Direct and Indirect Cognitive and Psychological Consequences of Workplace Neurotoxic Exposure

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B.A. (Hons). M.APP.PSYCH

This Thesis is presented for the degree of professional doctorate in Clinical Psychology at Murdoch University 2009.
I declare that this thesis is my own account of my research and contains as its main content work which has not previously been submitted for a degree at any tertiary education institution

Leonie Wilson Coxon
ABSTRACT

Cognitive assessments were conducted on aircraft crew who reported symptoms following exposure to jet oil engine emissions from BAe-146 aircraft. Results demonstrated impairments on tests of reaction time, processing speed and fine motor skills in most participants. Findings were significant but with such a small sample this may not be representative. However if extrapolated across the aviation industry, could indicate significant aviation safety problems. The possibility of consistent neuropsychological impairments with exposure to jet engine emissions indicates a need for more robust studies.

A second study investigated the psychological impact on spouses of aircraft maintenance engineers affected by the toxic chemicals used in the Deseal/Reseal program of F-III aircraft. Ninety one spouses of affected RAAF workers were administered the Personality Assessment Inventory (PAI); Zarit Burden Interview (ZBI); and Spouse Questionnaire (SQ). Controls were twenty five aged matched spouses of RAAF personnel not involved in the program. Results demonstrated significant differences between experimental group and controls on PAI Somatic Complaints, Anxiety, Depression, and Stress scales. Spouse Questionnaire of coping skills, demonstrated that the experimental group had significant difficulties coping with spouses. ZBI administered to experimental group only, indicated that their burden of stress was moderate to severe.
Despite limited control group, results were considered significantly robust and statistically significant, which suggested it unlikely that results would have been different, given a larger sample.

In the final study cognitive assessments were conducted on forty two health care workers exposed to the chemical glutaraldehyde. Workers were divided into two experimental groups: EXP1, currently working with glutaraldehyde, with protective measures; EXP2, previously worked with glutaraldehyde with poor protection. Controls were eighteen age matched health care workers, not exposed to glutaraldehyde.

All groups were administered the Hospital Anxiety and Depression Scale (HADS) for emotional impact of chemical exposure. Results indicated significant impairments in information processing speed, reaction time and accuracy of responses in experimental groups compared with controls. Differences were more significant in the extensively exposed EXP2 group, who also had higher elevations on the depression scale of the HADS.

Results demonstrated significant neuropsychological and emotional effects in individuals extensively exposed to glutaraldehyde, using few protective measures, compared with less severely exposed workers or controls. Implications of test results and importance of adherence to health and safety regulations are discussed. If extrapolated across the health care professions this could indicate occupational health and safety issues in hospitals and clinics, where chemicals are used.
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CHAPTER 1
Introduction and Literature Review

1.1 Overview of the Chapter

The first section reviews the historical background of neurotoxic substances and incorporates the accumulation of knowledge regarding the adverse effects of neurotoxins on the human body. It also outlines the effects of neurotoxins on the functioning of the human brain. The classification of neurotoxins and their specific neuropsychological and neurological effects are discussed and occupations which are considered to be at risk are outlined. The legislation which has been passed to monitor use of industrial chemicals is also documented and discussed.

The second section outlines the extent of the problem for workers in occupational settings where they are exposed to neurotoxic chemicals on a regular basis. The requirements for safety measures to protect workers, which are not always acknowledged or implemented in many workplaces, will also be discussed. The long term and accumulative effects of chemical exposure will be outlined.

The final section outlines the aims and purposes of the present studies. It will document and describe any deleterious effects on the cognitive and emotional functioning of aircraft flight crew and health care workers who are exposed to neurotoxic chemicals in their workplaces. It will also address the impact on the spouses of aircraft maintenance engineers who were adversely affected by neurotoxic exposure in the course of their work.
1.2 Historical Background of the Effects of a Range of Neurotoxic Substances on Workers in Different Workplace Settings

1.2.1 Organic Solvents

Organic solvents are chemicals used for extracting, dissolving or suspending materials not soluble in water. Such materials are fats, resins, oils, lipids, cellulose derivatives, waxes, plastics and polymers. Most solvents are liquids and their chemical composition may be simple, comprising a simple chemical substance like carbon tetra chloride, or they may be complex, comprising a mixture of chemical substances, which can sometimes be quite variable like those derived from petroleum (Hartman, 1995).

Over the 100 years since solvents were first produced, evidence has accrued suggesting their involvement in neurotoxic syndromes. It is estimated that approximately 10 million workers in United States of America are exposed to solvents on a daily basis, which suggests a sizable population at risk for neurotoxic exposure effects (Hartman, 1995).

Workers such as house painters, machine degreasers, printers and boat builders are among those exposed to organic solvents, like mineral turpentine, degreasers and glues, on a daily basis. These materials can enter the body by skin absorption, by inhalation or ingestion (Williams & Lees-Hadley, 1996; Baker, 1994; Edling et al., 1990).

Because solvents are lipophilic and pass through fat rich neuronal tissue, exposure to these chemicals has been implicated in a wide variety of
neuropsychological symptoms. Among these symptoms are; learning and memory difficulties; perceptual and information speed slowing; visuo spatial skills deficits; and psychomotor dysfunction (Singer, 1990; Ryan, Morrow, & Hodgeson, 1988; Spencer & Schaunburg, 2002; Morrow, Stein, Bagovich, Condray & Scott, 2001; Lezak, 2004).

However a number of studies reporting cognitive deficits following solvent exposure have been criticized on methodological grounds. Some researchers have identified weaknesses in solvent studies which included: selection bias in recruiting research participants; variability in tests selected to assess neurobehavioural functioning; between study variability in the solvents examined and the neurobehavioural deficits reported; over-reliance on subject recall in establishing pre-morbid functioning; failure to demonstrate dose response relationships; failure to control for potential confounders, such as education gender and psychiatric function; and small but statistically significant findings of doubtful clinical significance (Williams & Lees-Haley, 1996; Fiedler, 1996; Lees-Haley, 1997).

In 1996 Fiedler briefly reviewed neuropsychological tests which have been used to evaluate the effects of neurotoxicants. She identified factors which may heighten sensitivity to neurotoxins and discussed test parameters which would increase the sensitivity of neuropsychological tests in low level exposures. In conclusion Fiedler stated that the detection of behavioural performance decrements among susceptible individuals, such as those with multiple
chemical sensitivity will require more difficult tests than those used in current neuropsychological test batteries (Fiedler, 1996).

### 1.2.2 Acute Exposure to Solvents

During and immediately following acute exposure to solvents and related organics, individuals may complain of headaches, dizziness, undue fatigue, nausea mental confusion or ataxia. Others may have respiratory symptoms or skin irritations. Solvents which cause these problems may include glues, paints, marking pens, thinners and degreasers (Anger, 1992; Hartman, 1995; Lezak, 2004).

Specific cognitive deficits have been found among individuals exposed acutely to solvents in their workplace. Such workers have been found to have deficits in speed of information processing, co-ordination, concentration and vocabulary tasks (Chang & Dyer, 1995; Hartman, 1995; Costa & Manzo, 1998; Nilson et al., 1996).

The severity of dysfunction tends to be associated with the duration and intensity of exposure to the solvent. However, the effects of exposure to many organic chemicals is qualitatively similar, the toxic potential of each chemical, as measured by their individual exposure standards, can vary substantially.

Table I outlines a clinical diagnostic system integrating reversibility of findings and type of function, with DSM-III terminology for acute exposure to solvents (White et al., 1992a, as cited by Chang & Dyer, 1995).
TABLE I

I ACUTE ORGANIC MENTAL DISORDERS

A. Acute intoxication
   1. Duration: minutes to hours
   2. Residua: none
   3. Symptoms: CNS depression, psychomotor or attentional deficits

B. Acute toxic encephalopathy
   1. Symptoms: confusion, coma seizures
   2. Pathophysiology: cerebral oedema, CNS capillary damage, hypoxia
   3. Residua: permanent cognitive deficit may occur
      (White et al., 1992a, as cited in Chang & Dyer, 1995)

Studies of the cognitive effects of acute low dose and short-term exposures to solvents have identified laboratory tests of attention and monitoring as being the most sensitive to this type of exposure, but many of the most sensitive clinical tests have not been used in laboratory research on neurotoxins (Anger, 1992; Lezak, 1995 & 2004).

1.2.3 Chronic Exposure to Solvents

Most chronic solvent toxicity occurs in the workplace as a result of exposure to fumes from such substances as paints, glues and cleaning fluids (e.g. toluene, perchlorethylene and solvent mixtures). Other toxic solvents commonly found in the workplace are petroleum fuels, lubricating and degreasing agents, and chemicals used in the manufacture of plastics.
Table II outlines a clinical diagnostic system for chronic organic mental disorders.

**TABLE II**

### CHRONIC ORGANIC MENTAL DISORDERS

**A. Organic affective syndrome**
1. Symptoms: mood disturbance (depression, irritability, fatigue, anxiety)
2. Duration: days to weeks
3. Residua: none

**B. Mild chronic toxic encephalopathy**
1. Symptoms: fatigue, mood disturbance, cognitive complaints
2. Course: insidious onset, duration: weeks
3. Cognitive deficits: may include attentional impairment, motor slowing or in-coordination, visuo-spatial deficits, short-term memory loss
4. Residua: improvement may occur in absence of exposure, but permanent mild cognitive deficits can be seen

**C. Severe chronic toxic encephalopathy**
1. Symptoms: cognitive and affective change sufficient to interfere with daily living
2. Cognitive deficits: same as in mild chronic toxic encephalopathy, but more severe
3. Neurological deficits: abnormalities seen on some neurophysiological or neuroradiologic measures (e.g., computed tomography (CT), electromyography (EMG),
magnetic resonance imaging (MRI), and electroencephalogram (EEG)

4. Course: insidious onset, irreversible

5. Residua: permanent cognitive dysfunction

(White et al., 1992a, as cited in Chang & Dyer, 1995)

Among the subjective complaints of workers exposed to the above chemicals are: fatigue, memory and concentration difficulties, mood changes, depression, anxiety, social withdrawal, sleep disturbances and both sensory and motor symptoms involving the extremities (Gronwall, 1997; Haut et al., 1999).

In a number of studies of individuals exposed on a long-term basis to solvents, abnormal EEG patterns and brain atrophy have been found (Kilburn, 1994; Varney et al., 1998).

Other studies by Ford demonstrate chromosome abnormalities in human lymphocytes which were thought to reflect exposure to chemicals (Ford, 1998 & 1999).

Long-term exposure can also lead to lowered cerebral blood flow, particularly in the fronto-temporal areas (Hagstadius, Orback, Risberg & Lindgren, 1989).

Maximilian et al., investigated 32 industrial workers who were exposed to organic solvents over an average of 24.5 years, compared with controls. Significant correlations were found between age, length of exposure and regional cerebral blood flow (rCBF) levels. The results indicated the potential of
the rCBF method for elucidating functional cortical changes related to neurotoxic effects of organic solvents (Maximilian et al., 1982).

According to White and Proctor, chronic exposure to solvents can be associated with permanent cognitive changes, which can include attentional capacity, executive function, visuo-spatial skills, short term memory and mood or affect (White & Proctor 1997).

Sensory and motor changes can include impaired visual acuity, impaired colour vision, altered sense of smell and hypersensitivity to common environmental odours. Dick and Semple et al reported neurological deficits in solvent exposed painters, which included impaired colour vision, cognitive deficits, tremor and loss of vibration sensation. In this study 35 painters were assessed together with 42 community controls. Neuropsychological tests included Trail Making Tests A & B, Benton Visual Retention Test, Continuous Performance Test and Symbol Digit Substitution Test, Associate Learning Test and Delayed Associate Recall. All participants showed cognitive and neurological impairments on the above assessment instruments (Dick et al., 2000).

Such changes have been related to supra modal learning impairments and recall deficits. Other changes demonstrated have included; motor incoordination, cognitive inflexibility, poor verbal fluency and verbal memory, lowered manual dexterity, and numbness and weakness of the extremities (Haut et al., 1999; Dick et al., 2000).
Lezak states that specific cognitive deficits among individuals exposed to neurotoxins have been found on tests involving processing speed, co-ordination, concentration, memory and vocabulary (Lezak 1995 & 2004).

Morrow, Robin et al documented specific deficits in both forward and reversed digit span and in the acquisition of new information. Their findings suggested that the amount of material that the individuals exposed to neurotoxins were capable of processing, was significantly reduced (Morrow, Robin et al., 1992).

Not all studies have found neuropsychological dysfunction among solvent exposed workers. A study of solvent exposed South African paint workers by Myers et al failed to show neuropsychological deficits in 228 solvent exposed workers. However, these researchers did consider in their conclusions that the tests they used were perhaps not particularly sensitive to subtle neuropsychological changes, nor were some of them appropriate for the mostly illiterate paint workers (Myers et al., 1999).

Although an early study by Fiedler et al with 11 patients with multiple chemical sensitivity due to low level exposure to neurotoxins demonstrated neuropsychological test findings suggestive of CNS involvement, they later questioned such findings. In a later study, Fiedler et al found that the prevalence of an AXIS I Psychiatric Diagnosis was greater in both multiple chemical sensitivity patients and those with chronic fatigue, than in controls. They concluded that neuropsychological test results did not substantiate reported cognitive impairments. However a final comment was made regarding
the lack of sensitivity of the neuropsychological tests used in their research (Fiedler et al., 1992; Fiedler et al., 1996).

Reasoning and problem solving abilities may also be impaired in neurotoxically exposed workers, as well as visuo-spatial functions. Executive functioning disorders have been demonstrated, and may present as reduced spontaneity, mental inflexibility, impaired planning ability and situation dependency (Haut et al., 1999).

Emotional disturbances are often evident among chronically chemically exposed workers and can present as somatic preoccupations, depressive tendencies, anxiety and social withdrawal. A study by Morrow et al investigated psychiatric symptoms among workers exposed to organic solvents. In this study, 30 solvent exposed adults were evaluated via the Symptom Checklist - 90-R, (SCL-R), the profile of Mood Scales (POMS) and the Beck Depression Inventory (BDI). These 30 workers were compared to 30 normal controls. All three measures demonstrated statistically significant differences between the chemically exposed workers and the controls (Morrow et al., 1993).

Differences between the effects of particular solvents and how individuals are affected by them are the result of interactions between many variables. These include; duration; intensity of exposure; age; physical status; emotional state; rate of metabolism; and the particular variety of neurotoxin involved (Morrow et al., 1993; Lezak, 1995 & 2004; White & Proctor 1997; Costa & Manzo, 1998).
1.3 The Current Situation in Workplaces

There are many occupations in which workers are exposed to toxic chemicals which can cause health problems. Some of these chemicals have been found to have a detrimental effect on the human brain and as a result can cause neuropsychological dysfunction. These chemicals are known as neurotoxins because they are able to pass through the blood brain barrier and affect the functions of the brain.

There are many chemical compounds present in a variety of work settings which can produce a range of impairments in the human nervous system. The condition which arises from exposure to such compounds is known as neurotoxicity. Neurotoxic substances may be chemically manufactured, such as Glutaraldehyde, or they may be naturally occurring, such as lead or uranium.

Neurotoxic impairments among exposed workers can range from subtle neurological and behavioural disturbances, to more severe encephalopathy and peripheral nerve disease (Costa & Manzo, 1998; Baker, 1994; Edling et al., 1990; Hartman, 1995; Nilson, Bärregard & Bächtman, 1996; Spencer & Schaunburg, 2000; Lezak, 1995 & 2004).

There can be subtle changes in brain function following neurotoxic exposure, such as concentration and memory difficulties, confusion, and language dysfluency. However these symptoms are sometimes put down to “feeling unwell”, suffering “flu type” infections, or just “having a bad day” and are often ignored. However with sustained exposure to neurotoxic chemicals, especially
where few or no protective measures are put in place, serious health problems, such as encephalopathy may develop. In serious conditions such as these, brain function deteriorates significantly and physical or pathological changes can also be observed among the most severely exposed workers.

Although the toxic effects of certain chemicals and minerals on the human body and central nervous system have been documented for centuries, it has only been since the 1970's that occupational neurotoxicity has emerged as a specialized area of study. This is due to the more frequent use of chemicals in industrial, mining, aviation, agricultural and medical settings (Singer, 1990).

