assay used was based on the protein-dye binding method of Bradford (Bradford 1976). The Bradford protocol describes a standard assay with a linear detection range of 0.05 to 0.5mg/ml, and a microassay method with linear detection range of 8-80µg/ml. Both procedures were run simultaneously with high and low controls and a random selection of samples to determine which method was most suitable for use with our samples and equipment. With the standard procedure, protein was detected in undiluted but not in diluted urine, whereas the microassay procedure which did not involve diluting the urine, had some of the control samples above the limit of detection for the assay procedure. Some precipitation of the dye/protein occurred, which although mixed until dissolved may have affected the absorbence of those samples. As a result it was decided to adapt the microassay procedure, keeping the urine undiluted, but diluting the dye reagent 1:4 with deionised water, the dynamic range of the test was expanded by running an 11 fold calibration curve from 2mg/ml of bovine serum albumin to 0.00195mg/ml. This calibration curve resulted in a sigmoid curve showing both the upper and lower limits of detection, and included the protein range of all but one of the urine samples. The finalised method was as follows: 100µl of standard or sample was pipetted into the microtiter plate wells, and using the multipipet, 100µl of dye reagent was added and mixed in the plate using the pipet. Two

microtiter plates were run with calibration standards and urine samples (76 samples in total) in duplicate, and a further 10 samples selected out of the highest and lowest, were re-tested in duplicate to assess intra-plate variability. Plates were left to react at room temperature (15°C) for 30 minutes and measured for light absorbance in the spectrophotometer at 630nm wavelength. One sample remained above the limit of detection, to calculate concentrations this sample was diluted serially: 1:10, 1:50 and 1:100 with deionised water and run on a separate plate with a similar calibration curve and a selection of repeats in order to gain a value for this sample.

3.7.3 Hippuric acid microassay

The NIOSH method 8300 for measuring hippuric acid in urine, using a stock solution of hippuric acid at.5g/L and a five fold serial dilution was used with a selection of samples including a high and low control. This method is designed for a single sample spectrophotometer, therefore a micraoassay version of the same reaction was adapted using the same ratio of sample and reagents. This meant 100µl of standard or sample, 100µl of pyridinine and 140µl benzylsulfonyl chloride were mixed in 1.6ml micro-centrifuge tubes and left to react at room temperature for 30 minutes. The reaction was then stopped with 1ml methanol. The NIOSH and adapted method were run simultaneously and a high correlation

(r=.88) was found between the two methods. Therefore the microassay procedure was adopted for analysis with the full sample. Calibration diluents and samples were pipetted into the 96 well microtiter plate. The plates were analysed in the spectrophotometer at 405nm wavelength.

3.8 Statistical analysis

Summed total solvent and individual solvent concentrations, from the air sampling, were assessed for normal distribution. Regression analysis of individual and summed solvents with sample train, and canister were run to assess the possibility of bias due to contaminated equipment.

Means and standard deviations were calculated and univariate regression analysis was run between individual solvents and job title to assess which solvents were associated with different jobs (painter/panel beater). Summed and individual solvents were assessed against time spent on each task (painting, mixing, gunwashing, degreasing and bogging) and summed solvents were assessed against the variables collected in the workshop assessment.

Multivariate models were constructed by including all those factors that showed a statistically significant result in the univariate analysis into a multivariate model.

3.9 Statistical analysis of urine results

Urinary hippuric acid levels were adjusted by dividing by the protein level. CV values for duplicate results were run, then means were calculated, stratified by jobtitle and time of day. These values were compared to the mean toluene air sampling results for those participants, and to their observed use of gloves categorised as “Good”, “Fair” or “Poor”

3.10 Video exposure monitoring

Prototype equipment (designed by researchers at Perdue University USA) was available that allows for instantaneous (1 per second) measurements of total volatile organic compounds (VOCs) taken using a photo ionization detector (PID) to be closely analysed by task. Measurements are sent via bluetooth to a laptop running a programme which simultaneously graphs the exposures and records video camera feeds. The design allows for close analysis of task-based

exposures and offers the potential to define specific tasks or task methodologies which are associated with higher exposure levels than others.

4 RESULTS

4.1 Workshop and worker general characteristics

Sixteen collision repair workshops were surveyed for this report. Of these businesses, three (19%) had five employees or fewer, ten (62%) had between six and ten employees and three (19%) had more than ten employees. The largest workshop in this group had 19 employees, while the smallest had three employees. Two of the workshops were owned by tradesmen, one with an owner/painter and one with an owner/panel beater.

Table 5 shows workshop characteristics of the sample.

Table 5 Workshop characteristics

	no. workshops
No. employees	
<6	3
6-10	10
>10	3
No. painters	
2	10
3	4
5	1
6	1
Workshop volume m³	
<1000	6
1-2000	5
>2000	5
Paint brand	
De Beer	1
Dupont	5
PPG solvent-based	3
PPG water-based	4
Spies Hecker	1
Paint type	
Water-based paint system	4
Solvent-based paint system	11
Booth extraction	
Downdraft commercial booth	14
wall extracted commercial booth	2
No commercial booth	1
Mixing room extraction	
Floor level next to mixing bench	9
wall extraction next to mixing bench	4
Floor level away from mixing bench	2
wall extraction away from mixing bench	1
Gunwasher extraction	
In mixing room internally ventilated	5
In mixing room externally ventilated	4
In workshop internally ventilated	3
In workshop externally ventilated	3

All but one of the workshops surveyed had at least one commercial style spray booth with oven function, and four workshops (25%) had two commercial spray booths. Of the spray booths 90% were downdraft style (extraction is in floor of booth), while the remaining two had high powered wall extraction. The workshop with no booth had a room with a roller door and one wall-mounted extractor fan ducted to the outside for spray painting. Painting in this workshop was observed to be done with the roller door open to the workshop. This workshop also had three large ceiling extraction fans in the workshop which were generally switched on during spray operations. Five workshops (31%) had supplementary extraction systems in the workshop space, four out of those five extraction systems were high powered wall-mounted ventilation systems (extraction outlet area 2-20m^2) with filters.

All the workshops had a ventilated mixing room separate from the workshop for mixing the paints. Nine (56%) of mixing rooms were ventilated with floor level extraction next to the workbench, two (12%) used floor level extraction away from the main workbench. four mixing rooms (25%) had wall extraction immediately behind the main mixing bench while one had wall extraction on the wall adjacent to the mixing bench. Table 6 shows the relationship between ventilation characteristics and mean summed solvents in the sample.

4.2 Personal Air Sample Population

A total of 90 personal air samples were collected from 77 collision repair workers, see Table 9 for descriptive characteristics of the sample.

Table 6 Personal air descriptive statistics

	frequency	Mean sample period (minutes)	Mean summed solvents ppm (SD)	additive limit value
Whole sample	**80**	**349**	**1.05 (±1.66)**	
Office staff	**10**	**359**	**.46 (± .52)**	**0.010**
Panel beaters	**32**	**338**	**.66 (± .63)**	**0.015**
Painters and Apprentices	**48**	**356**	**3.53 (±3.17)**	
Painters	42	353	3.73 (±3.29)	**0.074**
No switch	12	320	2.87 (±1.89)	
Switch	36	364	4 (±3.6)	
Apprentices	6	376	1.98 (±1.51)	**0.049**

The additive limit value is a way of assessing exposure to a mixture of chemicals. To calculate, each solvent is calculated as a proportion of its 8 hour limit value and summed. Additive limit values ranged from 0.6 - 0.03 of the additive limit value for painters and from 0.01 - 0.09 for apprentices. This can be interpreted as a percentage of the limit value for the solvent mixture, in other words,

painters exposure ranged from 3 to 60% of the additive limit value, and apprentices from 1 to 9%.

Surprisingly, samples taken using a switch to disclude exposure while wearing a respirator had higher mean summed solvents than samples taken without switching off the sampler during respirator use. For regression analysis these groups were therefore pooled. (see section 4.6 below)

Painters spent more than twice as much time painting as apprentices. Painters also spent more time mixing paint and degreasing panels than apprentices but a similar amount of time cleaning spray guns. Work is generally delineated clearly between painters and panel-beaters, although in two workshops panel beaters were observed to undertake painting of primer coat. However these two panel beaters did not have air samples taken and so are not part of this sample. All 10 office staff sampled were observed to enter the workshop area. Office staff spent a mean time of 19 minutes in the workshop with a range of 2-60minutes. Table 10 shows mean minutes per task by job title.

Table 7 Mean number of minutes spent on tasks

	Office staff	Panel beaters	Apprentices	Painters
painting (total)	0	2.6	25.83	68.69
primer	0	2.6	14.2	9.2
solvent colour	0	0	7.5	31.2
water-based colour	0	0	0	8.6
clear coat	0	0	4.2	19.7
Mixing paint	1.1	.03	4.7	19.5
Gunwashing	0	0	9.2	8.2
Degreasing panels	0	1.6	15	19.62
Using epoxy resins	0	22.7	2.5	2.9

Table 11 shows mean exposure of individual solvents by job title. The exposure profile is generally similar across the different solvents and job titles. Noticeable variants are styrene, for which panel beaters have the highest mean exposure, and ethanol, for which exposure is very similar across all job titles. See also Figure 2. Regression of analysis of styrene exposure by time spent on tasks showed that styrene was associated significantly with time spent using filler (epoxy resin) coefficient 1.22 (1.12-1.22) pvalue <0.01, and not with any other tasks.