The number of situations in which neurotoxicity has been recognized in exposed workers has also grown significantly over the past 25 to 30 years (Costa & Manzo, 1998; Spencer & Schaunburg, 2000).

According to Costa & Manzo, (1998), 30% of the workplace chemicals, for which the American Conference of Governmental Industrial Hygienists have recommended maximum exposure concentrations, have been so listed in part because of their neurotoxic potential. Many other chemicals also have neurotoxic properties, but they have not as yet been recognised.

Toxic chemicals can be divided into five general groups. These are:-

- Solvents and Related Organics
- Pesticides
- Metals and Metalloids
- Gases
- Miscellaneous compounds (these may include formaldehyde, glutaraldehyde and naphthalene).

The above groups of compounds can be toxic to either the central nervous system, the peripheral nervous system or both. Their mode of action is generally multifactorial and the effects are not necessarily predictably reversible (Spencer & Schaunburg, 2000).

A report on multiple chemical sensitivity (MCS) by the Interagency Workgroup on MCS in 1998 stated:

“The scientific literature is currently inadequate to enable determination of the associations between human exposure(s) to chemicals in the development or exacerbation of MCS. Targeted research would reduce this uncertainty. Increased scientific knowledge about MCS and the role of environmental chemicals will inevitably be put into context of benefits and risk. Virtually all chemicals in use convey both benefits and risks. Every technology, no matter how beneficial, can exert a negative impact on some sector(s) of society. Many chemicals have well established toxicologic and allergenic properties; undoubtedly, others will be found to have adverse effects in the future. Public health leaders and other risk managers have an obligation to ensure that the benefits of technologies justify the risks. The public health vision is health for the entire population. The reality of public health will always involve balancing maximum benefit and minimum harm to the public’s health and well-being”.

(IWMCS August 1998).
The occupations which are at risk due to neurotoxic exposure are listed below in Table III.

**TABLE III**

<table>
<thead>
<tr>
<th>Occupations at Risk</th>
<th>Neurotoxic Substances</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agriculture and farm workers</td>
<td>Pesticides, herbicides, insecticides, solvents</td>
</tr>
<tr>
<td>Chemical and pharmaceutical workers</td>
<td>Industrial and pharmaceutical substances</td>
</tr>
<tr>
<td>Degreasers</td>
<td>Trichloroethylene</td>
</tr>
<tr>
<td>Dentists and dental hygienists</td>
<td>Mercury, aesthetic gases, Glutaraldehyde</td>
</tr>
<tr>
<td>Dry cleaners</td>
<td>perchloroethylene, trichloroethylene other solvents</td>
</tr>
<tr>
<td>Electronic workers</td>
<td>Lead, methyl ethyl ketone, methylene chloride, tin, trichloroethylene, glycol ether, xylene, chloroform, Freon, arsine</td>
</tr>
<tr>
<td>Hospital personnel</td>
<td>Alcohols, anaesthetic gases, ethylene oxide and Glutaraldehyde (cold sterilization)</td>
</tr>
<tr>
<td>Laboratory workers</td>
<td>Solvents, mercury, ethylene oxide, Glutaraldehyde</td>
</tr>
<tr>
<td>Painters</td>
<td>Lead, toluene, xylene, other solvents</td>
</tr>
<tr>
<td>Plastic workers</td>
<td>Formaldehyde, styrene, PVC’s</td>
</tr>
<tr>
<td>Printers</td>
<td>Lead, methanol, methylene chloride, toluene, trichloroethylene, other solvents</td>
</tr>
<tr>
<td>Rayon workers</td>
<td>Carbon disulfide</td>
</tr>
<tr>
<td>Steel workers</td>
<td>Lead, other metals, phenol</td>
</tr>
<tr>
<td>Transportation workers</td>
<td>Lead (in gasoline), carbon monoxide, solvents</td>
</tr>
<tr>
<td>Hobbyists</td>
<td>Lead, Toluene, glues, solvents</td>
</tr>
<tr>
<td>Office workers</td>
<td>Solvents</td>
</tr>
</tbody>
</table>

(Hartman, 1995)
In evaluating individuals exposed to toxins it is important to take into account the nature of the exposure. High level acute exposure is typically a one time event, occurring as an accidental release of toxic substances. Although long-term chronic exposure to lower levels of toxins may not have the observable effects of the single acute exposure, the cumulative effects of the toxin may nevertheless result in neurotoxic disorders over time (Baker, 1994, Lezak, 1995 & 2004).

Over the past decade or two, the issue of low level chemical exposures and the effects that such exposures may cause, has received considerable attention. While conventional toxicological concepts can explain the effects of high toxic exposures, the issue of effects from low level chemical exposure is a relatively new area of study (Winder & Balouet, 2001).

A study of workers with very low level exposures has demonstrated only mild deficits on attentional tasks requiring mental shifting and response speed, but no memory deficits or distress symptoms. However, low level exposure to chemicals which are used as nail treatments in beauty salons, has been associated with mild cognitive inefficiencies (Lezak, 2004).

Neurotoxic symptoms may differ greatly with variations in the degree and duration of exposure. Some neurotoxic effects may take time to evolve, and it may be decades after the exposure before the effects are clearly evident. There is also evidence to suggest that extremely low levels of pollutants that are insufficient to produce neurological symptoms, may predispose susceptible
individuals to the later development of a progressive nervous system disorder
(Costa & Manzo, 1998; Nilson et al., 2002).

Table IV below, illustrates a variety of neurological effects which have been observed following exposure to various chemicals in the workplace.

TABLE IV

The Neurological Effects of some Commonly Used Neurotoxins

<table>
<thead>
<tr>
<th>Chemical</th>
<th>Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Solvents</strong></td>
<td></td>
</tr>
<tr>
<td>Carbon disulfide</td>
<td>mild peripheral neuropathy, cranial neuropathy, ataxia, impairment of psychomotor function, Parkinson's Syndrome Psychosis, emotional instability, memory impairment</td>
</tr>
<tr>
<td>Methanol</td>
<td>impaired visual acuity, blindness, headache</td>
</tr>
<tr>
<td>Perchloroethylene</td>
<td>Encephalopathy, impaired psychomotor function, neurasthenia</td>
</tr>
<tr>
<td>Styrene</td>
<td>Neurobehavioural and neuroendocrine alterations</td>
</tr>
<tr>
<td>Toluene</td>
<td>Ataxia, emotional lability</td>
</tr>
<tr>
<td>Trichloroethylene</td>
<td>Cranial neuropathy, memory impairment</td>
</tr>
<tr>
<td><strong>Pesticides</strong></td>
<td></td>
</tr>
<tr>
<td>Chlorophenoxy compounds</td>
<td>Headache, dizziness, myotonia, neuropathy fatigue</td>
</tr>
<tr>
<td>Cyclodienes (chlordane, aldrin)</td>
<td>Ataxia, seizures, EEG pattern changes, chronic Motor disorders, psychological disorders</td>
</tr>
<tr>
<td>Dithiocarbamates</td>
<td>Muscle weakness, dizziness, inco-ordination</td>
</tr>
<tr>
<td>Substance</td>
<td>Effects</td>
</tr>
<tr>
<td>--------------------</td>
<td>-------------------------------------------------------------------------</td>
</tr>
<tr>
<td><strong>Organophosphates</strong></td>
<td>Acute cholinergic crisis, central and Autonomic NS toxicity, cranial nerve palsies, delayed peripheral neuropathy, spasticity, impaired psychomotor function</td>
</tr>
<tr>
<td><strong>Pyrethroids</strong></td>
<td>Tremor, choreoathetosis</td>
</tr>
<tr>
<td><strong>Gases</strong></td>
<td></td>
</tr>
<tr>
<td>Carbon monoxide</td>
<td>Encephalopathy, delayed syndrome, dystonia</td>
</tr>
<tr>
<td>Ethylene oxide</td>
<td>Headache, neuropathy, seizures</td>
</tr>
<tr>
<td>Cyanide</td>
<td>Ataxic neuropathy, visual disturbances (chronic)</td>
</tr>
<tr>
<td>Hydrogen sulphide</td>
<td>Encephalopathy</td>
</tr>
<tr>
<td>Methyl bromide</td>
<td>Visual and speech impairment, convulsions (acute); neuropathy, cerebellar symptoms (chronic)</td>
</tr>
<tr>
<td>Methyl chloride</td>
<td>Cerebellar dysfunction, ataxia, tremor, blurred vision, loss of recent memory</td>
</tr>
<tr>
<td>Nitrous oxide</td>
<td>Neuropathy</td>
</tr>
<tr>
<td>Waste anaesthetic gases</td>
<td>Headache, memory impairment</td>
</tr>
<tr>
<td><strong>Metals</strong></td>
<td></td>
</tr>
<tr>
<td>Aluminium</td>
<td>Encephalopathy</td>
</tr>
<tr>
<td>Arsenic</td>
<td>Mixed sensori-motor neuropathy, encephalopathy</td>
</tr>
<tr>
<td>Lead</td>
<td>Motor neuropathy, memory impairment, Impaired psychomotor function, neurasthenia</td>
</tr>
<tr>
<td>Manganese</td>
<td>Ataxia, Parkinsonism, dystonia, cognitive</td>
</tr>
</tbody>
</table>
impairment, emotional instability, psychosis

Mercury  
Tremor, fatigue, emotional disturbances,  
neurasthenia, cognitive impairment  
(elemental Hg)

Thallium  
Peripheral and autonomic neuropathy, ataxia,  
Emotional disturbances, psychosis

**Miscellaneous**

Acrylamide  
Sensori-motor neuropathy, ataxia, neurasthenia

Methyl methacrylate  
Sensori-motor neuropathy

Naphthalene  
Neuropathy, optic neuritis

(Costa & Manzo, 1998)

In Australia, on the basis that there were seen to be reasonable grounds for believing that the production, handling, use and disposal of industrial chemicals could give rise to a risk of adverse health effects, the Industrial Chemicals (Notification and Assessment) Act of 1989 was passed, (NICNAS, 1989). The object of the Act was to provide a national system of notification and assessment of industrial chemicals for the purpose of:-

(a)  Aiding in the protection of the Australian people and the environment, by determining the risks to Occupational Health and Safety; Public Health; and the environment; that could be associated with the importation, manufacture or use of the chemicals; and

(b)  Providing information and making recommendations, about the chemicals to Commonwealth, State and Territory bodies with responsibilities for the regulation of industrial chemicals; and
(c) Giving effect to Australia's obligation under international agreements relating to the regulation of chemicals; and

(d) Collecting statistics in relation to chemicals; being a system under which information about the properties and effects of the chemicals is obtained from importers and manufacturers of the chemicals (NICNAS, 1989).

The Industrial Chemicals (Notification and Assessment) Act (1989) was subsequently amended in 1997 to broaden its focus and this resulted in The Industrial Chemicals (Notification and Assessment) Amendment Act of 1997.

Worksafe Australia, in its February 1995 Newsletter, outlined grave concerns regarding the dangers of chemical exposure in workplaces in Australia. Worksafe estimated that there are annually 2,200 occupational deaths in Australia, which are chemically related. This is 80% of the total workplace deaths occurring annually.

The Australian Plaintiff Lawyers Association (APLA), (now the Australian Lawyers Alliance), has established a special interest group to investigate chemical injury cases, with a long term view of initiating legislative change in this area. The APLA Conference in 1998 included three papers on chemical injury; two by psychologists, and one by a medical practitioner (Shores & Simpson, 1998; Coxon, 1998; Donohoe, 1998).
Changes to Health and Safety Legislation can only be enacted when there is significant evidence that exposure to certain chemicals results in health risks to workers. For example, the chemical Glutaraldehyde (CAS No, 111-3008) was declared by the Commonwealth Minister for Industrial Relations as a priority existing chemical (PEC) under the *Industrial Chemicals (Notification and Assessment) Act 1989* (Commonwealth), (the Act), by notice in the *Chemical Gazette* of 2\textsuperscript{nd} March 1993.

The declaration was made on the basis that there were reasonable grounds for believing that the production, handling, use and disposal of Glutaraldehyde could give rise to a risk of adverse health effects. (NICNAS, 1997).

The most recent Safety Information Sheet released in October 2000, states. A product containing more than 0.1% Glutaraldehyde is classed as a Hazardous Substance. Glutaraldehyde is not classified under the Australian Dangerous Goods Code. However, solutions of more than 25% Glutaraldehyde are corrosive and would fit onto Class 8 of the Code. Lower concentrations meet the classification for 6.1 (b) substances. (NICNAS Website: 2009 www.nicnas.gov.au)

Priority Existing Chemicals (PECs) are existing chemicals which have been assessed on a priority basis in response to concerns about their health or environmental effects or both.

These chemicals undergo a six step review process in order to be classified as PECs.
These steps are:

**Step 1  Nomination**

Any person or organization with concerns about the public health, occupational health and safety or environmental effects of an industrial chemical, may nominate it for assessment.

**Step 2  Screening and Information Gathering**

Once nominated, chemicals are screened to determine if they are eligible for inclusion in the program.

**Step 3  Declaration**

The Director uses the information that is obtained through the screening and ranking process, together with any information from a Section 48 Notice to help decide whether to recommend to the Minister for Health and Ageing, that a chemical be declared as a PEC.

**Step 4  Assessment**

Once a chemical has been declared a PEC all importers and manufacturers are required to make an application for assessment within 28 days of the declaration. A “Weight of Evidence” approach is adopted in the assessment of each chemical, taking into account all available information including published literature, unpublished data, public information, international assessments and the data submitted in response to Notices placed in the Chemical Gazette.

**Step 5  Public Comment**

NICNAS is committed to industry and public involvement and sees consultation with these groups as an essential part of the assessment process.
Step 6  Outcomes

Through the assessment reports; information on any risks to human health and the environment and recommendations on ways to control and reduce any risks is made available to companies introducing chemicals to people within the workplace, to other Government agencies and the public.


1.4  Outline of the Problem

Due to the above mentioned range of health problems which can develop following exposure to neurotoxic substances, it is considered very important that an awareness of the early stages of neurotoxicity be recognized. This would ensure that measures can be put into place to prevent the insidious deterioration in brain function of exposed individuals, which could eventually become permanent in nature over time.

Workers can be exposed to neurotoxins via a number of routes, such as direct skin contact and absorption through the skin; via inhalation into the respiratory system; and also via ingestion into the alimentary tract. In agricultural settings there may be widespread use of neurotoxic sprays in the form of herbicides or pesticides, which infiltrate whole areas of the atmosphere and environment. In such situations, the wind factors involved may increase the exposures of these chemicals to individuals other than the workers themselves such as members of the public, children in nearby rural schools, and workers in other neighbouring areas.
In aviation settings where workers are situated in closed environments, such as aircraft cockpits and cabins, they are more vulnerable, as they are very dependent on adequately functioning air conditioning systems to supply vital supplies of oxygen. Should neurotoxic materials be leaked via their ventilation systems, into enclosed spaces, such as cockpits and galleys where pilots and flight crew are situated, the outcome can be serious. There have been reported incidents where pilots have been exposed to jet oil emissions via leaks in air conditioning seals, which have caused intoxication of both pilot and co-pilot, to the extent that a loss of consciousness was experienced (Winder et al., 2000; Winder, 2005, 2006; Coxon, 2002, 2005, 2006; Loraine, 2007; Michaelis, 2007, 2008).

Another factor which may interact with potential neurotoxic impacts is hypoxia, which may occur in pressurized aircraft cabins as postulated by Winder in his case study on hazardous chemicals on jet aircraft (Winder, 2006).

In another aviation setting an alarming situation has arisen in Australia over the past 25 years among RAAF aircraft maintenance engineers who have been exposed to jet fuels and toxic sealants as part of the F-III Deseal/Reseal Project. This project took place over a 25 year period from early 1975 to late 1999 (RAAF/ADF 2004).

Approximately 700 RAAF aircraft maintenance workers were involved in the Deseal/Reseal Program over a 25 year period, which resulted in significant health problems, which included; cardiovascular problems, respiratory tract
difficulties, neurological and neuropsychological deficits and mental health problems. When these health problems were identified, the program was terminated. The RAAF accepted liability and conducted a wide scale assessment of the health effects of the workers involved in the program. This wide scale health study resulted in the publication of “Study of Health Outcomes in Aircraft Maintenance Personnel” (SHOAMP, September 2004).

Not only were these RAAF workers adversely affected by their exposure to the toxic chemicals in their workplace, but also their spouses were indirectly affected in a number of ways (Coxon, Hartley et al., 2006).

The RAAF were so concerned about the impact of the chronic illnesses of the maintenance engineers involved in the Deseal/Reseal Program on their spouses, that a study was commissioned to investigate this impact, (Coxon, Hartley, et al., 2006) which took place in 2005 and 2006.

Another area, where only limited research has been carried out to date, is in the hospital setting, where many health care workers, such as nurses, x-ray assistants and radiographers are exposed to neurotoxic substances in the course of their work (SNFTAAS, 1999). With the HIV and AIDS “epidemic” of the early 1980’s, stronger and stronger chemicals were required to destroy the viruses responsible for these conditions. Hence potent chemical agents were introduced for the sterilisation of instruments, in order to prevent cross infection from one patient to another in operating theatres.
With the advent of “key hole” surgery in recent years, to reduce the intrusiveness of “open surgery”, very fine fibre optic endoscopes were introduced. These instruments, which were very delicate, could not be sterilized using traditional heat based autoclaves, as the high temperatures would have destroyed the delicate fibres. Consequently potent cold sterilization agents, such as Glutaraldehyde were required to effectively destroy bacteria and also dangerous viruses, such as HIV, which were prevalent at the time.

The major sterilization agent which was introduced in the early 1980’s for this purpose, was the chemical Glutaraldehyde. Glutaraldehyde is a colourless fluid which is manufactured with a variety of concentrations from 50% downwards, to be later diluted into 2-3% and 1% solutions. With its initial use in the early 1980’s, stronger 2-3% solutions were used, as speed of sterilization was essential, due to the cost of the endoscopes and the limited supply of these delicate instruments. As a rapid “turn around” period was required, due to the scarcity of endoscopes, individuals working in these sterilization units considered that stronger solutions would sterilize these instruments more rapidly and effectively, and thus valuable time would be saved.

Unfortunately due to this “time poor” situation, shortcuts were taken with the protective measures used. Nursing staff and other health care workers claimed that they did not have sufficient time to don gloves, aprons and respirators, which would have provided protection from chemical skin splashes and inhalation of fumes emanating from the Glutaraldehyde containers (Coxon, 1998). Warnings regarding the hazards associated with the use of Glutaraldehyde, appear to have been unheeded for quite some time, until
complaints of sickness among many health care workers began to be documented (Vyas, 1997; Clifford, 2003).

Vyas undertook a rigorous Glutaraldehyde study where 358 endoscopy nurses in 59 units were investigated for symptoms related to Glutaraldehyde exposure. Seventy percent of the nurses had respiratory tract symptoms, and nasal and lower respiratory tract symptoms were most common of these (Vyas 1997).

Gradually more and more health care workers began complaining of health problems such as; coughs, breathing difficulties, skin rashes on faces and hands and chronic headaches. However, after periods of time away from their workplaces these workers were thought to have “recovered”, as their symptoms reduced significantly.

However, with time, more concerning problems began to emerge as these early workers in the health care industry were being exposed more frequently and more intensively to Glutaraldehyde. They began complaining of cognitive problems, which included; concentration and memory difficulties, slowed motor speed, slowed reaction time to stimuli, feelings of “vagueness” and episodes of confusion.

A brief neuropsychological study was carried out in the 1990’s by researchers in New Zealand, where the problem of Glutaraldehyde exposure was considered to be of significant concern, as a radiographer had died after prolonged exposure to Glutaraldehyde (Clifford, 2003). This small scale study was
conducted by noted New Zealand Neuropsychologist, Professor Dorothy Gronwall, who demonstrated significant neuropsychological impairments in health care workers who were exposed to Glutaraldehyde in the course of their work. Their deficits included; poor visuo-spatial perception, impairments in nonverbal memory, lowered attention and concentration, slowed information processing speed, verbal fluency problems, slow reaction times and impaired executive functioning. However the numbers in the study were small and there was no control group for comparison (Gronwall, 1997).

Another psychologist in Australia, Richard Teo, used an electro-encephalograph study, via Auditory Event Related Potential, P300 recordings, involving nurses exposed to Glutaraldehyde in the 1980’s and 1990’s, with some significant findings. Teo & Naidu considered that their data of P300 recordings demonstrated a degree of brain dysfunction in a population of nurses who worked with Glutaraldehyde. However the numbers were small and no control group for comparison was used (Teo & Naidu, 1994).

According to Cognitive Neuroscientists, Ullsperger & Mecklinger, the P300 component of the Event Related Potential Recording reflects integrative information processing of the brain that is often described as “endogenous”. (Ullsperger & Mecklinger, 1996).

In order to support the hypothesis that health care workers exposed repeatedly to the chemical Glutaraldehyde would suffer cognitive dysfunction, this present study was undertaken.
A preliminary investigation was conducted by Coxon with four health care workers exposed to Glutaraldehyde, where only minimal protective measures were in place. The four workers were assessed neuropsychologically, via a battery of well known neuropsychological tests, including; WAIS-III, WMS-III and components of the Halstead Reitan Battery, which were considered to be sensitive to neurotoxic substances. This initial study suggested that there were a number of areas of brain dysfunction which could be found in individuals who were exposed to Glutaraldehyde on a long term basis. It was concluded that the areas of brain dysfunction following exposure to Glutaraldehyde were likely to include; speed of information processing; reaction time to stimuli; memory and concentration; and fine motor skills. It was then considered that further and more extensive investigations were required to replicate these findings with a larger group of participants, including a control group (Coxon, 1998).

As a consequence it was decided that a study would be conducted to investigate further the deleterious effects of Glutaraldehyde on health care workers, in terms of their cognitive functioning and emotional state. Assessments would include; processing speed, reaction time to stimuli, memory and concentration skills and measures of anxiety and depression. If the outcome proved positive, this evidence could well lead to more stringent safety measures being introduced in many workplaces where the chemical Glutaraldehyde is used. This would hopefully prevent adverse health problems from recurring in such work settings.
CHAPTER 2

Aims

2.1 The Aims of the Projects

The aims of the three research projects were:

(a) To determine whether the subjective reports of cognitive confusion, cognitive dysfunction and emotional distress following occupational exposure to aircraft jet engine fuel emissions in the aviation industry could be validated.

(b) To investigate whether chronic health problems and neuropsychological dysfunction suffered by RAAF maintenance engineers exposed to toxic chemicals as part of the F-III Deseal/Reseal program, would have impacted on the emotional state and coping capacity of their spouses.

(c) To determine if the subjective reports of cognitive confusion, cognitive dysfunction, neurological problems and emotional distress following exposure to Glutaraldehyde in hospital settings could be validated.

The above aims are proposed to be achieved by administering a range of psychometric tests, considered to be sensitive to chemical injuries, to a group of flight crew exposed to jet oil emissions of the BAe-146 aircraft; to administer burden of care and sensitive clinical inventories to the spouses of chemically exposed aircraft engineers; and to administer the above mentioned psychometric tests to two groups of health care workers, exposed to the chemical Glutaraldehyde in hospitals and clinics.
The research hypotheses of these studies are three fold:

1) Toxic jet oil emissions from faulty BAe-146 aircraft will affect the cognitive functioning of pilots and flight crew.

2) The burden of caring for chronically affected workers exposed to toxins in the RAAF F-III Deseal/Reseal program will impact significantly on the mental health and coping skills of their spouses.

3) Occupational exposure of health care workers to the chemical Glutaraldehyde, will result in cognitive dysfunction and emotional distress.
CHAPTER 3

BAe-146 Aircraft Study

3.1 Neurotoxicity Problems in Aviation Settings

The following is an extended version of an article published in the Journal of Occupational Health and Safety, Australia and New Zealand Volume 18 pp 313-319 2002 entitled “Neuropsychological Assessment of a Group of BAe-146 Aircraft Crew Members Exposed to Jet Engine Oil Emissions.”

Over the past 10 or more years, reports have been made by airline pilots, cabin crew and passengers, outlining an array of symptoms arising from travel on BAe-146 aircraft. The BAe-146 is a small jet aircraft that operates on short domestic flights within Australia, Britain, Canada, Alaska and Sweden. In Australia, the BAe-146 is used predominantly in the less populated states of Western Australia, Queensland and South Australia, as a means of transporting small numbers of passengers to the more remote areas (Winder, 2001 & 2005; Coxon, 2002 & 2005; Mackenzie-Ross, 2005, 2006; Michaelis, 2007 & 2008; Loraine, 2007).

The most common complaints which have been made by individuals exposed to engine oil emissions while flying on the BAe-146 aircraft are; breathing difficulties; chest pain; nausea; fatigue; chronic headaches; dizziness; light headedness; confusion; concentration problems; memory difficulties and hypersensitivity to a range of chemicals (Winder & Balouet, 2001; Coxon, 2002 & 2005; Winder, 2005).
Complaints are generally made when the crew and passengers are exposed to jet oil emissions through the air conditioning system of the aircraft, often during take off and landing.

The oil escapes through faulty oil seals and into the compressor bleed air, which is used to ventilate and pressurise the BAe-146 aircraft cabins (Tyrrell, 1999). The concentration of these emissions is considered to peak at take off and landing of the planes, or at other times when the engine is under load. Reports of foul smelling gases and the subsequent development of symptoms of nausea, breathing difficulties, chest pain, confusion and dizziness are most common among flight crew at times when the air conditioning systems are on full volume.

The jet oil used by the BAe-146 aircraft is a synthetic phosphate ester oil in which tricresol phosphates are constituents. One of these tricresyl phosphates, tri-ortho-cresyl phosphate (TOCP), is said to be a highly neurotoxic contaminant (Donohoe, 1998). However, other ortho-cresyl phosphates in the oil are present in higher concentrations and are known to be even more neurotoxic than TOCP (Winder & Balouet, 2001; Winder, 2006).

This oil also contains naphthalene and a broad range of other chemicals, many of which are considered hazardous to human health (Donohoe, 1998; Winder & Balouet, 2001).
On the International scene, the BAe-146, the MD80, the B737 and the A300 aircraft have been the cause of over 90% of the world wide cabin contamination problems identified. It is considered that this is due to the fact that the above mentioned aircraft are more prone to leakages of oil emissions, due to their particular design. The BAe-146 engine was reported to have been designed for use in combat helicopters during the Vietnam War. Post war these engines have been modified to fit into small jet aircraft operating on short domestic flights. Statistically, the BAe-146 aircraft operating in Australia, Canada, Alaska and Sweden are the highest ranking for all cabin air problems (Winder & Balouet, 2001; Loraine, 2007).

Several case reports and epidemiological studies suggest that chronic Central Nervous System effects may occur in solvent-exposed workers, such as workers exposed to jet engine oils. Headaches, dizziness, concentration difficulties, memory impairment, fatigue, irritability, depression, alcohol intolerance and personality changes are the most frequently reported symptoms. Psychometric testing has revealed disturbances in memory and perception, also prolonged reaction times and some loss of coordination (Costa & Manzo, 1988).

Hartman cites studies demonstrating acute neurophysiological effects on jet oil workers, which include; dizziness, headaches and fatigue. Chronic exposure produces symptoms of neurasthenia, anxiety, depression and increased reaction time to stimuli. Of the most severely affected in this study, 50% were considered to have mild organic brain syndrome (Hartman, 1995).
Flight safety is a major issue, when one considers the effects on crew who are exposed to jet engine oil emissions as described above (Winder et al., 2001). A pilot with disorientation, altered memory, concentration difficulties, blurred vision, slurred speech, and loss of balance and co-ordination could not be expected to operate and land an aeroplane safely, nor could cabin crew be expected to carry out their duties adequately when experiencing the above mentioned problems.

Despite numerous complaints of cognitive problems following exposure to BAe-146 jet oil emissions, very few psychometric assessments have been conducted to determine the nature and magnitude of the reported problems.

However, one study by Teo in 1999, in which he assessed five airline crew, including two pilots and three flight attendants, exposed to jet oil emissions, significant findings were demonstrated. Teo assessed each of the five individuals using Auditory Evoked Response Potentials (AERP). He reported that the AERP test is a useful tool for the detection of chemical exposure effects, as it can detect the depressant effects of organo-phosphates and other chemicals, even at sub clinical levels. He said that the resultant effects of organo-phosphate and solvent exposure are that the ability of individuals to attend and respond to stimuli is decreased (Teo, 1999).

The results of Teo’s 1999 study revealed that in each case, there was a significant deficit in the individual's capacity to process information efficiently.

This dysfunction impacted on the individuals' performances on cognitive and
psychomotor tasks. This was considered by Teo to be an air safety risk factor (Teo, 1999).

Despite the above mentioned AERP findings, there do not appear to be any comprehensive neuropsychological studies carried out in Australia on groups of individuals exposed to jet engine oil emissions.

According to Lezak, the lack of thorough investigation of reported cognitive problems among chemically exposed workers generally occurs because of the similarity between some of the reported complaints and those of both depression and neuroticism. This confusion, often coupled with the absence of distinct neurological symptoms, can lead naïve investigators into discounting chemically exposed workers’ complaints of cognitive deficits as being of no real concern (Lezak, 1995).

However, Lezak reported that when neuropsychological evidence is presented, individuals’ symptoms are often supported by positive objective findings. The most prominent of these cognitive deficits involve many aspects of attention and memory and also response time slowing (Lezak, 1995).

The health problems of cabin staff exposed to BAe-146 jet oil emissions were considered to be of such significant concern as to warrant an inquiry by the Australian Senate. The Journal of the Senate, No 24, dated 22 March 1999 stated that; “the following matter be referred to the Rural and Regional Affairs and Transport References Committee for Inquiry and Report. This matter was;
“(d) The examination of air safety, with particular reference to cabin air quality in BAe-146 aircraft”.

Six senators, representing five states of Australia, subsequently met in 1999 and 2000 to investigate the 24 public submissions and a number of other private submissions on air quality in the BAe-146 aircraft. A report was tabled in the Australian Parliament in October 2000 (Senate Rural and Regional Affairs and Transport References Committee October 2000).

3.2 BAe-146 Study in Western Australia

The aim of this study was to determine the presence of any neuropsychological deficits among a small group of airline pilots and flight crew exposed to jet engine oil emissions from the BAe-146 aircraft, in the course of their work.

3.3 Participants

A medical practitioner, based in Perth, Western Australia, who treated many of the flight crew affected by BAe-146 emissions, considered that neuropsychological assessment was necessary in order to determine the nature and extent of the problems which were being reported. She therefore referred five flight attendants for neuropsychological assessment. Another flight attendant and two pilots were referred by their own medical practitioners from the other states of Australia (Somers, 2005).

In total, eight air crew exposed to BAe-146 oil emissions were referred by their medical practitioners for neuropsychological assessment. These individuals
reported cognitive difficulties, such as; mental confusion, concentration difficulties and memory problems, following their exposure to jet oil emissions.

The eight individuals assessed were all females. Six were cabin crew members and two were pilots. Their ages ranged from 24 to 56 years and they had worked in their respective positions on the BAe-146 aircraft from two years to twelve years. All had completed twelve years of secondary school education and most had studied at a tertiary level. All participants were right hand dominant.

Mean age of participants was 36.13 years and mean education in years was 13.67 years.