Table 8 Mean individual solvents and job title

	Office staff	Panel beaters	Apprentices	Painters
Dimethoxyethane	.005 (±.009)	.004 (±.004)	.012 (±.015)	.04 (±.08)
Trimethylbenzene	.029 (±.023)	.05 (±.054)	.032 (±.028)	.128 (±.154)
Butanol	.013 (±.016)	.014 (±.016)	.029 (±.022)	.096 (±.094)
Propanol	.012 (±.026)	.012 (±.016)	.045 (±.05)	.078 (±.13)
Acetone	.011 (±.011)	.046 (±.088)	.127 (±.18))	.38 (±.66)
Methyl ethyl ketone	.019 (±.038)	.013 (±.013)	.084 (±.14)	.11 (±.11)
Butyl acetate	.048 (±.045)	.058 (±.052)	.133 (±.14)	.35 (±.31)
Ethanol	.17 (±.20)	.15 (±.12)	.21(±.18)	.28 (±.14)
Hexane	.016 (±.017)	.035 (±.042)	.16 (±.12)	.19 (±.18)
Methyl isobutyl ketone	.018 (±.01)	.012 (±.029)	.018 (±.01)	.09 (±.10)
Propyl acetate	.013 (±.017)	.015 (±.009)	.017 (±.013)	.035(±.02)
Styrene	.007 (±.007)	.061 (±.098)	.011 (±.014)	.016 (±.098)
Xylene	.092 (±.14)	.083 (±.062)	.3 (±.27)	.44 (±.33)
Toluene	.16 (±.19)	.29 (±.37)	.92 (±.88)	1.79 (±1.9)

Figure 2. Mean individual solvents and job title

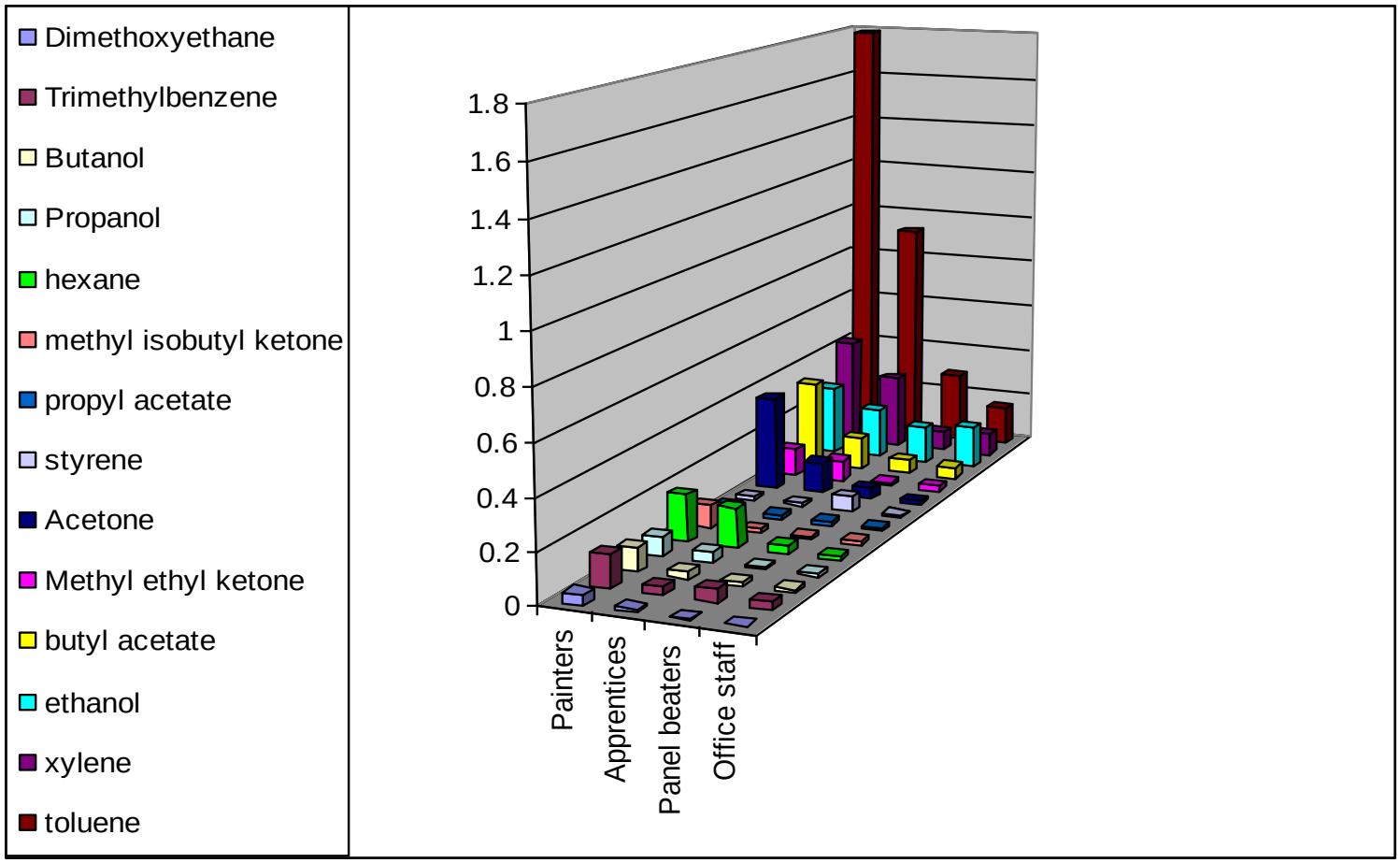


Table 9 Exposure characteristics with mean summed personal solvents (ppm)

	mean personal solvents (ppm)	standard deviation	samples	workshops
Paint type				
Water-based paint system	1.87	1.68	28	4
Solvent-based paint system	2.36	3.02	62	11
Paint Brand				
De Beer	1.09	0.67	5	1
Dupont	1.84	2.27	26	5
PPG solvent-based	4.13	3.96	21	3
PPG water-based	1.87	1.68	28	4
Spies Hecker	1.08	0.78	4	1
Booth extraction				
Downdraft commercial booth	2.13	2.77	74	14
Wall extracted commercial booth	0.57	0.25	3	2
No commercial booth	4.15	3.27	3	1
Mixing room extraction				
Floor level next to mixing bench	1.58	1.83	25	9
Wall level next to mixing bench	2.30	2.64	25	4
Floor level away from mixing bench	1.86	1.73	18	2
Wall level away from mixing bench	3.80	4.11	17	1
Gunwasher extraction				
In mixing room internally ventilated	1.45	1.73	29	5
In mixing room not internally ventilated	2.06	2.19	31	4
In workshop internally ventilated	2.24	2.61	12	3
In workshop not internally ventilated	3.80	4.11	17	3

25% (4) of workshops surveyed used water-based paint systems. Only one brand of water-based paint systems was used in this sample. All water-based

systems have water-based colour coat only and still use solvent-based primer and clear coats.

Storage facilities for PPE were generally adequate, ie, each worker had their own locker with door or closed box outside the mixing room for storing respirators. Two workshops provided poor or inadequate storage facilities for PPE (uncovered bench space only) and a further one workshop had storage for PPE only inside the mixing room.

4.3 Use of Personal Protective Equipment

Respiratory equipment was available in all workshops. Twelve painters (29%) used air supplied full face respirators when painting in the booth, while the remainder used cartridge half facepiece respirators. All painters used cartridge respirators when painting in the workshop. Three painters in workshops using water-based paint systems used cartridge masks for spraying colour coat (water-based) and an air-supplied respirator when spraying clear coat (solvent-based). One painter in a workshop using water-based paint did not wear a respirator when spraying colour coat, but used a cartridge respirator for spraying primer and clear coats. Two painters in workshops using a solvent-based paint system

did not wear a respirator when spraying in the spray booth. Both of these workers painted in downdraft style spray booths. Spray painting commonly took place in the workshop in the vicinity of other workers who were not wearing PPE. In all paint shops where water-based paints were used some jobs were still done using solvent-based paint. Invariably these jobs took place in the workshop, while the water-based paint jobs were conducted in the spray booth.

Respiratory protection equipment use during paint mixing was generally poor, only one painter was observed to wear a respirator during paint mixing processes, unless going from booth to mixing room to refill the spray-gun, in which case painters generally left their respirator on. Two painters were observed not wearing a respirator while washing spray equipment with solvent. One painter only was observed to wear a respirator during degreasing of panels prior to painting. Twenty four painters (57%) used gloves for all solvent-related tasks. See table 7 for use of PPE by task.

Table 10 Use of protective equipment by task.

Respirator use	Always used respirator	Always used gloves
Painters: All tasks	2%	57%
Spraying in booth	93%	89%
Spraying in workshop	98%	86%
Mixing paint	2%	81%
Cleaning gun	86%	86%
Degreasing panels	2%	52%
Sanding	50%	50%
Panel beaters: All tasks	0	0
Sanding	0	30%
Degreasing panels	0	27%
Using epoxy resins	0	10%
Working near spray painting	0	0

4.4 Ambient Air

Ambient samples are reported for mixing rooms of ten workshops. Table 8 shows mean ambient solvents compared with workshop characteristics.

Table 11 Mean Ambient solvents (ppm)

	mean ambient solvents	standard deviation	samples
Mean mixing room TWA	**8.94**	**9.47**	**10**
Paint Type			
Water based paints	4.17	0.59	3
Solvent based paints	12.29	11.25	7
Paint Brand			
De Beer			0
Dupont	3.07	1.21	3
PPG solvent-based	18.76	4.18	4
PPG water-based	4.17	0.60	3
Spies Hecker			0
Gunwasher extraction			
In mixing room internally ventilated	6.25	0.98	2
In mixing room externally ventilated	12.15	12.59	2
In workshop internally ventilated	2.91	0.41	3
In workshop externally ventilated	8.21	6.56	3
Mixing room extraction			
Floor level next to mixing bench	6.37	4.57	7
Wall extraction next to mixing bench	4.11		1
Floor level away from mixing bench	22.99	13.18	2
Wall extraction away from mixing bench			0

Mean ambient solvents were more than six times as high in PPG workshops with solvent based paint systems than Dupont brand workshops, and although only one third the levels of PPG solvent based paint workshops, water-based PPG paint workshops still had higher mean summed solvents than the three Dupont solvent-based paint workshops.