3.4 Measures

Each of the eight participants was administered a battery of neuropsychological tests, which had been used in previous research studies on neurotoxicants (Coxon, 1999; Miller, 1996, 1999; Worth et al., 1993; Crowe & Casey, 1999; Gronwall, 1997).
The Test Battery:

- WAIS-III Subtests
- Wechsler Memory Scale - Russell Adaptation
- Rey Complex Figure
- Controlled Oral Word Association Test (FAS Test)
- Symbol Digit Modalities Test
- Trail Making Tests "A" and "B"
- Card Version of Category Test
- Rey 15 Item Test
- Dynamometer Grip Test
- Reitan Finger Tapping Test
- Grooved Pegboard Test
- National Adult Reading Test
- California Computerized Assessment Package (CALCAP)

The Californian Computer Assessment Package (CALCAP) designed by Dr Eric Miller was added to the test battery as it is regarded as a sensitive measure of subtle changes in cognitive functioning among a number of populations, such as HIV positive individuals; chronic fatigue syndrome sufferers; and those with mild head injuries (Miller, 1993, 1999; Coxon, 1999; Worth et al., 1993; Crowe & Casey, 1999).
### 3.5 Results

#### TABLE V Summary of Test Scores

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<th>Age</th>
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<th>VIQ</th>
<th>PIQ</th>
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<td>-0.55</td>
<td>0.57</td>
<td>-0.33</td>
<td>-0.81</td>
<td>-0.53</td>
<td>0.37</td>
<td>-0.15</td>
<td>-0.19</td>
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<td>6.00</td>
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<td>6.00</td>
<td>10.00</td>
<td>13.25</td>
<td>9.50</td>
<td>25.70</td>
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<td>8.00</td>
<td>7.00</td>
<td>8.00</td>
<td>8.00</td>
<td>4.00</td>
<td>14.00</td>
<td>16.75</td>
<td>20.00</td>
<td>36.30</td>
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<tr>
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<td>18.00</td>
<td>13.00</td>
<td>15.00</td>
<td>16.00</td>
<td>10.00</td>
<td>24.00</td>
<td>30.00</td>
<td>29.50</td>
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<td>108.00</td>
<td>75.00</td>
<td>94.00</td>
<td>101.00</td>
<td>59.00</td>
<td>147.00</td>
<td>192.50</td>
<td>200.25</td>
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<td>8.00</td>
<td>8.00</td>
<td>8.00</td>
<td>8.00</td>
<td>8.00</td>
<td>8.00</td>
<td>8.00</td>
<td>8.00</td>
</tr>
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</table>
TABLE VI  Summary of Test Scores

| Pegg D | Pegg ND | Category | Rey 15 item | LM ST | LM LT | VR ST | VR LT | Rey copy | Rey Recall | SDMT W | SDMT O | Trails A | Trails B | SRT | RT | SEQRT | SEQRT2 |
| Mean | 63.88 | 66.66 | 38.57 | 14.14 | 21.06 | 18.13 | 10.31 | 8.25 | 32.17 | 15.67 | 44.38 |
| Std err | 4.01 | 6.19 | 6.61 | 0.55 | 0.90 | 0.99 | 0.64 | 1.00 | 1.01 | 1.56 | 5.61 |
| Std Dev | 11.33 | 17.50 | 17.48 | 1.46 | 2.54 | 2.79 | 1.81 | 2.82 | 2.48 | 3.83 | 15.87 |
| Kurtosis | -0.51 | 0.32 | 1.69 | -0.84 | -1.45 | 4.77 | 3.50 | -1.20 | -1.62 | 5.21 | -0.24 |
| Skewness | 0.54 | 1.09 | -0.64 | -1.23 | 0.24 | 2.07 | -1.13 | 0.04 | 0.07 | -2.25 | 0.44 |
| Range | 33.00 | 49.00 | 57.00 | 3.00 | 7.00 | 8.50 | 6.50 | 8.00 | 6.00 | 10.00 | 48.00 |
| Minimum | 49.00 | 51.00 | 7.00 | 12.00 | 18.00 | 16.00 | 6.50 | 4.50 | 29.00 | 8.00 | 21.00 |
| Maximum | 82.00 | 100.00 | 64.00 | 15.00 | 25.00 | 24.50 | 13.00 | 12.50 | 35.00 | 18.00 | 69.00 |
| Sum | 511.00 | 533.30 | 270.00 | 99.00 | 168.50 | 145.00 | 82.50 | 66.00 | 193.00 | 94.00 | 355.00 |
| Count | 8.00 | 8.00 | 7.00 | 7.00 | 8.00 | 8.00 | 8.00 | 8.00 | 6.00 | 6.00 | 8.00 |

<table>
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<tr>
<th>SDMT W</th>
<th>SDMT O</th>
<th>Trails A</th>
<th>Trails B</th>
<th>SRT</th>
<th>RT</th>
<th>SEQRT</th>
<th>SEQRT2</th>
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<td>3.77</td>
<td>7.16</td>
<td>1.18</td>
<td>1.53</td>
<td>0.49</td>
</tr>
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<td>9.04</td>
<td>10.67</td>
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<td>4.34</td>
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<td>Samp Var</td>
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<td>81.71</td>
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<td>409.98</td>
<td>11.22</td>
<td>18.80</td>
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<td>-0.84</td>
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<td>0.80</td>
<td>1.28</td>
<td>-1.15</td>
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<td>-1.30</td>
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<td>25.00</td>
<td>50.00</td>
<td>-8.77</td>
<td>-12.49</td>
<td>-3.63</td>
</tr>
<tr>
<td>Minimum</td>
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<td>34.00</td>
<td>25.00</td>
<td>50.00</td>
<td>-8.77</td>
<td>-12.49</td>
<td>-3.63</td>
</tr>
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<td>106.00</td>
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<td>0.80</td>
<td>0.37</td>
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<td>392.00</td>
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<td>-31.26</td>
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<td>8.00</td>
<td>8.00</td>
<td>8.00</td>
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</table>
Surface examination of test results are shown in Table VII below.

**TABLE VII  Test Results**

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<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th></th>
<th>Percentage Impairments</th>
</tr>
</thead>
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<td>Digit Symbol Test</td>
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<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td></td>
<td>87.5%</td>
</tr>
<tr>
<td>Picture Arrangement Test</td>
<td>8</td>
<td>13</td>
<td>7</td>
<td>12</td>
<td>8</td>
<td>9</td>
<td>11</td>
<td>7</td>
<td></td>
<td>62.5%</td>
</tr>
<tr>
<td>Digit Span Test</td>
<td>***</td>
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<td>16</td>
<td>12</td>
<td>10</td>
<td>8</td>
<td>10</td>
<td>9</td>
<td></td>
<td>50%</td>
</tr>
<tr>
<td>Letter Number Sequencing Test</td>
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<td>13</td>
<td>4</td>
<td>10</td>
<td>7</td>
<td>8</td>
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<tr>
<td>SDMT Written</td>
<td>*</td>
<td>*</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td>**</td>
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</tr>
<tr>
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<td>51</td>
<td>48</td>
<td>44</td>
<td>32</td>
<td>39</td>
<td>44</td>
<td>47</td>
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<td>59</td>
<td>45</td>
<td>50</td>
<td>34</td>
<td>40</td>
<td>49</td>
<td>56</td>
<td></td>
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<td>Trail Making Test “B”</td>
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<td>50</td>
<td>54</td>
<td>87</td>
<td>106</td>
<td>99</td>
<td>67</td>
<td>80</td>
<td></td>
<td>37.5%</td>
</tr>
<tr>
<td>Grip Right</td>
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<td>24</td>
<td>30</td>
<td>20</td>
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<td>Grip Left</td>
<td>27</td>
<td>25</td>
<td>29</td>
<td>23</td>
<td>21</td>
<td>20</td>
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<td>25</td>
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</tr>
<tr>
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<td>49.67</td>
<td>46</td>
<td>36.3</td>
<td>62</td>
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<td>42</td>
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<td>25%</td>
</tr>
<tr>
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<td>48.67</td>
<td>43</td>
<td>41.3</td>
<td>55.3</td>
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<tr>
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<td>61</td>
<td>82</td>
<td>66</td>
<td>60</td>
<td>58</td>
<td>49</td>
<td>78</td>
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<td>25%</td>
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<td>43</td>
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<td>42</td>
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<td>21</td>
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<td>0.14</td>
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<td>-0.69</td>
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<td>-8.77</td>
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<td>-0.44</td>
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<td>-2.88</td>
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<td>-0.34</td>
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<td>0.75</td>
<td>-0.92</td>
<td>-1.57</td>
<td>-2.62</td>
<td>-1.12</td>
<td>-1.04</td>
<td>-0.34</td>
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<tr>
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<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
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<td>2</td>
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<td>3</td>
<td>1</td>
<td>1</td>
<td>1</td>
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<td>64</td>
<td>32</td>
<td>43</td>
<td></td>
<td>57.1%</td>
<td></td>
</tr>
</tbody>
</table>

Impairments - * Mild   ** Mild to Moderate   *** Moderate   **** Moderate to Severe   ***** Severe

These results indicate that the tests which demonstrated greatest sensitivity to neurotoxic exposure were the CALCAP Reaction Time tests. Of the participants, 87.5% demonstrated impairments in the choice and sequential reaction time tasks. Interestingly, the simpler tests demonstrated the most severe impairments.
Surface examination of impairment levels are shown in Table VIII below.

### Table VIII Impairment Summary

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<th>Tests</th>
<th>Nil</th>
<th>Mild</th>
<th>Mild to Moderate</th>
<th>Moderate</th>
<th>Moderate to Severe</th>
<th>Severe</th>
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<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
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</tr>
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<td>1</td>
<td>1</td>
<td></td>
<td></td>
<td>100%</td>
</tr>
<tr>
<td>Grip Left</td>
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<td>2</td>
<td>1</td>
<td></td>
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<td></td>
<td></td>
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<td>25%</td>
</tr>
<tr>
<td>Grooved Pegboard Test   Lt</td>
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<td></td>
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<td>25%</td>
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<td></td>
<td></td>
<td></td>
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<td>25%</td>
</tr>
<tr>
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<td>2</td>
<td></td>
<td></td>
<td>3</td>
<td>87.5%</td>
</tr>
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<td>1</td>
<td>2</td>
<td>4</td>
<td></td>
<td></td>
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<tr>
<td>Short Term Verbal Memory</td>
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<td></td>
<td></td>
<td></td>
<td>87.5%</td>
</tr>
<tr>
<td>Long Term Verbal Memory</td>
<td>1</td>
<td>7</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>87.5%</td>
</tr>
<tr>
<td>Short Term Non Verbal Memory</td>
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<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>12.5%</td>
</tr>
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<td>1</td>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td>50%</td>
</tr>
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<td>1</td>
<td></td>
<td></td>
<td></td>
<td>57.1%</td>
</tr>
</tbody>
</table>

The results indicate that test scores of grip strength were found to be impaired among 100% of participants on their dominant side and 87.5% on the non dominant side, although the bulk of these were of a mild nature.

Impairments on the Digit Symbol Subtest of the WAIS-III occurred in 87.5% of participants (mean 7.38) and the Symbol Digit Modalities Test (mean 43.88).

These two tests comprise similar tasks of information processing speed. Only 60.5% of participants demonstrated impairments on the oral version of the SDMT (mean 49.00). Among other subtests of the WAIS-III, 62.5% showed impairments on the Picture Arrangement test of picture sequencing (mean 9.38), while 50% were impaired on the Letter Number Sequencing test (mean 8.75) and the Digit Span test, (mean 9.88). Both of these tests assess
concentration and attention span. All other subtests of the WAIS-III showed impairments in none, one or only two individuals, so were not considered to be of significance.

The National Adult Reading Test results of all eight individuals suggested that all pre-morbid IQ's would have been in the average to high average range (from 108 to 116; Mean = 113), and their academic records supported these findings. Of the eight participants, 62.5% demonstrated losses in Full Scale, Verbal and Performance IQ's.

Although memory deficits, as measured by the Wechsler Memory Scale - Russell Adaptation, were only mild, 87.5% of participants demonstrated impairments in both short and longer term verbal recall. Only 12.5% of participants demonstrated mild to moderate impairment in short term non verbal recall, but 50% demonstrated mild to moderate impairments in longer term non verbal recall.

The Trail Making test “A” of processing speed demonstrated only mild impairments in performance among 37.5% of the participants. In the Trail Making test “B”, where there is another component involving the changing set from number to letter, there were also mild impairments in 37.5% of participants’ scores.

The overall mean scores for both “A” and “B” versions of this test were found to be below average.
The tests which were least sensitive to neurotoxic exposure were those of fine motor skills involving manual speed and manual dexterity. Only 25% of the participants showed impairments in tapping speed and manual dexterity of their dominant hand. Although 25% showed impairments in manual dexterity on the dominant side, none showed impairments in tapping speed on their non-dominant side.

3.6 Discussion

Although a statistical analysis has not been carried out on these test results and there is no control group of individuals working in the same field but not exposed to BAe-146 jet engine oil emissions, it was considered that there were sufficient grounds to warrant further investigation of flight crew on BAe-146 aircraft.

The above mentioned pattern of test results reflected studies carried out in other occupational settings, where workers were exposed to organo-phosphates, solvents and hypoxia (Winder, 2006). According to Lezak, most chronic solvent toxicity occurs in workplaces as a result of long term exposure to fumes from such substances as paints, glues, cleaning fluids, petroleum fuel and lubricating and degreasing agents. The most prominent cognitive deficits found among these groups involve many aspects of attention and memory and also response time slowing. Lezak also reports that the transient effects of oxygen deprivation in high altitude environments, which have been studied in airline pilots can lead to mental dulling, diminished alertness with a loss of normal self-protective responses (Lezak, 1995 & 2004).
The concerns regarding the health of pilots and flight crew of the BAe-146 were reflected in the outcome of the Senate Inquiry, which was tabled in Parliament in October 2000. It read: "Eight recommendations were made with the aim of ensuring that appropriate assessments were carried out on the BAe-146 and other passenger aircraft, to ensure that proper standards of air quality are made mandatory for Australian aircraft, bearing in mind Australian operational activities". (SRRATR Committee Report 2000)

The recommendations made by the Senate Inquiry were particularly addressed to CASA as the Australian Air Safety Agency, and the administrator of aircraft operating regulations and standards. In addition, the Committee recommended that the Commonwealth initiate a number of responses to ensure that occupational health issues are addressed (Senate Rural and Regional Affairs and Transport References Committee, 2000).

To discuss and explore the issues arising out of the Senate Inquiry in greater depth and to extend the debate about air quality in commercial aeroplanes, an Aviation Air Quality Symposium was held at UNSW and ADFA in Canberra in December 2000. Eight papers were presented which covered the following topics: Air Quality Monitoring; Aircrew Air and Passenger Health; Airworthiness; and Aircraft Engineering Concerns (Winder et al., 2000).
3.7 Conclusions

Bearing in mind the above neuropsychological findings, coupled with the outcome of the Senate Inquiry, it was considered important to conduct a wider scale study of BAe-146 aircraft flight crew via a more comprehensive research study.

The hypothesis of this follow on study would be that BAe-146 aircrew who have been exposed to engine fumes would demonstrate neuropsychological impairments on a number of neuropsychological measures.

It was envisaged that an experimental group of at least 30 individuals could be administered the neuropsychological tests which proved most sensitive to the oil fumes in the Coxon study. These test results could then be compared with a control group, of the same number of individuals who do not fly on the BAe-146 and are therefore not exposed to the BAe-146 oil fumes. The results would be statistically analysed by analysis of variance to determine the presence of any significant differences in test scores between the different groups’ test scores.

The data gathered from this recommended research project, if positive, could be used as evidence to initiate the introduction of better working conditions for employees in the aviation industry.

Such a research project was conducted as a follow on study in the United Kingdom in 2006 with 27 airline pilots who had been exposed to jet engine fuel emission in the course of their work with different airline companies in the United
Kingdom and Europe. This study was conducted in London after The Safety Committee for Airline Regulation deemed this necessary (Mackenzie-Ross, 2006).

The findings were sent to the United Kingdom Department for Transport and the UK Government agreed to fit air-monitoring equipment on aircraft. It was admitted that there was a “large body of anecdotal and descriptive evidence linking ill-health among crew with poor air quality”. However, The Department for Transport said that more work was needed to establish a definite link (Starmer-Smith, 2008).

The outcome and conclusions of the above mentioned research project were that the pilots involved in the study were found to have similar cognitive deficits to those in the preliminary Western Australian study (Coxon 2005; Mackenzie-Ross, 2006).

The Mackenzie-Ross study, conducted at the University College in London revealed that all but one of the participants in the project showed significant cognitive impairments in speed of information processing, attention span and problem solving skills (Mackenzie-Ross, 2006).

The Department for Transport in the United Kingdom stated that it takes the health of passengers and crew very seriously, but they also stated that it was not known what, if any, substances were in cabin air, and that is why they undertook the above mentioned research as a matter of priority (Starmer-Smith, 2008).
It was concluded that these cognitive impairments, although only of a mild nature could impact severely on affected pilots' capacity to safely control their aircraft. The problem therefore is more than just a health hazard, it is also a serious flight safety problem. There are a number of recorded cases by pilots having their judgement impaired, or of finding themselves rendered incapable of functioning due to the effects of contaminated air. Research studies have demonstrated that 70% of plane crashes are caused by pilot error (Michaelis, 2008; Loraine, 2007).
CHAPTER 4

Neurotoxicity Problems Among Aircraft Engineers and the Psychological Effects on their Spouses

4.1 Introduction

An alarming situation has arisen in Australia over the past 30 years among RAAF aircraft maintenance engineers who had been exposed to jet fuels and toxic sealants as part of the F-III Deseal/Reseal Project. This project took place over a 25 year period from early 1975 to late 1999 (RAAF/ADF, 2004).