Ambient solvents in the mixing rooms which had the gunwasher placed in the mixing room had approximately double the mean solvents of mixing rooms without a gunwasher.

4.5 Video Exposure Monitoring

The prototype video exposure monitoring system had a number of problems meaning that a full survey could not be completed. Nevertheless results of instantaneous exposures associated with different tasks were recorded. No solvents were detected in the painters breathing zone during spray painting in the booth with water-based colour coat. With solvent-based colour coat instantaneous peaks of up to 120ppm were recorded in the spray booth within the painter's breathing zone. These exposure levels dropped off rapidly, and most of the recording time (10 minutes), solvent levels did not go over 50ppm. During spray gun cleaning in a gunwasher with automated internal ventilation, peaks were recorded in the painters breathing zone (outside respirator) of up to 1200ppm. Drop off in exposure levels was slower than in the spray booth. At another workshop the gunwashing machine had a custom made hood. During gunwashing at this workshop peaks of up to 40ppm were recorded in the painters breathing zone (outside RPE) which dropped off rapidly. Video

exposure monitoring conducted during degreasing of panels recorded peaks of up to 140ppm in the painter's breathing zone. Monitoring during paint mixing (2 samples, 5 minutes each) showed few major peaks higher than the general background level of exposure in the mixing room and none over 50ppm in the painter's breathing zone. These exposures were during mixing only of paint which had already been measured out. No samples were taken during paint measuring tasks.

4.6 Statistical analysis of personal air exposure

Relationships between individual solvents and all solvent measurements showed log normal distribution. Univariate analysis was performed using log transformed summed solvents against workshop characteristics. Coefficients were exponentiated for reporting and 95% confidence limits were calculated. Univariate analysis was run using log transformed summed solvents and canister number and sample train number to assess equipment bias. All values were non significant (not shown). Table 12 shows the full univariate analysis.

Table 12 Univariate analysis of summed solvents

	Obs (n=90)	R-square	Proportion compared to reference	Lower 95% CI	Upper 95% CI
workshop		.40			
1			5.88*	1.20	28.78
2	ref				
3			1.32	.27	6.46
4			4.45*	1.10	17.94
5			5.49*	1.26	23.89
6			3.12	.85	11.48
7			2.10	.48	9.13
8			2.03	.50	8.18
9			8.51**	1.74	41.61
10			1.08	.31	3.75
11			2.56	.79	8.25
12			8.45**	2.37	30.16
13			1.28	.29	5.56
14			2.15	.53	8.66
15			1.59	.41	6.07
16			16.65**	4.13	67.13
Job title		.56			
Office staff	ref				
Panel beater			1.81	.98	3.36
Apprentice			5.30**	2.23	12.58
Painter			10.31**	5.64	18.83
Paint brand		.18			
De Beer	ref				
Dupont			0.84	.28	2.50
PPG solvent-based			3.29*	1.06	10.20
PPG water-based			1.32	.44	3.99
Spies Hecker			0.98	.21	4.47
Paint system		0.0			
Water based	ref				
Solvent based			1.007	.58	1.76
Number of painters		.07	1.19	.99	1.45
Number of employees		.01	0.98	.93	1.03
			Ratio ‡		
Time spraying		.28	1.1**	1.07	1.15
Time spraying primer		.10	1.48**	1.16	1.90
Time spraying colour (solvent)		.19	1.14**	1.08	1.21
Time spraying colour (water)		.05	1.20*	1.02	1.41
Time spraying clear coat		.19	1.28**	1.15	1.43
Time mixing		.24	1.41**	1.24	1.60
Time gunwashing		.18	2.03**	1.47	2.81
Time degreasing panels		.23	1.49**	1.27	1.73

		R-square	Proportion compared to reference	Lower 95% CI	Upper 95% CI
degreasing cloth in breast pocket		.03	4.36	.77	24.58
Natural ventilation†		.01	1.002	.99	1.005
Mixing room extraction		.07			
Floor level next to mixing bench	ref				
Wall level next to mixing bench			1.23	.64	2.36
Floor level away from mixing bench			2.26*	1.13	4.50
Wall level away from mixing bench			0.65	.23	1.82
Gunwasher ventilation		.10			
In mixing room internally ventilated	ref				
In mixing room externally ventilated			1.65	.89	3.03
In workshop internally ventilated			1.13	.52	2.48
In workshop externally ventilated			2.98**	1.45	6.11

* p value <0.05

** p value <0.01

† Workshop volume/open door area x number of painters

‡ Ratio of increase in solvents with each 10 minutes of increased exposure.

In the analysis by workshop the workshop with the lowest total exposure has been made the reference so that the others could be compared against this lowest exposure workshop. This shows us that each sample in the highest exposure workshop had on average seventeen times the solvents of the lowest exposed workshop, although this value accounts for the number of samples it does not account for job title, so the heavily exposed workshops may simply have a higher ratio of painters to office staff. A natural ventilation category was calculated by dividing workshop volume by open door area times the number of painters in the workshop. There was no association found between this natural ventilation variable and personal exposure, or any of the 3 variables separately (volume, open door area and number of painters)

Paint brand and system (water or solvent-based) was not associated with personal air, but of note is the fact that all the paint brands showed non-significant decrease in exposure when compared to PPG water-based paint.

Time spent on tasks were analysed as continuous variables, however the number of minutes was divided by ten to show the ratio of increase in personal exposure (per 1ppm) per increase in each ten minutes of that task. Job title showed a highly significant result for painters and apprentices compared to office staff, while job title 'panel beater' coefficient was close to statistical significance with p value=0.057

One ventilation category related to mixing room ventilation, and one related to gunwasher ventilation were significantly associated with personal solvent exposure. These were mixing room ventilation floor level, away from main bench, and gunwasher in workshop without internal ventilation or hood.

Keeping a solvent soaked rag in the breast pocket, based on only two painters, also showed a strong correlation coefficient of 4.36, with solvent exposure, but was not statistically significant because of low numbers.

Table 13 Multivariate model

Model R-square = .77 Model Prob> F =0.0000		Obs.	coefficient	Lower 95% CI	Upper 95% CI
Job title					
Office staff	ref				
Panel beater		33	1.85*	1.09	3.14
Apprentice		6	4.78**	1.97	11.66
Painter		42	6.30**	3.33	11.90
Paint brand					
De Beer	ref				
Dupont		15	2.08	.82	5.28
PPG solvent-based		14	3.56**	1.59	7.97
PPG water-based		14	4.21*	1.24	14.27
Spies Hecker		2	3.17*	1.01	10.01
Mixing room extraction					
Floor level next to mixing bench	ref				
Wall level next to mixing bench		11	.74	.34	1.64
Floor level away from mixing bench		10	3.06**	1.51	6.19
Wall level away from mixing bench		3	1.06	.39	2.83
Gunwasher ventilation					
In mixing room internally ventilated	ref				
In mixing room externally ventilated		17	.86	.47	1.55
In workshop internally ventilated		6	.84	.38	1.85
In workshop externally ventilated		12	2.19**	1.34	3.59
			Ratio ‡		
Time spraying primer		90	1.07	.90	1.27
Time spraying colour (solvent)		90	1.04	.97	1.12
Time spraying colour (water)		90	1.13	.94	1.34
Time spraying clear coat		90	.94	.80	1.11
Time mixing		90	1.13	.995	1.28
Time gunwashing		90	.85	.60	1.21
Time degreasing panels		90	1.02	.89	1.16

* p value <0.05

** p value <0.01

‡ Ratio of increase in solvents with each 10 minutes of increased exposure.

Workshop variable was left out of the final model due to collinearity with workshop ventilation and paint brand variables. This model was able to explain

77% of the variance in the summed solvent exposure data, and the ventilation categories that were statistically significant in the univariate analysis remained so in the multivariate model where they were adjusted for job title, paint brand and time spent on each painting task.

Analyses were run using the same method but using only the painters and apprentices. The univariate analysis showed similar trends, with the mixing room and gunwasher ventilation characteristics explaining a similar level of variance. Due to the small number of observations in this group (n=48) only time spent painting solvent colour remained statistically significant in the multivariate model. See Appendix 5 for tables showing these analyses. It must be pointed out that the time spent on tasks used in this analysis included periods when the samplers were switched off because PPE was being used. This means that these figures do not indicate the actual exposures of each task, but are indicative of the general intensity of exposure and can be seen in this analysis as a proxy for work intensity. The use of PPE is also reflected in these figures with those tasks most frequently done using PPE, gun washing and spraying clear coat, showing the lowest exposure ratio.

PPG solvent based and water-based paint systems reversed their association with water-based paint showing the highest exposure levels in the multivariate model, this reversal is partly due to more painters being sampled in workshops

using PPG solvent based systems, so once the value is adjusted for job title in the multivariate analysis, PPG solvent-based paints are no longer associated with the highest solvent levels.

Given the size of the effect measure for degreasing cloth kept in breast pocket the multivariate model was re run, including this variable. The cloth in breast pocket variable had a coefficient of 2.37, not statistically significant, and the relationships reported in the multivariate model above remained the same.