In 2001 the Royal Australian Air Force (RAAF) acknowledged that personnel involved in the F-III Deseal/Reseal program had been consistently exposed to chemicals (particularly solvents and sealants) known to be hazardous to human life (RAAF, 2001). During this time, individuals had repeatedly reported acute and chronic symptoms of chemical poisoning such as mucosal membrane irritation, breathing difficulties, skin rashes, dizziness, mood changes and other psychiatric problems, motor dysfunction, gastro-intestinal problems, headaches, and cognitive dysfunction including loss of memory and poor concentration. Even now, some thirty years or so after the program’s inception, individuals who were involved in the F-III Deseal/Reseal program are continuing to report some of the longer term effects of the chemical exposure including various cancers and growths, infertility, hepatic and kidney dysfunction, and lasting cognitive deficits. After such a lengthy period of time the effects on the health of these exposed workers are likely to be permanent, without any possibility of reversal of their symptoms. There is a possibility that long-term solvent exposure may
ultimately produce an Alzheimer – like dementia, as found in chronically exposed painters (Lezak, 2004).

Even in the absence of a frank dementia, solvent exposure may contribute to poorer cognitive functioning by interacting with the normal aging process (Nilson et al., 2002).

4.2 Magnitude of the Problem
Approximately 700 RAAF aircraft maintenance workers were involved in the Deseal/Reseal Program over a 25 year period, which resulted in significant health problems. When these health problems were identified, the program was terminated. The RAAF accepted liability and conducted a wide scale assessment of the health effects of the workers involved in the program. This wide scale health study resulted in the publication of “Study of Health Outcomes in Aircraft Maintenance Personnel” (SHOAMP), in September 2004.

4.3 Details of the Study
There were 659 exposed workers and 1095 controls in the study: They were all assessed on a number of measures for:
General health and wellbeing
Cardiovascular health
Respiratory health
Dermatological abnormalities
Neurological problems
Sexual dysfunction
Mental health problems

Neuropsychological deficits

Many health outcomes emerged from this study, but those related to neuropsychology which were of significance were; lowered performances on tests of; executive functioning, problem solving, processing speed, memory capacity, and new learning skills.

It was found that the most toxic component of the desealing agent used was a chemical known as SR51. This sealant contained 75% solvesso150, which is a mixture of aromatic hydrocarbons. It also contained 10% Dimethylacetamide, 10% Thiophenol and 5% Triethylphosphate. With both organic solvents and an organophosphate present, this chemical has a neurotoxic potential. In all the analyses carried out, this particular chemical agent demonstrated the most widespread symptoms and health effects (RAAF/ADF, 2004).

As a result of the above study, it became evident that the health of many of these individuals had been significantly compromised as a result of being involved in the F-III Deseal/Reseal program.

However, what was less clear was the impact that their chronic illness had on their partners and spouses.

Research has indicated that chronic illness can have a profound effect on the family members of the individuals involved, particularly on the spouse, who is
generally the primary caregiver (Horowitz, 1985). Many partners feel obliged to provide 24 hour a day, informal, unpaid care for their family member who has experienced a serious illness or injury. Research has revealed that previously healthy spouses often find themselves developing a variety of physical and mental health problems within two years of the onset of a serious illness or injury of a family member, thought to be due to the stress associated with this burden of care (Cantor, 1983).

The present research project endeavoured to ascertain the psychological implications for spouses and partners of the F-III Deseal/Reseal program personnel who suffered chemical injuries.

Stress as a concept is difficult to define, due to the subjective nature of the experience for the individuals involved. However, it is often conceptualised as psychological distress occurring in situations in which the demands of the situation are perceived to tax or exceed the individual's available resources (Lazarus & Folkman, 1984). The level of perceived stress by the individual is determined by the interaction of: (a) a primary appraisal of the event as involving harm, threat of harm, or challenge; (b) a secondary appraisal identifying available coping resources; and (c) a coping response (Chwalisz, 1996). Chronic stress can be associated with illnesses such as high blood pressure, irritable bowel syndrome and respiratory difficulties, and also with disease progression in persons who are already unwell (Greenwood, Muir, Packham, & Madeley, 1996). The mechanism of this action is as yet relatively unclear, however it appears that there are at least two major interactions
associated with stress related illnesses. These are; firstly, the action of the stress hormones cortisol, epinephrine, and norepinephrine stimulating peripheral activity, which can lead to “wear-and-tear” on cells from repeated arousal and inefficient control of physiological responses (McEwen, 2000); and secondly, the triggering of compensatory risky health behaviours stemming from poor coping strategies such as; poor diet, sedentary behaviour, and substance abuse (Vitaliano, Zhang, & Scanlan, 2003).

The effects of caregiver stress can be both physical and psychological in nature. For example, a meta-analysis of 23 studies found that caregivers had a 23% higher level of stress hormones than demographically matched controls, and concluded that the act of caregiving significantly influenced the physical health of the caregiver (Vitaliano et al., 2003). One identified psychosocial response to the stress of caregiving is the perceived burden of care. It results from the physical, psychological, emotional, social and financial problems experienced by families caring for impaired adults (George & Gwyther, 1986). Burden can manifest as feelings of embarrassment, overload, depression, anxiety, entrapment, resentment, isolation from friends and family, loss of control, and poor communication (Zarit, Reever, & Bach-Peterson, 1980). Given that the stress that is felt by a caregiver of a person with a progressive condition, such a chemical poisoning, is likely to be both prolonged and intractable, it is not surprising then that these caregivers often report more perceived distress, physical health complaints, and risky health behaviours than do non-caregivers.
One of the more under researched areas of caregiver burden is the psychosocial impact of caregiving both directly and indirectly. Research has demonstrated that providing care to a family member is associated with increased psychological distress (Donaldson, Tarrier, & Burns, 1998). For example, up to 48% of dementia caregivers have been identified as being at risk for psychiatric symptomatology (Draper, Poulos, Cole, Poulos, & Ehrlich, 1992). Often caregivers are faced with difficult caregiving tasks and also behavioural problems of their care recipients, such as verbal and physical aggression and confusion (Teri, Truax, Logsdon, Uomoto, Zarit, & Vitaliano, 1992). Additionally, providing care to a disabled relative often restricts the personal life, social life, and employment of the caregiver. For example, caregivers may have less time to spend with friends, to fulfil other family obligations, or to pursue leisure pursuits (Zarit et al., 1980). A meta analysis of 84 studies relating to the psychological and physical health of caregivers determined that caregivers are consistently more stressed, depressed, and have lower levels of subjective well-being, physical health, and self-efficacy than non-caregivers (Pinquart & Sorensen, 2003).

Given that it is evident that there can be a wide range of negative consequences on the psychological and physical health of caregivers and family members, the present research attempted to determine whether there is a psychological effect on the spouses of the F-III Deseal/Reseal program personnel in order to document and define any impact that the program has had in a wider sense, than just the personnel themselves. It was postulated that there would be a statistically significant difference in the psychological functioning of the spouses of the
individuals involved in the F-III Deseal/Reseal program. Given the previous research with spouses of individuals suffering chronic illnesses, it was hypothesised that the spouses of individuals involved in the F-III Deseal/Reseal program would demonstrate higher levels of depression, anxiety, and stress than spouses of individuals not involved in the F-III Deseal/Reseal program.

4.4 Method

Phase 1 – Preliminary Study

In order to obtain a sense of the variety and magnitude of issues involved in caregiving for individuals involved in the F-III Deseal/Reseal program and to develop and select the appropriate questionnaires for the main study, a preliminary study was conducted involving a small sample of spouses of the affected individuals. The Chief Researcher met with six F-III Deseal/Reseal program spouses over a two day period in Brisbane Queensland to conduct structured interviews and psychological assessments of each individual. The Personality Assessment Inventory (PAI); (Morey, 1991) and a range of burden of care questionnaires were administered. These included the Zarit Burden Inventory (ZBI); (Zarit et al., 1980) and other questionnaires researched via PsycINFO.

The six participants then rated the questionnaires for their appropriateness in representing the difficulties they faced in caring for their chemically affected spouses. Some of their spouses were severely affected by the chemicals and were home bound, being unable to drive a vehicle or leave the home without a carer present. Among the burden of care questionnaires, the ZBI was rated the
most useful in terms of delineating burden of care, and five of the six individuals obtained scores which placed them in the moderate to severe range. All of the preliminary study participants’ PAI profiles demonstrated significant peaks on the Depression scale, the Somatic Complaints scale, and the Anxiety and Stress scales, across all participants.

Information collected from the structured interview outlining the problematic issues faced by these individuals in caring for their disabled spouses was collated and transformed into a 28-item questionnaire entitled the “Spouse Questionnaire” (SQ). The draft questionnaire was then reviewed by the representatives of the spouse group and the RAAF project manager and the necessary modifications were made. This preliminary study resulted in the selection of the assessment instruments deemed most appropriate for the F-III Deseal/Reseal program spouse study, that is, the PAI, the ZBI, and the SQ.

**Phase 2 – Main Study**

**Experimental Group**

The experimenters obtained a list of spouses and partners of the F-III Deseal/Reseal program personnel who had consented to participate in the study from the RAAF. Of the 110 individuals invited to participate, 91 completed the questionnaires sent out to them, indicating a response rate of 83%. The age of the participants ranged from 27-73 years (mean = 49) and all were female.
Control Group

The experimenters obtained a list of spouses and partners of personnel who had not been involved in the F-III Deseal/Reseal program who had consented to participate in the study from the RAAF. These spouses were not in a situation where they had to care for non chemically injured workers. Some of them had retired spouses. Of the 52 individuals invited to participate, 25 completed the questionnaires sent out to them, indicating a response rate of 48%. The age of the participants ranged from 34-69 years (mean = 47.1). Twenty one of the participants were female and four were male. The size of the Control Group was considered adequate for statistical power. It was not considered that the inclusion of male carers would add bias to the study.

4.5 Measures

Personality Assessment Inventory (PAI). The PAI is a self-administered, objective inventory of adult personality and psychopathology. The PAI contains 344 items comprising 22 non-overlapping full scales, including four validity scales; (Inconsistency, Infrequency, Positive Impression and Negative Impression) eleven clinical scales; (Somatic Complaints, Anxiety, Anxiety Related Disorders, Mania, Paranoia, Schizophrenia, Borderline Features, Antisocial Features, Alcohol Problems, Drug Problems); five treatment scales; (Aggression, Stress, Non Support, Suicidal Ideation, and Treatment Rejection); and two interpersonal scales; (Dominance and Warmth) (Morey, 1991). In addition to the measurement of clinical constructs, interpretation of results also provides measures for detecting attempts to feign or manipulate symptomology as well as an assessment for the individual’s motivation for treatment.
Respondents are asked to indicate to what extent they believe the statements in the test are an accurate representation of themselves on a 4-point ordinal scale (F = False; ST = Slightly True; MT = Mainly True; VT = Very True).

**Zarit Burden Inventory (ZBI).** The ZBI is a 22-item measure of the perceived impact of caregiving on the caregiver’s financial status, physical health, emotional health, and social activities (Zarit et al., 1980). The respondents indicate on a 5-point scale describing how much each statement applies to him or her, ranging from “Never” to “Nearly Always”. The maximum score possible on the ZBI is 88 and a high score is indicative of higher levels of perceived burden of care.

**Spouse Questionnaire (SQ).** The SQ was developed using the information obtained from the participants in the preliminary phase of the study. It contained 28 questions relating to feelings and emotions commonly associated with caregiving burden such as stress, and social isolation (e.g., “Do you feel that you are currently under a great deal of pressure?,” “Do you feel rejected by family and friends?”). The respondents indicate on a 4-point scale describing how much each statement applies to him or her ranging from “Not at all” to “Always”.

### 4.6 Procedure

Each of the 162 spouses invited to become involved in the research were mailed a package containing a consent form, the PAI question booklet, a PAI HS Answer Sheet, the SQ, and an information sheet outlining the procedures related to correctly completing the questionnaires (e.g. test instructions).
Additionally, packages mailed to the Experimental Group included the ZBI (as this is an inventory that is highly specific to caregivers it was deemed inappropriate to give to the Control Group). Participants were instructed to return the completed packages along with their signed consent form, in a self-addressed, reply paid envelope, provided by the researchers. Reminder letters were sent to those participants who had not returned their packages after a period of four weeks. In addition, letters and additional self-addressed reply paid envelopes were sent to participants who had returned incomplete packages (e.g., missing questionnaires or unsigned consent forms). Altogether 122 packages were returned, however of these six packages were excluded from further analysis. Of these six, three were excluded because the consent form had not been signed despite further written requests, and three because it was clear that the individual involved in the F-III Deseal/Reseal program had filled in the questionnaires and not the spouse. These individuals were sent new packages with a request for the spouse to fill them out, however they were not returned.

The PAI and ZBI were scored according to the procedures determined by their original authors. The SQ was scored by coding each of the four points on the answer scale (e.g., “Not At All” = 0, “Always” = 3), followed by reverse coding three of the negative items, then summing all the items. Data analysis was completed using computer software designed for inferential statistics. Ethics approval for this research project had been granted by the Murdoch University Ethics Committee and written informed consent was obtained from all study participants.
4.7 Results

Independent sample t-tests were carried out to determine whether there was a difference on the PAI validity scales, between the Experimental Group and the Control Group. No significant differences were found between the two groups, on the four validity scales (Inconsistency; \( t = 1.50, p = 0.14 \); Infrequency; \( t = 0.787, p = 0.43 \); Negative Impression; \( t = 1.48, p = 0.14 \); and Positive Impression; \( t = 1.48, p = 0.14 \)). This indicates that both groups attended to the items consistently and appropriately, and did not attempt to present an unrealistically favourable or negative impression.

Independent sample t-tests were also performed to determine whether participants assigned to the Experimental Group reported higher levels on the clinical scales of the PAI, than those in the Control Group. Of the 11 scales, significant differences were found between the groups on four of these: Somatic Complaints, Anxiety, Depression and Antisocial Features. The Experimental Group reported higher levels of Somatic Complaints (\( t = 3.06, p = 0.002 \)), Anxiety (\( t = 3.62, p = 0.0004 \)), and Depression (\( t = 2.76, p = 0.0068 \)). The Control Group scored higher on the Antisocial Features scale (\( t = -2.33, p = 0.02 \)), when compared to the Experimental Group. However on further analysis of the individual participant data pertaining to this scale, it appears that the mean obtained had been highly influenced by three unusually elevated outliers. On removal of these outliers there was no significant difference between the two groups (\( t = 0.9, p = 0.37 \)) and thus this anomaly is excluded from further discussion.
Four independent sample t-tests were carried out to determine whether participants in the Experimental Group obtained higher scores on the treatment scales of Aggression, Suicide, Stress, Non-Support, and Treatment Rejection than those in the Control Group. The Experimental Group reported significantly higher levels of Stress ($t = 3.61, p = 0.0004$) when compared to the Control Group. There was no significant difference between the groups on the levels of Aggression, Suicidal Ideation, Non Support or Treatment Rejection.