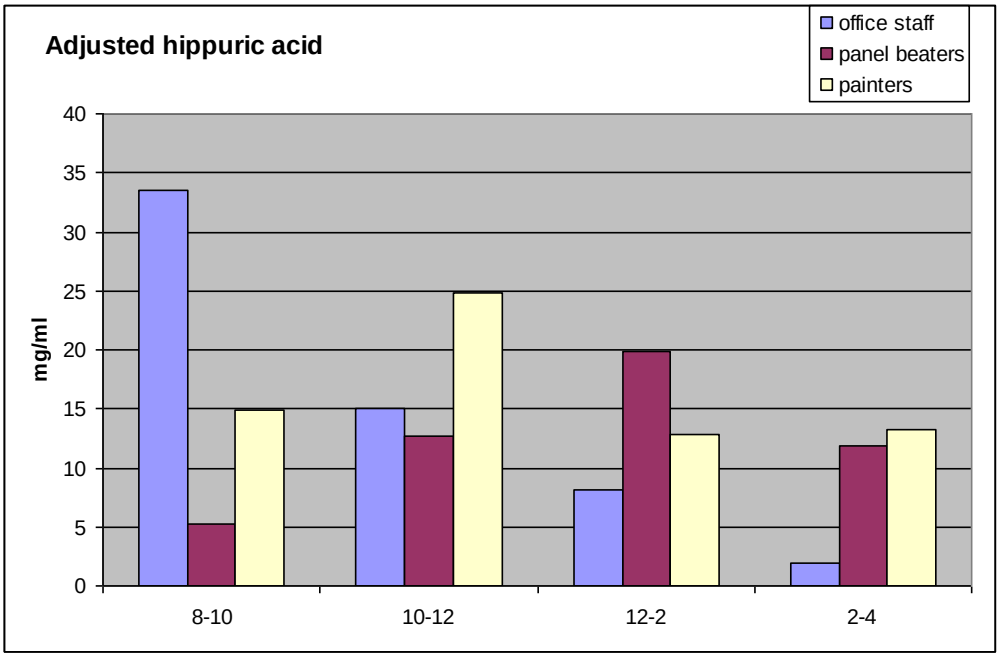
4.7 Urine sampling results

Seventy six samples were collected from from 18 individuals. Table 14 shows mean hippuric acid adjusted for protein stratified by job title and time of day. Results show some non-significant evidence of the expected workshift pattern of urinary hippuric acid for panel beaters and painters, however the office staff pattern of urinary hippuric acid change is not explainable by workplace exposures (see figure 3). Note that 8-10am office staff hipuric acid is based on one observation only.

Table 14 Urine results stratified by job title

Hippuric Acid adjusted for protein	8-10am	10am-12pm	12-2pm	2-4pm
office staff	33.5 (1)	15 (3)	8.2 (1)	2.0 (2)
panel beaters	5.2 (2)	12.7 (5)	19.8 (7)	11.8 (11)
painters	14.9 (7)	24.86 (6)	12.8 (7)	13.3 (13)

Figure 3 Hippuric acid by job title and time

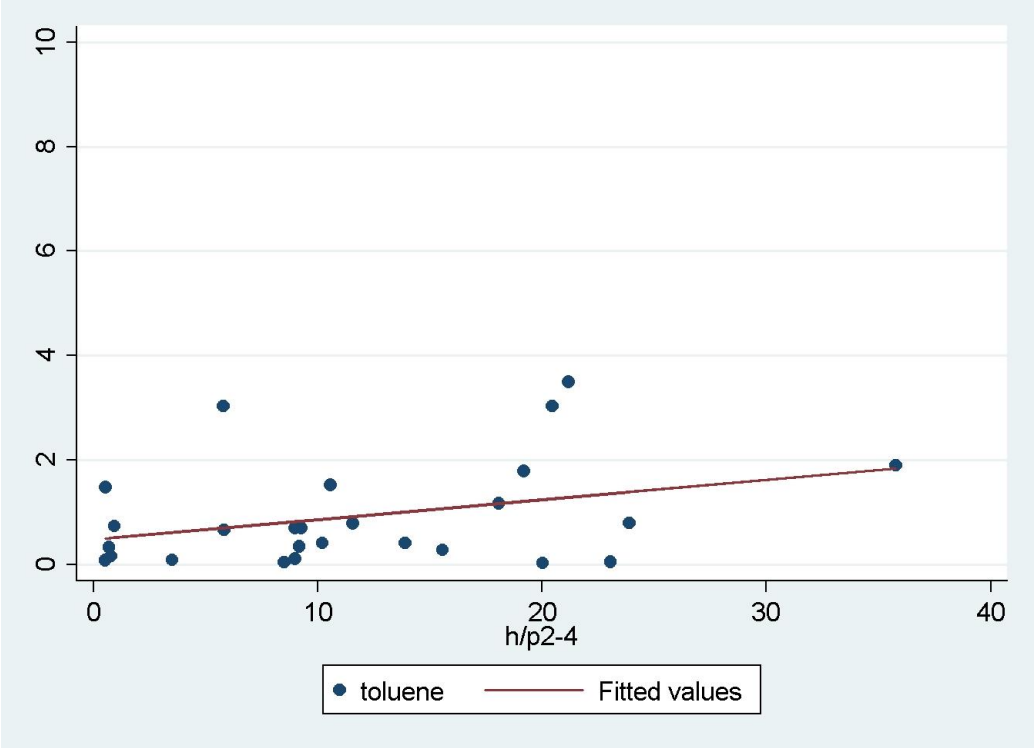


A slight non-significant increase in 2-4pm urinary hippuric acid is also seen when compared against toluene in personal air see Table 15 and figure 4.

Table 15 Mean personal toluene by hipppuric acid at 2-4pm

adjusted hippuric acid	mean toluene	standard deviation	frequency
< 1	.56	.58	5
1-10	.71	.98	8
>10	1.2	1.1	13

Figure 4 2-4pm hippuric acid against toluene with regression line fitted

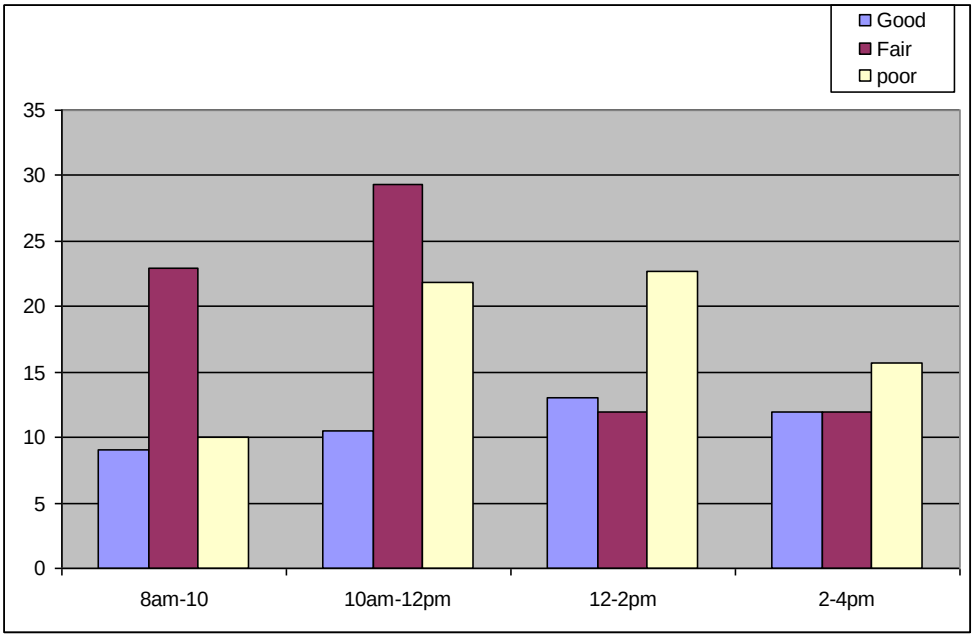


There is also no clear relationship between urinary hippuric acid and glove use in this small sample (see Table 16 and Figure 5)

Table 16 Mean hippuric acid with glove use category (number of observations)

Painters	8-10am	10am-12pm	12-2pm	2-4pm
Glove use:				
Good	9.1 (3)	13.1 (3)	13.4 (5)	12.1 (6)
Fair	28.7 (2)	46.9 (2)	12.6 (1)	12.8 (4)
poor	10.0 (2)	16.0 (1)	9.9 (1)	16.3 (3)

Figure 5 Hippuric acid by glove use.



Regression analysis of urinary hippuric acid at 2-4pm against water-based or solvent-based paint system showed a non-significant negative correlation between hippuric acid and solvent based paint compared with water-based.

All analyses were run using hippuric acid unadjusted for protein, and no signs of any correlations were found.

5 DISCUSSION

Despite many studies described in the literature review above showing no association between solvent exposure and neurobehavioural health effects, overall the literature supports an association, and this is particularly clear in studies of collision repair painters. Four out of four such studies which assessed painters with at least 5 years of exposure and reported collision repair painters' results separately from other workers, found poorer neurobehavioural health in the exposed group (Hanninen 1976, Eloffsson 1980, Daniell 1992 and Bockelmann 2002). What is also evident is the difficulty of assessing health effects due to a low level chronic exposure that has such a wide variability in presentation of disease.

One of the most important issues for cross-sectional studies is to define a reference group with sufficient similarity to the exposed group, so as to render the highly sensitive neurobehavioural testing used in these studies comparable. Many studies of occupational solvents and neurobehavioural health effects have been affected by differences in education level (Williamson and Winder 1993), initial intelligence (Spurgeon 1994, Hanninen 1976), alcohol consumption (Antti-Poika 1985) or age (Triebig 1992), which weaken the ability to draw causal associations with solvents.

One factor which has not been explored in the literature is that numerous social issues, both from within and outside, the workplace are likely to impact on neurobehavioural testing outcomes as depression is known to. This has been addressed by Spurgeon 2001, where she promotes the use of a biopsychosocial model (whereby key social factors are measured and analysed alongside other health effects and confounders and health is viewed as a continuum rather than a dichotomous outcome) in epidemiological research. Although adding many extra variables into an analysis can weaken the ability to find statistically significant results if subject numbers are too low, it is likely that research into neurodegenerative health effects will need to adopt such an approach in future to gain insight into a health issue that is extremely prevalent, yet poorly understood.

Another difficulty intrinsic to occupational solvent studies is that solvents are usually used in mixtures (Olsen and Seedorf 1990), limiting research into effective interventions. Although a number of individual solvents have been identified as more toxic (ie. benzene, styrene and n-hexane), it may be that solvents that are individually relatively benign, may increase toxic reaction to other solvents (Noraberg & Arlien-Soborg 2000, Dick 2006). This process could be caused simply through the mechanism of overloading the liver's metabolic rate of processing solvents, thereby increasing exposure to solvents in the blood.

There is some evidence that alcohol may also act in this way (Lundberg 1992, Cherry 1992).

Animal studies do not support neurotoxic effects of solvents, however they are generally conducted using one solvent only, and few animal studies are conducted over a period of longer than 2 years (Ridgway 2003), making them essentially non-comparable to occupational solvent research in many industries such as collision repair where solvents are used almost exclusively in mixtures.

The difficulty of quantifying solvent exposure is further compounded by the fact that solvent levels in many workplaces have been found to have reduced over the past three decades (Ihrig 2005, Gregerson 1988, Lundberg 1995). How large this reduction may be is difficult to ascertain from epidemiological reports as different measurement methodologies have been used; some studies measuring personal air using full-shift (Daniell 1992, Williamson and Winder 1992, Bratveit 2004, Vitali 2006) and other studies task-based or short time period measurement techniques (Hanninen 1976, Medinilla and Espigares 1984, Moen and Hollund 2000, Caro and Gallego 2008) and other studies measuring only ambient air (Triebig 1992). Solvent panels (the solvents chosen to test for) have also varied widely for different studies. Only two studies (Medinilla and Espigares 1984 and Williamson and Winder 1992) reported running a screening analysis for all components of the collected air prior to running against a

designated panel of solvents. Medinilla and Espigares reported finding 18 individual solvents and Williamson and Winder; 17 (these figures do not include isomers which are all grouped as one solvent)

There is some evidence that levels reported in these epidemiological studies of collision repair painters may considerably underestimate the real solvent exposure of collision repair painters. Although Table 2, page 26, which explores the relationship between the number of solvents measured and mean summed solvents reported, does not show any clear pattern, nevertheless table 1, page 25, which shows the full list of individual solvents measured in all 11 studies in the group shows that only six out of 30 solvents were measured by at least half the group. Perusal of those solvents measured in only one study show that levels found of these solvents are similar to levels found of solvents more commonly measured, suggesting that few of these reports are a comprehensive representation of collision repair solvent exposure.

Bratveit et al, who reported the lowest level of all the studies in the group report mean and range of 51 personal measurements, (see table 3). The range of the individual solvents reported is very wide, suggesting that many of the painters in their group had very little exposure, while a smaller number had much higher exposures. For example, mean acetone was 0.1ppm (parts per million), while the highest level measured was over 22ppm. This factor was discussed by the

authors who described one workshop in which the participating painters spent a far higher proportion of their time working on painting tasks. In this workshop, summed mean solvents were 29.6ppm compared to the overall mean of 2.3ppm (for solvent based workshops). In this workshop, painters completed an average of four paint jobs each, while the median in the other workshops was 1 to 2 paint jobs per painter. Unfortunately number of paint jobs per painter is not available for other studies for comparison.

Another study conducted by the same group in the same city only two years earlier had found considerably higher mean summed solvent levels (13.7ppm) despite these measurements having been taken inside respiratory equipment (Moen & Hollund 2000). However, as these samples were task-based and Bratveit et all used full-shift sampling they are not comparable.

Similarly results of Vitali et al were skewed by two of the eight workshops where mean summed solvents were four times higher than those of the other six workshops. The authors noted the painters in these two workshops with higher personal solvent levels disregarded all safety precautions in conducting their painting work.

Product contents (see appendices 5.1 and 5.2 for a sample) show a very wide variety of chemicals in common use. Two important factors dictating which

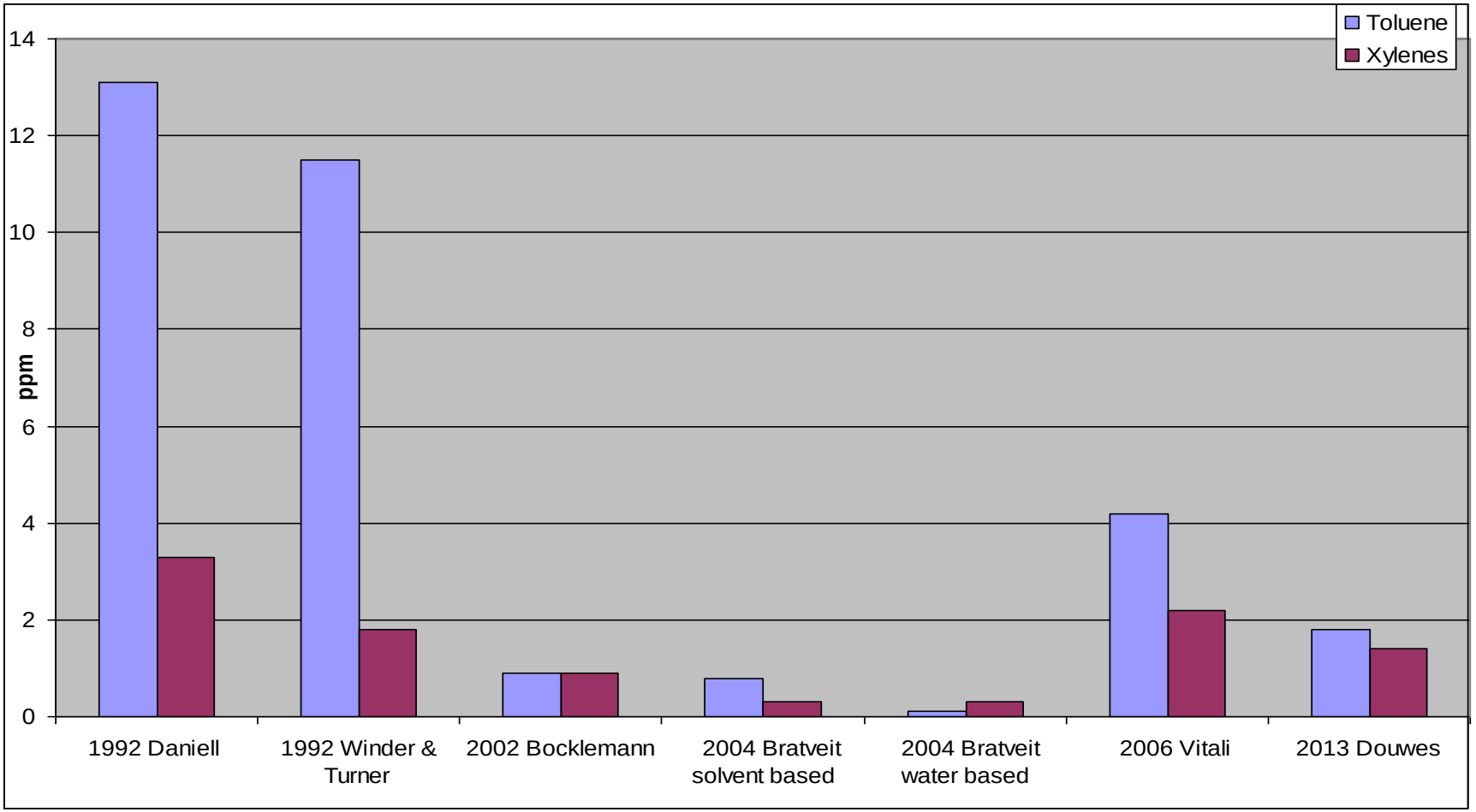
solvents may be measured on any particular day are the colours of paint that are being painted on that day, and the time of year, or temperature of the workshop, which dictates which thinner is chosen for spraying purposes. Another factor described to the author by painters in our sample was the quality of job expected; different thinners and lacquers are chosen to provide a different quality of finish, often chosen to suit the age of the car being painted. Unfortunately the variety in use would make it very unlikely a study such as this could find any associations at all if these differences were to be taken into account in the data.

In summary it is likely that differences in solvent levels reported in these studies represent differences in workload and product use as much as any real change in exposures over time. While certain practices such as the use of high pressure low volume spray guns, and a greater prevalence of downdraft style spray booths have been introduced over the same period, these factors were assessed in a study of 5 small US collision repair workshops by Heitbrink et al 1995, who found that while the introduction of such equipment did reduce paint overspray, they did not significantly reduce solvent exposure.

It is important to note that although overall levels of solvents were low compared to exposure limits set by the New Zealand government, neurobehavioural effects have been found in studies of collision repair workers

with similar and even lower levels (Eloffson 1980, Bleeker 1991, Bockelmann 2002). Figure 6 shows a selection of studies that reported similar methodologies to the current study (ie. full-shift personal air measurements) along with our own results for toluene and xylene (Douwes 2013). Overall, toluene and xylene levels are essentially similar, and while there is some evidence that there has been a reduction in toluene exposure since the turn of the millennium, there is no such evidence of a reduction in exposure to xylene.