### TABLE IX
Comparison of group means for Experimental and Control Groups

<table>
<thead>
<tr>
<th>Scale</th>
<th>Experimental Means</th>
<th>Control Means</th>
<th>SD</th>
<th>T-Values</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Validity Scales</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inconsistency</td>
<td>51.5</td>
<td>48.3</td>
<td>9.37</td>
<td>$t = 1.50, df=114$</td>
<td>$p = 0.14$ (ns)</td>
</tr>
<tr>
<td>Infrequency</td>
<td>50.3</td>
<td>51.8</td>
<td>8.24</td>
<td>$t = 0.787, df=114$</td>
<td>$p = 0.43$ (ns)</td>
</tr>
<tr>
<td>Negative Imp</td>
<td>56.7</td>
<td>52.7</td>
<td>11.9</td>
<td>$t = 1.48, df=114$</td>
<td>$p = 0.14$ (ns)</td>
</tr>
<tr>
<td>Positive Imp</td>
<td>49.2</td>
<td>51.4</td>
<td>10.7</td>
<td>$t = 0.928, df=114$</td>
<td>$p = 0.36$ (ns)</td>
</tr>
<tr>
<td><strong>Clinical Scales</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Somatization</td>
<td>60.5</td>
<td>51.2</td>
<td>13.5</td>
<td>$t = 3.06, df=114$</td>
<td>$p = 0.0028$ **</td>
</tr>
<tr>
<td>Anxiety</td>
<td>61.7</td>
<td>51.9</td>
<td>12.0</td>
<td>$t = 3.62, df=114$</td>
<td>$p = 0.0004$ ***</td>
</tr>
<tr>
<td>Anxiety Disorders</td>
<td>57.4</td>
<td>53.4</td>
<td>12.2</td>
<td>$t = 1.47, df=114$</td>
<td>$p = 0.14$ (ns)</td>
</tr>
<tr>
<td>Depression</td>
<td>65.3</td>
<td>56.9</td>
<td>13.5</td>
<td>$t = 2.76, df=114$</td>
<td>$p = 0.0068$ *</td>
</tr>
<tr>
<td>Mania</td>
<td>46.6</td>
<td>47.9</td>
<td>9.71</td>
<td>$t = 0.607, df=114$</td>
<td>$p = 0.55$</td>
</tr>
<tr>
<td>Paranoia</td>
<td>52.6</td>
<td>52.8</td>
<td>11.0</td>
<td>$t = 0.68E-01, df=114$</td>
<td>$p = 0.95$</td>
</tr>
<tr>
<td>Schizophrenia</td>
<td>57.1</td>
<td>52.3</td>
<td>13.4</td>
<td>$t = 1.57, df=114$</td>
<td>$p = 0.12$</td>
</tr>
<tr>
<td>Borderline</td>
<td>55.1</td>
<td>52.7</td>
<td>11.7</td>
<td>$t = 0.926, df=114$</td>
<td>$p = 0.36$</td>
</tr>
<tr>
<td>Antisocial Features</td>
<td>43.6</td>
<td>47.5</td>
<td>6.84</td>
<td>$t = 2.50, df=114$</td>
<td>$p = 0.014$</td>
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<td>Alcohol</td>
<td>48.5</td>
<td>51.4</td>
<td>9.18</td>
<td>$t = 1.40, df=114$</td>
<td>$p = 0.16$</td>
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<tr>
<td>Drug</td>
<td>49.6</td>
<td>49</td>
<td>7.45</td>
<td>$t = 0.326, df=114$</td>
<td>$p = 0.74$</td>
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<tr>
<td><strong>Treatment Scales</strong></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Aggression</td>
<td>48.2</td>
<td>50.3</td>
<td>11.3</td>
<td>$t = 0.805, df=114$</td>
<td>$p = 0.42$</td>
</tr>
<tr>
<td>Suicide</td>
<td>55.1</td>
<td>50.2</td>
<td>15.0</td>
<td>$t = 1.46, df=114$</td>
<td>$p = 0.15$ (ns)</td>
</tr>
<tr>
<td>Stress</td>
<td>57.1</td>
<td>48.8</td>
<td>10.1</td>
<td>$t = 3.61, df=114$</td>
<td>$p = 0.0004$ ***</td>
</tr>
<tr>
<td>Non support</td>
<td>53.2</td>
<td>50.0</td>
<td>11.3</td>
<td>$t = 1.25, df=114$</td>
<td>$p = 0.21$</td>
</tr>
<tr>
<td>Treatment Rejection</td>
<td>49.7</td>
<td>52.4</td>
<td></td>
<td>$t = 1.27, df=114$</td>
<td></td>
</tr>
<tr>
<td><strong>Interpersonal Scales</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dominance</td>
<td>44.8</td>
<td>46.5</td>
<td>10.0</td>
<td>$t = 0.731, df=114$</td>
<td>$p = 0.47$</td>
</tr>
<tr>
<td>Warmth</td>
<td>47.3</td>
<td>47.3</td>
<td>10.6</td>
<td>$t = 0.549E-03, df=114$</td>
<td>$p = 1.00$</td>
</tr>
<tr>
<td>Spouse Q</td>
<td>38.7</td>
<td>20.8</td>
<td>13.0</td>
<td>$t = 6.05, df=113$</td>
<td>$p = 0.0001$ ***</td>
</tr>
<tr>
<td>Zarit Burden Q</td>
<td>41.4</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td></td>
</tr>
</tbody>
</table>

NB: NS = $p>0.05$, * = $p<0.05$, ** = $p<0.005$, *** = $p<0.0005$

An independent sample t-test was used to determine whether there was a
difference on the SQ scores between the Experimental Group and the Control
Group. The Experimental Group scored very significantly higher (t = 6.05, p<0.0001) on this measure of distress than the Control Group.

The ZBI scores were calculated only for the Experimental Group to determine their level of burden of care (mean = 41.42). This score indicated that they had experienced a Moderate to Severe level of stress in caring for their disabled spouses compared with test normative data. This score does not include factors regarding whether or not the carer perceived that the care would be required indefinitely.

4.8 Discussion

The results of the study indicate that there are significant deleterious effects on the psychological functioning of spouses of individuals involved in the F-III Deseal/Reseal program as a result of the program itself. While only a limited number of control participants took part in the study, some very robust results were obtained at high levels of significance. Therefore, the results of the study can be taken at face value despite such limitations, as it is unlikely that anything different would be obtained with a larger control sample.

In addition to the significant differences between the Experimental and Control Groups on the PAI clinical scales of Somatic Complaints, Anxiety, and Depression, the scores for the Experimental Group fell into the significantly elevated range when compared to a normative population sample. According to Morey (1996), when Somatic Complaints scores are between 60 and 69 such as those in the Experimental Group (mean = 61), it reflects individuals with concerns about health functioning which would not be uncommon in individuals
with specific medical conditions, and those under significant levels of stress. Anxiety scores in the range between 60 and 69 as were seen in the Experimental Group (mean = 62) represented individuals who were likely to be experiencing stress and be worried, sensitive and emotional. Depression scores between 60 and 69 such as those in the Experimental Group (mean = 65) indicate a group of people who were likely to be unhappy, sensitive, pessimistic and self doubting. However, the below average Treatment Rejection scores from 43 to 52 like those obtained by the Experimental Group (mean = 48) indicate that they; were willing to acknowledge the need to make some changes to their life; had a positive attitude to the possibility of change; and accepted the importance of personal responsibility. Conversely, among the Control Group participants scores there were no significant elevations on the PAI scales compared to a normative population sample. The Treatment Rejection scores in this Control Group (mean = 52.4) indicated individuals who are generally satisfied with themselves and see little need for major changes in their cognitions, emotions, and behaviour.

It was determined that 63.73% of the Experimental Group obtained significantly elevated Depression Scores (i.e., scores over 60) ranging from 60 to 108, some of whom (25.27%) had highly elevated Suicidal Ideation scores. This sub-group was then separated out to determined the potential for suicide via the Suicide Potential Index (SPI) of the PAI. The mean SPI for this sub-group was 10.09 which indicated that they were in the low category for suicide risk (Morey, 1996). However, as some group members had extremely elevated Suicidal Ideation scores in addition to high levels of Depression, Anxiety, and Stress, it
was considered prudent to calculate the sub-group’s potential response to treatment and the likelihood of treatment success via the Treatment Process Index (TPI) of the PAI. This sub-group had a mean TPI of 2.8 which indicated the presence of numerous personal assets that may assist in the treatment process (Morey, 1996). This low TPI in consideration with a below average Treatment Rejection Score, suggests that these individuals acknowledge that they have significant problems and perceive that they have a need for assistance in dealing with their problems. In volunteering to participate in this study, one could well suggest that these spouses had an expectation of assistance, hence their low TPI score. However, this was not offered to them initially. Every spouse of the F-III Deseal/Reseal participants was contacted to participate in the study, consequently it was considered to be a representative sample of spouses. People in this category reported a positive attitude towards the possibility of personal change, and recognised the value of therapy and the importance of personal responsibility. They seem interested and willing to engage in introspection, in order to bring about self-improvement (Morey, 1996). Therefore, the TPI and SPI of this sub-group indicated that participants who had elevated Suicidal Ideation scores would be in the low risk group for suicidal or self-harm behaviours, but would be likely to respond well to treatment, given that they acknowledged and perceived a need for help in dealing with their problems. Bearing in mind these important factors, if treatment were offered to members of the Experimental Group, who were suffering significant emotional distress, it is likely that they would respond well to this offer and that the resources provided would be well utilised.
4.9 Conclusions

As the literature indicates, individuals enduring the burden of caring for their chronically ill and disabled spouses are likely to suffer emotional and physical distress themselves. The present research project supports these findings and clearly demonstrates the levels of somatic or physical health complaints, plus the anxiety, depression and stress that the spouses and partners of F-III Deseal/Reseal program personnel have suffered as a result of their caring role.

The SQ, which was constructed to outline the problems faced by the F-III Deseal/Reseal program spouses, demonstrates its usefulness in delineating the specific difficulties experienced by these individuals. The difference between the Experimental and Control Groups was extremely significant at a probability level of 0.0001, highlighting the unique problems faced by the spouses of the F-III Deseal/Reseal program personnel. As the ZBI placed the F-III Deseal/Reseal program spouses in the Moderate to Severe range for burden of care, compared to a normative sample, it demonstrates that this group of individuals is struggling to cope with the burden of care placed upon them. Some of these individuals recorded significantly high suicidal ideation scores as well, which indicates their potential risk for self harm. These high scores also indicated that their level of psychological distress was beginning to exceed their available coping strategies.

Given that there is clear evidence to suggest that the F-III Deseal/Reseal program has had a deleterious effect on the psychological functioning of the spouses of the individuals involved, it was considered responsible for the research project organisers to offer appropriate evidence based psychological...
treatment for this group, focusing on the areas of most concern. These areas are; stress, depression, anxiety, suicidal ideation, generalised coping strategies and physical health problems. Such treatments could be, cognitive behavioural therapy focused on anxiety or depression, schema focussed therapy and other therapies approved by the Australian Psychological Society for the treatment of such conditions. Other suggested interventions could include the development of weekly support groups, funded by the RAAF, where the spouses could have an outlet to discuss and vent emotional distress with other individuals in similar situations and circumstances and to facilitate more effective coping strategies.

Additionally, regularly funded respite breaks would be recommended for the spouses to enable them to engage in self-care activities to increase their resilience to the psychological distresses they face on a daily basis. As the above results have demonstrated a willingness for treatment and the likelihood of positive treatment outcomes for members of the Experimental Group, any future resources allocated for this purpose would be likely to be well utilised by these individuals.
CHAPTER 5

Neurotoxicity in Hospital Settings

5.1 Introduction

Most of the research on neurotoxicity has been conducted in the areas of manufacturing, agriculture, mining and aviation settings. Some research has also been conducted on Health Care Workers who have been exposed to chemicals in the course of their work, such as those working in laboratories where they are exposed to formaldehyde and other preservative agents. However, little research has been conducted into the effects of sterilization agents such as Glutaraldehyde on the workers who handle such chemicals. The research which has been conducted has focused mainly on the general health problems associated these sterilization agents, such as respiratory tract disorders, skin rashes and chronic fatigue; but very few studies have actually addressed the neuropsychological impact of these chemicals on exposed health care workers. This is despite the frequent complaints of cognitive difficulties, such as “fogginess” in the head, confusion, memory lapses, “spacing out”, and poor concentration.

Glutaraldehyde is an aliphatic aldehyde of molecular formula C₅H₈O₂. The chemical is not manufactured in Australia, but it is commercially available here. It is distributed as a clear aqueous solution at concentrations up to 50% WW (NICNAS, 1994).

Glutaraldehyde is a chemical used extensively in hospitals and dental surgeries as a convenient disinfectant for optic fibre endoscopes and other delicate...
medical instruments. It is effective against viruses and bacteria and is used as a 1% or 2% solution in instrument disinfecting. It is also used as a biocide in cooling towers and as a fixative in microbiology and histopathology laboratories. It is a tanning agent for leather and is also used as a component of the developer solutions which are used in x-ray film processing.

Glutaraldehyde was first synthesised around 1908, and as health concerns about formaldehyde emerged, its usage increased (SNFTAAS, 1999).

In the 1960's and 70's, Glutaraldehyde was used mainly as a fixative in histology laboratories, and as a hardener in x-ray developer solutions and as such was used by only a small number of workers. But in the late 1960's Glutaraldehyde was documented as being a useful cold sterilizing agent for urological instruments, clinical thermometers, and dental instruments and was therefore used more frequently (O’Brien, Mitchell, Haberman, Rowan, Winford & Pellet, 1966; Lane, McKeever & Fallon, 1996; Metzger, 1967). With the advent of the HIV problem in the 1980’s there was a re-evaluation of the efficacy of cold sterilization agents in use at the time, and some agents were not considered adequate to destroy the AIDS Virus. Hence Glutaraldehyde was suggested as a more effective alternative in hospitals and surgeries (Menzies, 1995).

This meant that the risks of Glutaraldehyde poisoning rose as:

- Greater volumes of Glutaraldehyde were being used
- More workers were exposed to Glutaraldehyde
• The controls for Glutaraldehyde were poor, in terms of ventilation, protective clothing and storage methods (Ellett, Mikels & Fullhart, 1994).
• Lack of written policies on correct usage of Glutaraldehyde

5.2 Human Studies
The first reported adverse health reaction to Glutaraldehyde was published in the British Medical Journal in 1968, and it was concerned with contact dermatitis (Sanderson & Cronin, 1968). However, the most serious problems documented nowadays are; irritations to the nose and throat; general tightness of the chest; occupational asthma; rhinitis; and eye irritations. These problems have been experienced by health care workers exposed to Glutaraldehyde vapours of varying concentrations (NICNAS, 1994 & 1997; Norback, 1988; Newman & Kachuba, 1992; Tkaczuk et al., 1993; Cullinan, 1992; Ellett, Fullhart & Wright, 1996; Photosol Ltd, 1999). Connaughton, reported palpitations and tachycardia in seven health care workers exposed regularly to Glutaraldehyde (Connaughton, 1993).

In two more recent studies with dental workers exposed to Glutaraldehyde and formaldehyde it was found that dental hygienists and dental assistants who sterilize dental instruments are suffering allergic contact dermatitis. In one study by Ravis et al with 101 dental workers found that almost 15% were found to be allergic to Glutaraldehyde. Given that chronic occupational skin disease has a relatively poor prognosis, it was considered imperative that dental care workers be educated about proper hand hygiene, to avoid potential
allergens and chemical exposure and to recognize problems early (Ravis et al., 2003; Hamann et al., 2005).

As documented in NICNAS, Glutaraldehyde has been added to the indicative list of respiratory sensitisers on the recommendation of the Industrial Injuries Advisory Committee as a chemical that may cause occupational asthma (NICNAS, 1994 & 1997).

The above mentioned research studies, investigating the effects of Glutaraldehyde on health care workers focus almost entirely on physical, dermatological and respiratory symptoms. However, individuals exposed to Glutaraldehyde often report cognitive difficulties such as attention and concentration problems, memory deficits, problems solving difficulties and slowed information processing speed (Glass, 1997; Coxon, 1998; Davis, 2002).

Despite these cognitive difficulties, which have often been reported to medical professionals, little attention appears to have been devoted to them. Investigation of these reported difficulties via comprehensive neuropsychological assessments, appears to have been infrequent.

Lezak states that the lack of investigation of cognitive problems among chemically exposed workers generally occurs because of the similarity of some of these complaints to those of neuroticism or depression. This, coupled with the absence of distinct neurological symptoms, can lead the naïve investigator into discounting the worker’s complaints of cognitive deficits. However, where
neuropsychological evidence is available, symptoms are often supported by positive objective findings (Lezak, 1995).

5.3 Neurotoxic Effects of Glutaraldehyde

One brief neurophysiological study was conducted in New South Wales in the 1990’s investigating the effects of Glutaraldehyde on brain function.

Dr Richard Teo investigated the Auditory Evoked Response Potentials (AERP) of health care workers exposed to Glutaraldehyde in an endoscopy unit for various periods of time. Teo's study included three health care workers exposed to Glutaraldehyde for varying periods of time. However there were no specific details of the total duration of exposure to the chemical of any of the three participants in the study. The only measure of impairment was the P300 latency component of the AERP recording, and there was no control group to verify Teo's findings. However, Teo concluded that his test results suggested that the participants' rate of response to stimuli, as reflected in the P300 component, was impaired. He postulated that these impairments were due to the effects of low dose Glutaraldehyde exposure (Teo & Naidu, 1994).