Figure 6. Comparative levels of toluene and xylene in epidemiological studies of collision repair workshops.



In the present study, two ventilation characteristics, namely mixing room ventilation floor level, away from main mixing bench, and gunwasher placed in workshop without separate ventilation were found to have a strong and statistically significant association with personal exposure to solvents in the air for all workers. Mean ambient solvents in the mixing room were shown to be approximately double for those with a gunwasher, compared to mixing rooms without a gunwasher. Together these results show the gunwasher, especially if not separately ventilated, is a strong driver of overall solvent exposure levels, not only for painters, but also for panel beaters and office staff. Mixing room ventilation characteristics, likewise showed an extremely clear relationship with floor level ventilation if not immediately next to the main mixing bench providing significantly less value in terms of extraction than other categories in this group. These two ventilation characteristics are easily modified, making this an important finding.

A strong association was observed between summed solvents and job title, as expected. And paint brand also showed significant variability in terms of exposure in both the univariate and multivariate analyses. The fact that PPG waterbased paints had the strongest association with solvent exposure in the multivariate analysis is a surprising finding which is discussed further in section 5.1.

Workshops were associated strongly with personal solvent exposure in the univariate analysis, however, much of this variance was explained by paint brand and the ventilation characteristics, as shown by the fact that when this variable was added into the model, numerous categories dropped out due to collinearity, and R-square remained essentially the same.

Statistically significant associations were found between solvents and time spent on each task in the univariate analysis, and although the coefficients did not change much in the multivariate model none were statistically significant, although time spraying solvent colour and time mixing both came close to statistical significance. As mentioned previously the time spent on tasks included time when the sampler was switched off, meaning these tasks would all have stronger associations with solvents in personal air if the samplers had run continuously for the sample period.

Painters had higher exposure than apprentices, panel beaters and office staff in all individual solvents except for styrene for which panel beaters had the highest exposure, this was related to time spent bogging (using epoxy resin fillers) with a highly statistically significant coefficient of 1.22 (1.12-1.23). This represents an increase in exposure to styrene of 22% for each ten minutes spent using epoxy resin fillers.

Only one other collision repair exposure study ran regression analysis to look at associations with exposure. Bratveit et al 2004, found that the paint type (ie water-based vs solvent based) and time spent on paint job were both positively correlated in a multiple regression model with the additive factor of exposure limits (summed proportions of exposure limits reached). The R-square value of their regression model was .55 and also included number of painters per booth which was negatively correlated with solvent exposure.

A surprising find in our study was the lack of a similar association between solvent exposure and a water-based paint system. This study failed to find decreased exposure associated with one brand of water based [paints used in four workshops. This finding is inconsistent with that of Bratveit et al 2004, who found significantly lower exposure in both personal air and biological samples taken in shops using water-based paint systems. Bratveit et al took the same number of personal air measurements as this study (28) in the same number of workshops using water based paints (4) as this study. One difference is that only one of the four workshops in their assessment used PPG brand paints while the other three used Glasurit brand. Other possible differences include the ventilation characteristics of the mixing rooms.

Of note in relation to these findings is that there is no difference in clear coats and degreasing products in water and solvent based paint systems. These paint systems only differ in terms of the colour coat. Importantly this means that workshops using water-based paint systems have the same equipment and solvents in the mixing room as solvent-based paint shops. None of the shops sampled used exclusively water-based paint, so solvent based paints were being mixed and sprayed alongside water based paints in all these workshops.

The fact that video exposure monitoring showed no solvents in the spray booth during colour spraying, yet despite this, time spraying water-based paint showed a statistically significant increase in summed solvents per minutes painting water-based colour suggests that painting water-based paint is associated with solvent exposure, although that exposure may not be happening in the booth, but from other associated tasks. Of note is that mean ambient solvent of the two PPG types of paint – both solvent and water based are higher than mean Dupont, the only other brand we have an ambient mixing room sample from. These factors raise the question of whether another brand of water based paint might be associated with less general solvents than the PPG products.

5.1 Peak Exposures

Unfortunately the prototype equipment used for video exposure monitoring did not function sufficiently well to conduct a full survey of work practices and short-term exposure levels, and for this reason conclusions cannot be drawn from data. However the few examples recorded suggest the possibility of a misalignment between the potential for exposure and appropriate use of personal protective equipment. PPE use was poorest during degreasing of panels, suggesting that painters regard this as a low-exposure task. This assumption was not borne out in video exposure monitoring taken on one afternoon only. Peak exposure levels during degreasing of panels were similar to levels recorded during spraying in the booth, and higher than during paint mixing. This area of exposure monitoring urgently requires further research, as the consequences of misunderstanding exposure potential may be serious and widespread.

5.2 Biological exposure assessment

Results from the urine analysis component of this study do not allow interpretation. The lack of pre exposure samples made it difficult to analyse individual exposures, and the group was too small to show group trends.

However information from other studies suggest that dermal exposure is likely to be a significant contributor to solvent exposure in New Zealand, because of inappropriate use of PPE

5.3 Industry recommendations

Business owners and staff should be educated immediately to inform them of the significance of workshop ventilation characteristics on personal exposure outcomes. All workshops should be encouraged to install a hood over the gunwasher, ventilated to the outside. One workshop in this study with a custom-made hood over its gunwasher showed a significant difference to peak exposures during gunwashing (40ppm compared to 1200ppm; measured using video exposure monitoring). It is likely that this method (namely placing a ventilation hood over all gunwashers) may be highly effective in managing solvent levels in collision repair workshops, and protecting the health of all workers.

Further encouragement to use PPE, especially respirators during mixing paint and degreasing panels, and gloves for all tasks is needed to ensure workers are getting as much protection as they should from the harmful effects of solvents. A recommendations to not keep solvent soaked rags in the pockets, where they increase both respiratory and dermal solvent exposure, is reasonable despite

the findings not reaching statistical significance. It is likely this fact was due only to small numbers (two painters only) and not a lack of a causal link.

5.5 Research recommendations

Further research to assess short term peak exposures during various tasks is urgently required. The small amount of evidence gathered here suggest PPE practices may not be aligned with exposure potential. Generally use of PPE by painters was reasonable during gunwashing and spraying, but very poor during paint mixing and degreasing panels. Evidence from this study suggests exposure potential is not significantly lower for those tasks least attended to in terms of protective equipment. But this study was not able to fully assess these differences.

A survey conducted into ventilation characteristics at all workshops in New Zealand will allow greater understanding of the problem of solvent exposure in collision repair workers.

The ongoing study into neurobehavioural effects has the opportunity to take further exposure measurements. More measurements in workshops using

water-based paint other than PPG and further urine sampling may resolve some of the issues here which remain unclear.

Much research is needed into the use of solvent mixtures. A survey of product contents by evaporation rate compared against paint brands and personal exposures has the potential to shed light on why some brands are associated with higher exposures than others. The method of measuring alveolar air used by Caro and Gallego 2008 could be used in the assessment of how the body metabolises solvent mixtures, as such measurements can be taken very frequently over a controlled exposure period, and give a good indication of blood solvent levels.

5.6 Conclusions

These results clearly demonstrate that environmental factors, namely mixing room ventilation characteristics and the placement and ventilation of gunwashers are important contributors to exposure to solvents in collision repair workers. This method of building a model of exposure characteristics has been shown to be extremely useful for gaining insight into differences in exposure outcomes.

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7 APPENDICES

7.1 APPENDIX 1

7.1.1 Contents as reported in Material Safety Data Sheets (PPG)

Prepsol (degreasing agent)

30-60%	Toluene
10-30	cyclohexane
	Heptane and isomers
0-10	Other hydrocarbons
	Methyl cyclohexane
	n-hexane
	1,2,4 trimethylbenzene
	Xylene
	Ethylbenzene

Fast thinners

30-60%	Methyl isobutyl ketone,
10-30	Butanone
10-30	2-Methoxy-1-methylethyl acetate
10-30	Toluene

Slow thinners

30-60%	Ethyl 3-ethoxypropionate
10-30	Ligroine
	4-Methylpentan-2-one
	Butanone
0-10	Xylene
	Ethylbenzene
	Toluene

Medium thinners

30-60%	Methyl isobutylacetone
10-30	pentyl propionate
	n-Butyl acetate
	2-Methoxy-1-methylethyl acetate
	Solvent naphtha (petroleum), light arom.
	1,2,4-Trimethylbenzene
	Xylene

Primer white (2K)

10-30%	Talc,not containing asbestiform fibres
	Titanium dioxide
	Barium sulfate
5-10	n-Butyl acetate
	Xylene
1-5	2-Methoxy-1-methylethyl acetate
	Solvent naphtha (petroleum), light arom.
	Ethylbenzene

	1,2,4-Trimethylbenzene
0.5-1.5	Heptan-2-one

Primer grey (2K)

15-40%	Parachlorobenzotrifluoride
7-13	Barium sulfate
	Talc, not containing asbestiform fibres
	Titanium dioxide
5-10	Kaolin
1-5	Xylene
	Heptan-2-one
0.1-1	Ethylbenzene
	Carbon black respirable

Blue tint

10-30%	Butyl acetate
0-10	Ethyl 3-ethoxypropionate
	2-Methoxy-1-methylethyl acetate
	Xylene
	2-Butoxyethyl acetate
	Ethylbenzene
	Copper
	Toluene