Although the above study is not robust nor is it statistically sound, the findings support subjective reports of cognitive deficits among health care workers exposed to Glutaraldehyde.

Another early study conducted by Dorothy Gronwall from New Zealand, assessed a small group of health care workers who were exposed to the
chemical Glutaraldehyde, which was being used as a cold sterilization agent for endoscopes. Although the findings were significant, and all three nurses were found to have deficits in information processing speed, concentration span and working memory, there was no control group in the study and no details of any protective measures used by the individuals involved were taken into account. This study did not document the quality of ventilation systems involved in each of the work settings, nor did it take into account the concentration of the chemical used, or the weekly duration of use by the workers involved (Gronwall, 1997).

The inclusion of this type of data would have added significant weight to the study. The inclusion of more informative data may also have had an impact on the safety monitoring of work settings where Glutaraldehyde was being used. This may have led to earlier changes in cold sterilization use, so that less individuals working in this industry would have suffered cognitive decline. Perhaps if this were used as a preliminary study in New Zealand, then a more robust study could have followed, with more conclusive results.

5.4 Background to the Present Proposed Study

There is evidence in the literature that health care workers in endoscopy units, veterinary surgeries, x-ray departments, dental surgeries and hospital operating theatres have experienced concentration and memory difficulties, and slowed speed of information processing (Glass, 1997; Coxon, 1998; Davis, 2002). Complaints regarding the above mentioned problems have been made by workers who were regularly exposed to 1% and 2% solutions of Glutaraldehyde
over prolonged periods of time, sometimes up to twenty years of accumulated exposure.

Complaints such as these from several workers, led to the decision to conduct an investigation of the problem.

5.5 Preliminary Study

In the course of clinical practice during 1995 and 1996, two endoscopy unit nurses, one dental technician and one x-ray assistant, who were exposed to Glutaraldehyde in the course of their work, were interviewed and assessed psychometrically. The dental technician and one of the endoscopy unit nurses had the most intense and direct exposure to Glutaraldehyde, as they experienced both skin contact and inhalation of the chemical. They were exposed to Glutaraldehyde for periods of 18 months and 15 months respectively. As well as their reported cognitive changes, they were found to have EEG changes and both had experienced seizures. The endoscopy unit nurse and the x-ray assistant were exposed to Glutaraldehyde for longer periods, (8 and 9 years, respectively), but their exposure was less intense and their problems were found to be less severe (Coxon, 1998 & 1999).

All four individuals were administered components of the Halstead Reitan Battery of tests, the Spielberger Anxiety Inventory and the Beck Depression Inventory. On assessment, the most commonly occurring neuropsychological deficits which were found among these four health care workers were:

- Lowered attention span (Digit Span Subtest of the WAIS-R)
- Short term memory problems (Wechsler Memory Scale – Russell Revision)
- Slowed speed of information processing (Digit Symbol and Trail Making tests)
- Lowered manual speed (Reitan Finger Tapping test)
- Lowered manual dexterity (Grooved Pegboard test)
- Significant levels of anxiety and depression were found (Spielberger Anxiety Inventory and Beck Depression Inventory)

These four individuals fell into two distinct groups:

**Group 1**
These two health care workers were exposed more acutely to higher concentrations of Glutaraldehyde over shorter periods of time with few protective measures (15 to 18 months), and they suffered the greatest neuropsychological impairments.

**Group 2**
These two health care workers were exposed less severely to low concentrations of Glutaraldehyde over prolonged periods of time (8 to 9 years) and suffered less severe impairments.

Due to the relatively significant findings from the above mentioned case studies, which supported the previous findings of Teo, Naidu and Gronwall, a wider scale research project was proposed to investigate the effects of Glutaraldehyde use on health care workers (Teo & Naidu, 1994; Gronwall, 1997).
5.6 The Proposed Glutaraldehyde Study

The purpose of the current study was to determine the extent of cognitive impairment if any, experienced by a group of health care workers exposed to Glutaraldehyde. The study also aimed to verify the findings of Teo and Naidu, that health care workers exposed to low doses of Glutaraldehyde solutions have impairments in their rate of response to stimuli (Teo & Naidu, 1994).

The proposed study also examined the effects of Glutaraldehyde use on the emotional state of the workers involved.

Among the above mentioned groups of workers in medical, and aviation industries, there were found to be some common areas of neuropsychological deficit. These deficits were found in; memory functioning, processing speed, reaction time, attention span and some aspects of fine motor skills.

Although industrialization is considered a necessary feature of economic growth, it does bring with it occupational health and safety problems. With the increasing incidence of occupational neurotoxic diseases there is a demand for safer working conditions, better occupational health services and a broader coverage of health education.

By conducting studies such as this, with individuals exposed to Glutaraldehyde and other chemicals, researchers can acquire a greater understanding of the effects of chemicals on the human central nervous system. This can also
assist workers to become more mindful of the necessity for using protective measures in all workplaces, to reduce the occurrence of neurotoxic illnesses.

5.7 Assessment Methods Used

Assessment methods utilized previously in the literature on neurotoxicity have included a range of commonly used neuropsychological test batteries, including; the Halstead Reitan Battery of Tests; the Wechsler Adult Intelligence Scales; Wechsler Memory Scales; various tests of Reaction Time; Executive Functioning tests; Fine Motor Skills tests to assess the Peripheral Nervous System; and other tests utilizing Electro Encephalograph (EEG) readings, such as the P300 or P100 readings.

The most meaningful results in assessing individuals with reported cognitive deficits following chemical injuries have been via the most sensitive of the Wechsler Intelligence Scale Subtests, the Digit Symbol and Digit Span tests, which assess processing speed and attention span, respectively. The Paired Associate Test from the Wechsler Memory Scale-Revised is also frequently used as it assesses verbal new learning capacity and is sensitive to mild brain insults (Gronwall, 1997; White & Proctor, 1997; Bowler et al., 2001).

Some researchers have also utilized measures of executive or frontal lobe functioning in their research, such as the commonly used Trail Making Tests A and B, the Symbol Digit Modalities Test of written and oral information processing and the Controlled Oral Word Association Test of language fluency. (White & Proctor, 1997; Gronwall, 1997; Bowler et al., 2001).
A variety of reaction time tests have been used to detect any slowed response
times among chemically injured workers. The California Computerized
Assessment Package of Reaction Time has been considered useful in a variety
of settings, particularly where minor changes in response time are recorded
(Crowe & Casey, 1999; Shores & Simpson, 1998; Batchelor, Shores & Meares,
2007).

A number of studies have utilized very lengthy neuropsychological test
batteries (Chang & Dyer, 1995), while others have used more brief and tailored
batteries or even just one or two AERP readings such as P300 or P100 in their
research projects on chemical exposure effects (Teo & Naidu, 1994; Dick et al.,
2001).

The numerous Scandinavian studies on solvent use in the painting and glue
industries have adhered to their own test batteries, which appear to capture the
cognitive processes typically affected by toxins, such as formaldehyde, toluene,
benzene and other hydro carbons such as petroleum fuels (Hagstadius et al.,
1989; Etling et al., 1990).

Fiedler and colleagues used a battery of tests encompassing overall verbal
ability, spatial relations, concentration and attention, motor skills, visuo-spatial
skills, memory, sensory and affect in their studies. They concluded that these
tests were not significantly sensitive to detect deficits in low level exposures to
toxins (Fiedler, 1996; Fiedler et al., 1996).
Because so much research has been carried out with petrol and glue sniffers, there is now more clear cut evidence as to the actual areas of the brain affected by long term use of such neurotoxic substances. As many deaths occur as a result of chronic solvent inhalation, autopsies have been conducted on brain matter, so that more exact locations of brain matter destruction can be isolated. Once this knowledge has been obtained, then it is easier to design a test battery to assess the functioning of these particular areas. However, with the chemical Glutaraldehyde, there has not been a great deal of research carried out, so information on the areas of the brain affected by this chemical is limited. The only reasonable guidelines to follow are those relating to formaldehyde, which is a similar member of the aldehyde family of chemicals.
CHAPTER 6

The Establishment of the Test Battery

6.1 Introduction

It is because of the above mentioned paucity of research on the chemical Glutaraldehyde and its effects on the brain, that the establishment of the test battery was a somewhat difficult process.

The first consideration in the selection of tests for inclusion in the research project, was to investigate closely the studies already conducted with individuals exposed to Glutaraldehyde and the tests which proved most sensitive to neurotoxic substances. In the study undertaken by Gronwall with a small group of three health care workers exposed to Glutaraldehyde, all participants were found to have information processing speed, concentration and memory deficits on the Wechsler Subscales of Digit Symbol, Digit Span and Paired Associate Learning (Gronwall, 1997).

A small preliminary clinical study conducted by Coxon, (1999) with four health care workers had also demonstrated deficits on the above mentioned tests utilized by Gronwall. These were on the Digit Span, Digit Symbol subtests and also Wechsler Memory Scale subtests. However, deficits in functioning were also found in other areas which were tested. These were in the Trail Making Tests A and B, the Reitan Finger Tapping Test and the Grooved Pegboard Test. In addition, there were significantly high levels of anxiety and depression found on the Spielberger and Beck Inventories (Coxon, 1999).
Although the above mentioned studies were conducted on a very small scale with only four participants in each study and there were no control groups for comparison, it was considered that the tests utilized in this study, which had demonstrated significant deficits, should be included in the test battery for this research project.

Other researchers such as Shores & Simpson and Crowe & Casey, suggested that reaction time to stimuli was an important factor in research of this nature. They had obtained significant findings utilizing subtests of the short form of the CALCAP group of tests. Hence this group of four short subtests of the CALCAP Package was included in the test battery (Shores & Simpson, 1998; Crowe & Casey, 1999).

In a bid to keep the duration of the test battery as short as possible for ease of recruitment of participants, only those tests which were considered to be sufficiently sensitive to demonstrate even minor deficits in functioning were considered.

As the National Adult Reading Test is used in many research projects as a measure of Pre Morbid Intelligence, it was included in the battery of tests as a measure of pre-exposure IQ. The Hospital Anxiety and Depression Scale was included as a short but adequate measure of emotional distress (Zigmond, 1983).
Based on the above information, the following battery of tests was selected.

**The Test Battery**

- Digit Symbol Subtest of WAIS-III
- Digit Span Forwards Test of WAIS-III
- Digit Backwards Test of WAIS-III
- Trail Making Test A
- Trail Making Test B
- Grooved Pegboard Test
- Paired Associate Learning Test of WMS-R
- Controlled Oral Word Association Test
- CALCAP Simple Reaction Time Test
- CALCAP Complex Reaction Time Test
- CALCAP Complex Reaction Time Accuracy
- CALCAP Sequential Reaction Time 1 Test
- CALCAP Sequential Reaction Time 1 - Accuracy
- CALCAP Sequential Reaction Time 2 Test
- CALCAP Sequential Reaction Time 2 - Accuracy
- Hospital Anxiety and Depression Scale
- National Adult Reading Test
6.2 Descriptions of Tests

Digit Symbol Coding

In this test, a series of numbers is paired with its own corresponding hieroglyphic-like symbol using a key and the testee writes the symbol corresponding to its number.

The diagnostic value of this subtest has been demonstrated over many years, and Matarazzo, (1972) as cited by Tulsky, (2003) was one of the first researchers to point out that the Digit Symbol test is not simply a power test, it is also related to mental speed. As such, it is a test in which performance declines over time and it is sensitive to a range of clinical conditions such as brain trauma, dementia and chemical exposure, as outlined by Lezak, (1995).

One reason why the Digit Symbol test is so clinically useful is because there are so many reasons for poor performance on the task. Kaplan et al., (1991) as cited by Tulsky, (2003) have listed the various reasons for poor performance which are; poor motor coordination, short term memory deficits, visuo-perceptual problems, and impaired clerical speed and clerical inaccuracy. It is for these above reasons, and also because neurotoxicity researchers have frequently used this sensitive test, that it was included in the test battery.

Digit Span

The Digit Span Test comprises a series of orally presented number sequences that the testee repeats verbatim in Digits Forwards and recites in reverse order in Digits Backwards. Although in the WAIS-III test, the test score is a
combination of the forward and the backward components into a single score, this study chose to separate them, as they are two very distinctively different measures. Digit Forwards can be successfully executed with simple rote recall, while Digit Backwards requires more mental manipulation and the visualisation of the numbers (Kaufman & Lichtenberger, 1999). It is because both these components of the Digit Span test assess discrete aspects of attention span that they were considered appropriate inclusions in the test battery.

**Trail Making Test**

The Trail Making Tests A and B are essentially tests of processing speed or psychomotor functioning. However the Trail Making B component is of greater complexity in that it includes an attention shifting or set shifting component which is considered to be an executive functioning activity, which engages the frontal lobes of the brain (Lezak, 2004).

In the simple Trails A Test, the testee is merely required to connect a series of circles in ascending order from 1 to 25 while being timed.

The Trail Making B Test however, requires the individual to commence with the number 1, then connect that to the first letter of the alphabet and continue alternating numbers and letters until the testee reaches the number 13. This process is also timed.

As the Trail Making Test is a well normed test with good validity and is frequently used in neuropsychological assessments internationally, it was
included in the test battery. It is sensitive to frontal lobe dysfunction, and therefore is considered relevant for studies on the effects of neurotoxins on the brain.

**The Grooved Pegboard Test**

The decision to include this test in the battery was made because peripheral neurological deficits have often been found among individuals who are exposed to neurotoxic chemicals (Lezak, 2004; Coxon, 2002). This test requires the individual to place small metal rods, with round and square sides, into a board with matching holes, which are placed in different orientations. It is considered an excellent measure of fine motor skills and is particularly sensitive to early cognitive decline.

**Paired Associate Learning Test**

This subtest of the Wechsler Memory Scale – Revised (WMS-R), is considered to be a good basic measure of capacity for new verbal learning. It comprises 2 components, word pairing with simple connections and word pairs which have no connection, to assess different levels of new learning capacity.

**Controlled Oral Word Association Test**

This assessment is frequently used as a method of measuring verbal fluency and also aspects of executive functioning, and was selected due to its sensitivity to minor brain insults. Other researchers have discovered verbal dysfluency among individuals who have been exposed to neurotoxic substances (Lezak, 2004).
Californian Computerized Assessment Package

This group of tests was selected for its sensitivity to minor brain impairments and its usefulness with a range of conditions (Worth et al., 1993; Crowe & Casey, 1999; Shores & Simpson, 1998; Batchelor et al., 2007). Short forms of the selected subtests were used in order to reduce the time taken to complete the test battery. The short form had also been used in the above mentioned studies.

The group of CALCAP subtests selected were:

**Simple Reaction Time Test** where the subject is asked to press a computer keyboard key when he or she sees anything at all on the screen. This procedure provides a base measure of reaction time.

**The Complex Reaction Time Test** of visual selective attention requires individuals to press a key as soon as they see a specific number, such as “7”, on the screen, otherwise they do nothing. This procedure has a simple element of memory, in addition to reaction time.

**The Sequential Reaction Time – 1** which is a serial pattern matching test where subjects are asked to press a computer key only when they see two of the same number sequences. For example, when they see a “3” followed by another “3”, or a “4” followed by another 4”, they respond by pressing a key. This procedure adds a more complex element of memory, since the testee must keep in mind the last number that was seen.
The Sequential Reaction Time – 2 is a test of serial pattern matching, which requires the subject to press a key only when they see two numbers in sequence and in ascending order. For example if they see the number “3” followed by the number “4” then they respond, or the number “6” followed by the number “7” and so on. This is the most complex of all the subtests of the CALCAP and is considered to be the test most likely to identify impairment either in the speed at which the task is executed or the accuracy of the response style (Miller, 1995 & 1999).

Hospital Anxiety and Depression Scale

This scale was included as a means of identifying basic elements of emotional distress among participants. It is a test used originally among hospital patients to rapidly assess elements of anxiety and depression which may require treatment. It has 20 Items, 10 of which measure anxiety and 10 of which measure depression. The Hospital Anxiety and Depression Scale (HADS) is a self report inventory, which can be answered within a few minutes (Zigmond & Snaith,1983). Mykleton, Stordal & Dahl considered the HADS excellent in terms of its factor structure, inter correlation, homogeneity and internal consistency, based on data from a large population of 51,930 individuals in Norway (Mykleton et al., 2001).