Lemon yellow tint

30–60%	Lead sulfochromate yellow
10–30	n-Butyl acetate
0–10	Xylene
	Ethyl 3-ethoxypropionate
	Lead sulphate
	Barium sulfate
	2-Methoxy-1-methylethyl acetate
	Antimony trioxide
	Silicon dioxide
	2-Butoxyethyl acetate
	Ethylbenzene
	Toluene

Strong yellow

10–30%	n-Butyl acetate
	Iron hydroxide oxide
0–10	Ethyl 3-ethoxypropionate
	2-Butoxyethyl acetate
	Xylene
	2-Methoxy-1-methylethyl acetate
	Solvent naphtha (petroleum), light arom.
	Ethylbenzene
	Toluene

Orange tint

30-60%	n-Butyl acetate
0-10	Diketo Pyrrolo Pyrrol Pigment.
	2-Methoxy-1-methylethyl acetate
	Ethyl 3-ethoxypropionate
	Xylene
	Toluene
	Ethylbenzene
	Styrene

Moly red tint

30-60%	Lead chromate molybdate sulfate red
10-30	n-Butyl acetate
0-10	Lead chromate
	2-Methoxy-1-methylethyl acetate
	Xylene
	Ethyl 3-ethoxypropionate
	Ethylbenzene
	Toluene

Brilliant red

30-60%	n-Butyl acetate
0-10	2-Methoxy-1-methylethyl acetate
	Ethyl 3-ethoxypropionate
	Xylene
	2-Butoxyethyl acetate
	Solvent naphtha (petroleum), light arom.

	1,3-Benzenediol, 4-[4,6-bis(2,4-dimethylphenyl)-reaction products with 2-[(dodecyloxy)methyl]oxirane and 2-[(C10-16-alkyloxy)methyl]oxirane
	Ethylbenzene
	Toluene

Prussian blue

10–30%	n-Butyl acetate
	Xylene
0–10	Prussian blue
	2-Methoxy-1-methylethyl acetate
	Ethyl 3-ethoxypropionate
	Ethylbenzene
	2-Butoxyethyl acetate
	Solvent naphtha (petroleum), light arom.
	1,2,4-Trimethylbenzene
	Mesitylene
	Naphtha (petroleum), hydrodesulfurized heavy

Hardener

30–60%	n-Butyl acetate
15–40	Hexamethylene diisocyanate, oligomers
1–5	Xylene
0.5-1.5	Solvent naphtha (petroleum), light aromatic
0.5-1.5	Ethylbenzene
0.1–1	1,2,4-Trimethylbenzene
0.1-1	Mesitylene

4-Isocyanatosulphonyltoluene

Clear

10-30%	Benzyl alcohol
	(1,3-dimethylbutylidene)
	Ethylenediamine 10 - 30 25707-0-10
0-10	Mixture of Cycloaliphatic Amines
	Tertiary amine
	2,4,6-Tris(dimethylaminomethyl)phenol
	3,6-Diazaoctanethylenediamin
	Nonylphenol
	Xylene
	Ethylenediamine
	Ethylbenzene

Clear

30-60%	Xylene
0-10	Solvent naphtha (petroleum), light arom.
	Ethylbenzene
	1,2,4-Trimethylbenzene
	Bis(1,2,2,6,6-pentamethyl-4-piperidyl) sebacate
	Methyl 1,2,2,6,6-pentamethyl-4-piperidyl sebacate

Clear

10-30%	Solvent naphtha (petroleum), heavy arom.
	2-Butoxyethyl acetate
0-10	1-Methoxy-2-propanol

Hexane, 1,6-diisocyanato-, homopolymer, Me Et ketone oxime-blocked

1,2,4-Trimethylbenzene

Naphthalene

7.1.2 Contents as reported in Material Safety Data Sheets (Dupont)

Clear

20-30%	Solvent naphtha (petroleum), medium aliph.
10-20	Quartz (SiO2)
5-10	Glycerine
3-5	Silicon dioxide
0.3-1.0	1,2,4-Trimethylbenzene
0.3-1.0	Mesitylene
0.1-0.3	Octane

Clear

10-20%	n-Butyl acetate
	Ethyl 3-ethoxypropionate
5-10	Solvent naphtha (petroleum), light arom.(<0,1% benzene)
	4-Methylpentan-2-one
	Xylene
3-5	1,2,4-Trimethylbenzene
	2-Butoxyethyl acetate
	Pentyl acetate
1-3	2-Methylbutyl acetate
	Ethylbenzene
0.3-1.0	Mesitylene
0.1-0.3	Acetic acid
	Cumene

Medium gloss vinyl binder

30-40%	Acetone
10-20	n-Butyl acetate
10-20	Butanone
10-20%	Low boiling point naphtha (<0,1% benzene)
5-10%	Xylene
3-5%	Heptane (mixture of isomers)
1-3%	Amorphous silica - precipitated
1-3%	Dimethyl glutarate
1-3%	Ethylbenzene
	Toluene

fast thinner

30-40%	Toluene
10-20	n-Butyl acetate
	2-Methoxy-1-methylethyl acetate
	Xylene
5-10	Solvent naphtha (petroleum), light arom.(<0,1% benzene)
	Propane-1,2-diyl diacetate
3-5	1,2,4-Trimethylbenzene
	Ethylbenzene
	Pentyl acetate
1-3	2-Methylbutyl acetate
	1-Methoxy-2-propanol
0.3-1.0	Mesitylene
0.1-0.3	Cumene

Thinner

30-40	Toluene
10-20	n-Butyl acetate
	2-Methoxy-1-methylethyl acetate
	Xylene
5-10	Solvent naphtha (petroleum), light arom.(<0,1% benzene)
	Propane-1,2-diyl diacetate
3-5	1,2,4-Trimethylbenzene
	Ethylbenzene
	Pentyl acetate
1-3	2-Methylbutyl acetate
	1-Methoxy-2-propanol
0.3-1.0	Mesitylene
0.1-0.3	Cumene

Slow thinner

20-30%	Toluene
10-20	n-Butyl acetate
	2-Methoxy-1-methylethyl acetate
5-10	Solvent naphtha (petroleum), light arom.(<0,1% benzene)
	Pentyl acetate
	Propane-1,2-diyl diacetate
	Xylene
3-5	1,2,4-trimethylbenzene
	2-methylbutyl acetate
1-3	Ethylbenzene
	1-methoxy-2-propanol

0.3-1.0	Mesitylene
0.1-0.3	Cumene

Degreaser

50-60%	Naphtha (petroleum), hydrotreated light(<0,1% benzene)
30-40	Naphtha (petroleum), hydrodesulfurized heavy (<0,1% benzene)
5-10	Toluene
10-3	1,2,4-Trimethylbenzene
	Xylene
0.3-1.0	Mesitylene
	n-Propylbenzene
	Ethylbenzene

Red satin pearl

20-30%	Xylene
10-20	Iron oxide
5-10	n-Butyl acetate
	Ethylbenzene
	Mica
0.3-1.0	Methyl methacrylate
	Pentyl acetate
0.1-0.3	Ethanediol
	2-Hydroxyethyl acrylate
	Toluene

Blue satin pearl

20-30%	Xylene
10-20	Rutile (TiO2)
5-10	n-Butyl acetate
	Ethylbenzene
	Mica
0.3-1.0	Methyl methacrylate
	Pentyl acetate
0.1-0.3	Ethanediol
	2-Hydroxyethyl acrylate
	Tin oxide
	Toluene

violet blue

30-40%	Xylene
10-20	n-Butyl acetate
5-10	Pigment blue 60
	Ethylbenzene
1-3	Pentyl acetate
	Rosin, hydrogenated
0.3-1.0	Methyl methacrylate
0.1-0.3	2-Hydroxyethyl acrylate
	Toluene

Medium yellow

40–50	Lead sulfochromate yellow
10–20	Xylene
5–10	n-Butyl acetate
3– 5	Ethylbenzene
0.3-1.0	Methyl methacrylate
	Pentyl acetate
0.1-0.3	Ethanediol
	Toluene

7.2 Appendix 2

Table 17 Univariate analyses of painters and apprentices

	Obs (n=90)	R-square	Proportion compared to reference	Lower 95% CI	Upper 95% CI
workshop		.54			
1			4.91*	1.31	18.34
2	ref				
3			.84	.17	4.24
4			5.16*	1.38	19.28
5			2.42	.73	8.07
6			1.91	.61	5.99
7			1.77	.47	6.60
8			1.52	.41	5.70
9			4.52*	1.21	16.88
10			1.91	.57	6.37
11			2.16	.76	6.12
12			4.92**	1.63	14.83
13			5.54*	1.10	27.86
14			1.55	.46	5.15
15			1.86	.56	6.21
16			6.74**	2.24	20.31
Paint brand		.07			
De Beer			.58	.22	1.50
Dupont			.76	.44	1.33
PPG solvent-based			1.57	.89	2.76
PPG water-based	ref				
Spies Hecker			.66	.21	2.04
Paint system		0.0			
Water based	ref				
Solvent based			.99	.60	1.65
Number of painters		.07	1.15	.98	1.34
Number of employees		0.0	.99	.95	1.04
Natural ventilation†		.03	1.002	.99	1.004
Gunwasher ventilation		.10			
In mixing room internally ventilated	ref				

In mixing room externally ventilated		1.23	.70	2.18
In workshop internally ventilated		1.51	.70	3.24
In workshop externally ventilated		1.94*	1.04	3.61
Mixing room extraction	.05			
Floor level next to mixing bench	ref			
Wall level next to mixing bench		.82	.46	1.46
Floor level away from mixing bench		1.25	.69	2.29
Wall level away from mixing bench		.68	.26	1.81
		Ratio ‡		
Time spraying	.19	1.05**	1.02	1.08
Time spraying primer	.001	1.02	.83	1.24
Time spraying colour (solvent)	.17	1.07**	1.02	1.11
Time spraying colour (water)	.02	1.05	.94	1.17
Time spraying clear coat	.10	1.10*	1.01	1.19
Time mixing	.09	1.12*	1.00	1.24
Time gunwashing	0.0	.99	.75	1.33
Time degreasing panels	.01	1.04	.90	1.20

* p value <0.05

** p value <0.01

‡ Ratio of increase in solvents with each 10 minutes of increased exposure.

Table 18 Multivariate analysis of painters and apprentices

Model R-square = .61 **Model Prob> F =0.0082**		**Obs.**	**coefficient**	**Lower 95% CI**	**Upper 95% CI**
Paint brand					
De Beer	ref				
Dupont		15	1.91	.57	6.38
PPG solvent-based		14	2.43	.89	6.70
PPG water-based		14	3.30	.50	22.00
Spies Hecker		2	2.06	.45	9.44
Mixing room extraction					
Floor level next to mixing bench	ref				
Wall level next to mixing bench		11	.45	.13	2.09
Floor level away from mixing bench		10	1.54	.61	3.93
Wall level away from mixing bench		3	.51	.12	2.09

Gunwasher ventilation					
In mixing room internally ventilated	ref				
In mixing room externally ventilated		17	.97	.42	2.26
In workshop internally ventilated		6	1.61	.45	5.72
In workshop externally ventilated		12	1.82	.97	3.42
Time spraying primer		48	1.04	.86	1.25
Time spraying colour (solvent)		48	1.09*	1.01	1.17
Time spraying colour (water)		48	1.20	.99	1.45
Time spraying clear coat		48	.93	.79	1.09
Time mixing		48	1.09	.97	1.23
Time gunwashing		48	.71	.50	1.03
Time degreasing panels		48	1.06	.92	1.23

* p value <0.05

** p value <0.01

‡ Ratio of increase in solvents with each 10 minutes of increased exposure.

7.3 Appendix 3

Information Sheet

Neurotoxic effects of occupational solvent exposure

Principal Investigators:
Professor Jeroen Douwes, Director of the Centre for Public Health Research
Professor Neil Pearce, Centre for Public Health Research, Massey University, Wellington
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Dr Duncan Babbage, School of Psychology, Massey University
Mr Samuel Keer, Centre for Public Health Research, Massey University, Wellington

Venue of study:
Centre for Public health Research, Massey University, Wellington Campus.

What is this study about?
We are inviting you to take part in a study about solvent exposures and neurological symptoms (brain function). It is estimated that 100,000 workers are potentially exposed to solvents in New Zealand but there has been little research into the effects of these occupational exposures.

The study is made up of two parts. For the first part of the study we will interview 400 people working in the collision repair industry to ask about their work and health. We will compare this information to interviews from 200 people who are not in this industry. If you decide to take part in the study we will also ask you to wear a sampling canister which is a small device that measures your exposure to solvents and other chemicals. The canister is attached to a belt worn around your waist in the morning and worn throughout your work day (it only weighs about 800 grams). We will also ask you for a sample of your urine to be taken at the end of the sampling shift. Participation in the study would take approximately 30-40 minutes in total and would be at your workplace. We have obtained permission from your manager before approaching you.

We will invite a small group of 150 of the spray painters from the questionnaire study to take part in the second part of our study which looks more closely at the relationship between solvent exposure and brain function. This part of the study will involve wearing the canister again. We will also measure exposure by using Video Exposure Monitoring in a smaller number of workers. This requires wearing a sampler in a small backpack and someone following you with a video camera. The Video Exposure Monitor will tell us the levels of exposure to different solvents during different work tasks. If you are asked to take part in the second part of the study, which is of course voluntary, you will be invited to sit down with our nurse and complete a set of brain function tests. The computer assisted tests are very easy and will be conducted on a Monday morning and a Friday afternoon. We ask that you abstain from alcohol consumption two days prior to these tests. Participation in the second part of the study would be at your workplace. It will take a couple of minutes to attach the canister and Video Exposure Monitoring equipment, and a further 30-40 minutes on the Monday morning and the Friday afternoon. Again, this will only be done with a small number of workers from the main group of 400 and is entirely voluntary.
The research nurse will show the brain function tests to the doctor and then talk to you about the results of the tests with you. If there are any concerns she will ask that these results be sent to your GP.

If you wish to participate, please read through this information sheet, and complete and return the enclosed consent form, or contact us at the 0800 number or email address supplied. We can then get in touch with you to arrange a suitable time.

All information you give us is confidential. Urine samples will be labelled with a number, and analysed at Syft Laboratories in Christchurch for solvent related content only. Each questionnaire will be entered into a database using ID numbers. When all the interviews have taken place we will analyse the information, for example looking at the percentage of the workforce who are exposed to particular solvents, or levels of solvents, and so on. **No**

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individual information, names or employer information will be published. Questionnaires will be seen by named researchers only, and when the study is completed all questionnaires will be locked away in filing cabinets, which will be the responsibility of the Director of the Centre for Public Health Research. We may try to contact you in the future to invite you to take part in a follow-up to this study. You are under no obligation to do so.

You have the right to:

- ❍ decline to participate
- ❍ refuse to answer any particular questions
- decline to give urine ?
- ❍ withdraw from the study at any time
- ❍ be given access to a summary of the study findings when it is completed

This project has received ethical approval from the Multi-region Ethics Committee. Application MEC/10/08/083.

Please contact us at the Centre for Public Health Research to discuss any queries or concerns about the study.

Thank you very much for your time in considering this study.

We hope that with your help we can find out more about the neurological effects of occupational solvent exposure in New Zealand.

7.4 Appendix 4

Workshop checklist

Number of staff	painters	
	panel beaters	
	office staff	
	office staff/ painters	
	office staff/ panel beaters	

Paint	Brand	
	Waterbased Y/N	

Booth extraction	Floor extraction only, full floor	
Tick one	Floor extraction only, less than full floor (describe proportion)	
	wall extraction and floor extraction (describe)	
	wall extraction only (describe)	

Booth extraction description (proportion of floor/wall, height above floor level, etc)

Booth extraction filters	frequency of change	
	Last changed	

Mixing room extraction	floor level extraction next to mixing bench	
	floor level extraction away from mixing bench	
	wall extraction at bench height, behind/next to mixing bench	
	wall extraction at bench height away from mixing bench	
	wall extraction, head height or higher	

Describe mixing room extraction:

volume of rubbish in mixing room (rags, tins pottles) m^3	
bin with lid closed	
bin with open/ no lid	
volume of rubbish in workshop	
bin with lid closed	
bin with open/ no lid	
Number of open pottles and solvent containers in mixing room	
number of open pottles and solvent containers in workshop	

Gunwasher:	In mixing room, internally ventilated	
Tick one	In mixing room, externally ventilated	
	In workshop internally ventilated	
	In workshop, externally ventilated	
	In workshop, unventilated	

Describe gunwasher:

time spent spraying in booth	Total
undercoat	
colour coat	
clear coat	

Time spent spraying in workshop (all staff)	Total
undercoat	
colour coat	
clear coat	

Persons painting a boot or engine interior or under a car in the booth		
person	minutes	Total

Persons painting a boot or engine interior or under a car in the workshop		
person	Minutes	Total

Please complete a floor plan including dimensions, average stud height, and size of openings

THANKS

7.5 Appendix 5

Air-Sampling Record Sheet

ID number:	S	E					

Name:

Employer:

Town:

Sample Train ID:	Remote sampler unit (*if used*):
Canister ID:	Date of vacuum:
Canister volume:	Flow rate:
Date:	
Start Time:	Pressure:
Finish Time:	Pressure:

Tasks performed today:	YES	*Please indicate YES: Tick, NO: Leave empty, N/A: Strikethrough task name*
Spraying primer paint	☐	Hours/minutes today _____ Solv. Based ☐ Wat. Based ☐ 2k ☐
Spraying colour paint	☐	Hours/minutes today _____ Solv. Based ☐ Wat. Based ☐ 2k ☐
Spraying topcoat paint	☐	Hours/minutes today _____ Solv. Based ☐ Wat. Based ☐ 2k ☐
Mixing paint	☐	Hours/minutes today _____ Solv. Based ☐ Wat. Based ☐ 2k ☐
Bogging/filling	☐	Hours/minutes today _____ Bog used: _____
Sanding and Chiselling	☐	Hours/minutes today _____
Masking out	☐	Hours/minutes today _____
Degreasing panels/parts	☐	Hours/minutes today _____ Cleaner used: _____
Disassembly/reassembly	☐	Hours/minutes today _____
Using Break/parts/gun cleaners or aerosols	☐	Hours/minutes today _____ Products used: _____
Office/admin work	☐	Hours/minutes today _____

Notes on above and general:

Gloves worn? Mixing ☐ Priming ☐ colour/clear ☐ Degreasing ☐ bogging ☐ Sanding ☐ Cleaning (gun) ☐

Skin exposed to solvents/paints/during spray painting? (*please describe)*

Facial Hair? Yes ☐ No ☐ (*Describe*) _____

Resp. protection type used spraying in booth: ☐ Air-fed full-mask ☐ Cartridge half-mask ☐ None

Resp. protection type used spraying outside booth: ☐ Air-fed full-mask ☐ Cartridge half-mask ☐ None

Physical symptoms experienced today:_____

_____