The National Adult Reading Test

This test is used frequently in the English speaking world to identify an individual’s pre-morbid or pre-injury IQ. It is based on the principle that the capacity to orally read words is established early on in one’s education and is a
skill which is maintained over time, and in spite of brain insults. This task includes 50 words of varying complexity of pronunciation and the testee is asked to read each word orally. A list of correct pronunciations is provided to the tester for immediate scoring of the test. (Lezak, 2004).

This test is used very frequently in research studies to estimate changes in IQ following an acquired brain injury.

This entire test battery was selected based on the outcomes of previous studies and also on the preliminary study with four individuals exposed to Glutaraldehyde in their workplaces.
CHAPTER 7

Negotiations with the Australian Nursing Federation

7.1 Introduction

Prior to the commencement of the proposed study, permission was sought from the Ethics Committee of Murdoch University, to conduct such a study.

The decision of the Ethics Committee was that the study could proceed providing the National Body of the nursing profession (The Australian Nursing Federation) was involved.

Consequently the Australian Nursing Federation offices in Western Australia, South Australia, Victoria and New South Wales were contacted by the researcher.

However, the only significant responses were forthcoming from the Western Australian and the Victorian Branches.

Submissions were made to both WA and Victorian Central ANF offices and these submissions were put to both their Boards for approval.

The Victorian Branch was particularly interested in the project and initiated three face-to-face meetings to discuss the parameters and the logistics of the study.
A group of nurses who had been exposed to Glutaraldehyde were invited by the ANF (Victoria) to meet with the researcher to discuss test procedures, the interview format, test content and the time frame for the research project.

This above mentioned group of nurses offered valuable information regarding their history of Glutaraldehyde use and the health issues which had emerged for themselves and their colleagues.

Their input was invaluable in the establishment of the Interview for participants, in terms of its content and format. Discussion with these individuals also initiated the inclusion of sensitive reaction time and processing speed tests to identify any deficits in these particular areas.

The Western Australian Branch of the Australian Nursing Federation agreed to participate on the same basis as their Victorian counter parts. However they could not provide office space for testing, so the researcher’s suburban office was used for this purpose.

The Victorian Branch of the ANF made available two offices for testing procedures on each of the six visits for the collection of data, for the researcher and her research assistants. The visits usually extended over two or three day periods over a two year period.
CHAPTER 8

Recruitment of Participants

8.1 Participants

Participants were recruited following negotiations with the Australian Nursing Federation offices in both Western Australia and Victoria. Advertisements were placed in newsletters in both states advertising the study and providing the telephone contact number of the researcher and her supervisor (Appendix A).

When the list of interested individuals was compiled from each state, they were allocated into one of the three groups; Experimental Group 1; Experimental Group 2 and the Control Group.

Exclusions

Volunteers were excluded if they suffered any of the following conditions

Head injury

Chronic illness

Under the age of 21

8.2 Group Criteria

Experimental Group 1

Experimental Group 1 comprised health care workers who had worked with Glutaraldehyde for up to 20 years and continued to work with the chemical.
Experimental Group 2
Experimental Group 2 comprised health care workers who had worked with Glutaraldehyde for up to 35 years, but no longer worked with the chemical.

Control Group
The Control Group comprised health care workers who had never worked with Glutaraldehyde or any other solvents in their workplaces.

Group Demographics

| TABLE X |
|-----------------|-----------------|-----------------|
| **Age and Education of Participants** |
| Exp Group-1 | ExpGroup-2 | Controls |
| N = 19 | N = 23 | N = 18 |
| Age | Mean = 45 | Mean = 48 | Mean = 42 |
| Range | (35 ► 63) | Range (45 ► 64) | Range (30 ► 62) |
| Education |
| Years | Mean = 13.4 | Mean = 12.1 | Mean = 12.8 |

Once the participants were allocated to each of their respective groups, a testing schedule was devised.

8.3 Measures
The test measures used to assess all participants were those described in Chapter 6 (The Establishment of the Test Battery). As outlined above, the tests were selected for their sensitivity to neurotoxins as indicated in other studies.
8.4 Procedure

The two research assistants who were recruited to assist with the testing procedures were both graduate psychologists with experience in research processes and the collection of data. They were trained by the principal researcher on the correct administration of each test in the test battery. There were no significant differences between the two research assistants at the time of data collection.

**Research Assistant A**

Age: 47 years  
Years of Education: 19 years

**Research Assistant B**

Age: 45 years  
Years of Education: 20 years

The research assistants tested the participants in a randomised manner. They assessed participants from each of the groups at both time 1 and time 2.

Once the volunteer participants from each state were contacted and allocated their group placement, the testing procedure commenced.

At the initial session, each participant was asked to sign a “Commitment to Participate” form, which was endorsed by the Murdoch University Ethics Committee and the Researcher’s Supervisor. In signing this document, participants agreed that they would participate in the testing procedures associated with the study, but could withdraw at any stage should they so wish (Appendix B).
Once this form was signed and demographic data obtained, an interview was conducted to gather information on; participants’ exposure to Glutaraldehyde; the concentration of the Glutaraldehyde used; any protective measures used; the symptoms if any, suffered by the participant since Glutaraldehyde exposure; and any other health problems they suffered (Appendix B).

The list of symptoms included; skin rashes; eye irritations; asthma, breathing difficulties; headaches; blood nose; stomach cramps; petit mal seizures; fainting spells; and chronic sinus infections.

**Testing Process**

Following the completion of the clinical interview and the signing of the commitment to participate, the psychometric testing procedure commenced.

Each participant was assessed for evidence of anxiety or depression; intellectual functioning level; processing speed; problem solving capacity; and fine motor skills, via The Test Battery described in Chapter 6. All scores were then entered onto a summary sheet (Appendix B). All participants were tested in the mornings (Test 1 condition) and the evenings (Test 2 condition), to rule out the effects of tiredness and the effects of the individuals’ 24 hours circadian rhythms. The participants were randomly selected for either morning or evening testing at their initial assessment session, then tested at the reverse time of day on their second assessment session. Circadian rhythms are considered to be possible confounding factors in the neuropsychological assessment of older
individuals, as they tend to perform better in the mornings rather than the evenings (Stuss, 2008).

Offices were allocated to the researcher and research assistants at Headquarters of the Australian Nursing Federation in Melbourne, and in Perth the researcher’s metropolitan office suite was utilized. The entire testing exercise took place over a period of two and a half years and involved eight visits to Melbourne to set up the project and test and re-test participants. The visits to Melbourne generally extended over 2 to 3 day periods. Under certain circumstances where it was not possible for the participants to travel to the city, visits were made by the research team to rural and semi-rural areas in Victoria. The additional time required for the distances travelled extended the data collection period beyond its original expectation of one year.

8.5 The Test Battery

The battery of tests which was administered to all participants in the study was selected for its sensitivity to chemical exposure and is described comprehensively in Chapter 6. Test protocols are included in Appendix B. The tests included in the Battery which were administered to all participants were:-

The Digit Symbol Subtest of the WAIS-III
Digit Span Forwards of the WAIS-III
Digit Span Backwards of the WAIS-III
Trail Making Test A
Trail Making Test B
Grooved Pegboard Test
Paired Associate Learning Test of the WMS-R
Controlled Oral Word Association Test
CALCAP Simple Reaction Time Test
CALCAP Complex Reaction Time
CALCAP Complex Reaction Time Accuracy
CALCAP Sequential Reaction Time - 1
CALCAP Sequential Reaction Time - 1 Accuracy
CALCAP Sequential Reaction Time - 2
CALCAP Sequential Reaction Time - 2 Accuracy
Hospital Anxiety and Depression Scale

The duration of the initial testing session was approximately 45 minutes, due to the additional time taken for the interview. The second testing session was of approximately 30 minutes' duration.

The testing sessions were held from two months to nine months apart, to minimise practice effects.

The initial interview information was then rated for risk factors such as; frequency and intensity of exposure; the number of protective measures used; and exposure to other chemicals or drugs. A single score was derived from this process and this was entered onto summary sheets. Another appointment was then made for the second assessment, which was conducted some months later.
If the first assessment had been carried out prior to starting work, then the second assessment had to be carried out at the end of the individual’s work day. This was done to rule out the tiredness factor and the impact of Circadian Rhythms.

Once all the raw data were collected, the participants’ results were entered onto summary sheets for data analysis. The three groups’ summary sheets were then colour coded according to their status regarding exposure to Glutaraldehyde and their state of origin.

**Experimental Groups 1**

Red / Yellow - Still working with Glutaraldehyde / Victoria
Red / Green - Still working with Glutaraldehyde / Western Australia

**Experimental Groups 2**

Blue / Yellow - No longer exposed to Glutaraldehyde / Victoria
Blue / Green - No longer working with Glutaraldehyde / Western Australia

**Control Groups**

White / Yellow - Never worked with Glutaraldehyde / Victoria
White / Green - Never worked with Glutaraldehyde / Western Australia

It was envisaged initially that the data could be then divided into two groups for analysis, Victoria and Western Australia, but due to the low numbers from Western Australia, where only 13 participants took part, this was not considered
a feasible option. Therefore all state groups were combined into single groups of Experimental 1, Experimental 2 and the Control Group.

Due to the fact that on analysis there were such insignificant differences between the Test 1 and Test 2 conditions, the test scores were averaged over the two testing times. This allowed for individuals who had only been able to attend one testing session, to have their scores included, by just adding their one score.

The absence of these participants at the second testing session occurred because some individuals relocated away from their state of origin, or were overseas at the scheduled time of the second assessment.

Three participants chose to withdraw from the study and their data was not included for analysis. Two were from Victoria and one was from Western Australia.
CHAPTER 9

Results

9.1 Data Collection and Storage

All data collected from the three groups of participants was entered onto summary sheets for each individual’s testing sessions.

These results were then entered onto a Pentium Computer for storage until the analysis of the data was carried out.

The Raw data are presented in (Appendix E).

9.2 Analyses of Results

All the data were then entered into an Excel program and the means for age and education of participants were calculated for the groups individually. The demographics for all these groups of participants are set out below in Table XI.

<table>
<thead>
<tr>
<th>TABLE XI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Descriptive Summary Statistics</td>
</tr>
<tr>
<td><strong>Overall</strong></td>
</tr>
<tr>
<td>N=58</td>
</tr>
<tr>
<td>Mean (Age) = 49.25 years</td>
</tr>
<tr>
<td>SD (Age) = 7.67</td>
</tr>
<tr>
<td>Range (Age) = 24-64 years</td>
</tr>
<tr>
<td>Mean (Education) = 15.64 years</td>
</tr>
<tr>
<td>SD (Ed) = 2.54</td>
</tr>
<tr>
<td>Range (Ed) = 10-21 years</td>
</tr>
</tbody>
</table>

| **Experimental Group 1** |
| N=18 |
| Mean (Age) = 48.76 years |
| SD (Age) = 7.80 |
| Range (Age) = 31-63 years |
| Mean (Education) = 15.35 years |
| SD (Ed) = 2.15 |
| Range (Ed) = 10-19 years |
| M (Exposure) = 8.15 years |
| SD (Exp) = 5.88 |
| Range (Exp) = 0.50-20 years |
**Experimental Group 2**
N=23
Mean (Age) = 50.91 years  
SD (Age) = 6.66  
Range (Age) = 42-64 years  
Mean (Education) = 15.67 years  
SD (Ed) = 2.80  
Range (Ed) = 10-21 years  
M (Exposure) = 11.06 years  
SD (Exp) = 7.34  
Range (Exp) = 3-35 years

**Control Group**
N=17
Mean (Age) = 47.47 years  
SD (Age) = 8.65  
Range (Age) = 24-58 years  
Mean (Education) = 15.91 years  
SD (Ed) = 2.63  
Range (Ed) = 11-21 years

Table XI details indicate that there were no significant differences between the three groups in age or years of education. However, the participants in Experimental Group 2, had a longer range of exposure times to Glutaraldehyde than Experimental Group 1 i.e. 3 to 35 years, (Mean 11.06 years) as compared with 0.5 to 20 years (Mean 8.15 years). There were more participants in Experimental Group 2, (23) than either of the other groups Experimental Group 1, = (18) and Control Group, = (17).

The data from the Excel spreadsheet was then entered into the SPSS 15 program for further analysis. These data are presented in (Appendix F).

### 9.2.1 Preliminary investigation of the IQ variables

The NART provides an indication of pre-morbid IQ, that is, a factor that was present prior to the chemical exposure. Therefore, if the pre-morbid IQ’s of the
3 conditions (Control, E1 & E2) differ significantly from each other, then this may have an effect on the scores on the other Dependent Variables (DV)s.

A one-way between groups ANOVA, demonstrated that FSIQ differed significantly between the different conditions (F (2, 57) = 4.600, p = 0.014). Post hoc multiple comparisons using the Bonferroni Test showed that the Control and Experimental 1 Groups differed significantly (p = 0.013) from one another, where the Control Group had a significantly higher mean FSIQ (M = 119.18) than Experimental Group 1 (M = 114.11). However, neither group differed significantly from Experimental Group 2 (M = 115.74).

As such, differences may be found between the groups on the other DVs as a result of differences in their FSIQ rather than differences that are a result of the exposure to Glutaraldehyde. If this were a possibility, then a MANCOVA, could have been used which holds the FSIQ factor constant. However, given there are a number of difficulties with this (e.g. unbalanced design – unequal number of participants in each group, low sample size for all groups) as well as possible difficulties in the NART accurately determining pre-morbid IQ, it was decided that the apparent differences in FSIQ are nothing to be overly concerned with. In addition, education level is another factor which may have affected the Dependent Variables and as such this may need to be considered when looking at the overall group differences. However Table XI indicated that there were no significant differences between the three groups in age or education levels. Thus given the complexity of the data and the resultant difficulty of assessing it with a MANCOVA, it was considered best to tackle this matter from an
alternative perspective. So, for this reason the analysis was continued without giving further consideration to FSIQ or ED scores.

9.2.2 Type of analysis to be used and consideration of dependent variables

Since there were multiple DVs, a Multivariate Analysis of Variance (MANOVA) was considered the most appropriate analysis to conduct. However, the power of the MANOVA to detect effects decreases considerably as correlation between the DVs increases. In fact, a number of authors have suggested that it is simply wasteful to conduct a MANOVA when a number of the DVs overlap. In other words, if there are separate DVs where scores are expected to be very similar, it is best not include them in the analysis. Alternatively, a composite score could be created for the DVs which overlap. Rather than simply eliminating measures from the analysis altogether, it was considered better to combine the scores of each subtest to produce a composite score for the overall test.

Another reason for the necessity of combining the subtest scores rather than examine them individually is that, when using MANOVA, there must be more cases than DVs in every cell. Since the lowest sample size of one of the groups (the control condition) is 17, there must not be more than 16 DVs. Even then, the assumption of homogeneity of variance-covariance is likely to be rejected if there are only one or two more cases than DVs. Based on the information from the thesis proposal regarding groupings of tests, it was decided to only include in the analysis the following overall DVs: Digit Symbol, Digit Span, Trail Making, CALCAP, PAL, Grooved Pegboard, FAS, Anxiety, and Depression.
At this point, it was important to determine whether it was worthwhile to include Time as a factor. If there is not likely to be any difference in test scores from Time 1 to Time 2, then these scores should also be combined in order to decrease the total number of DVs from 18 to 9 (since, given the sample size, there should be no more than 16 DVs and also decreasing the likelihood of the assumption of homogeneity of variance-covariance being violated).

An investigatory split-plot ANOVA was conducted (using the Huyn-Feldt Epsilon correction for a violation of sphericity) to assess whether it was likely that time was an important factor. This determined that the effect of Time did not differ significantly across the subtests (Test Type): $F(3.616, 198.890) = 2.075$, $p = 0.092$. In addition, a graphical representation of the Time x Test Type interaction suggests there is very little change in score for each test type from Time 1 to Time 2 (see Figures 1 and 2 below).

**FIGURE 1**
Interaction between time and test type

![Estimated Marginal Means of MEASURE_1](image-url)
Although the SPANOVA suggested that the interaction of time and condition was significant \( F(2, 55) = 5.274, p = 0.008 \), the figure below should be considered:

**FIGURE 2**
Interaction between time and condition

Estimated Marginal Means of MEASURE_1

![Graph showing estimated marginal means for time and condition](image)

This figure shows that scores on the tests decreased quite considerably from Time 1 to Time 2 for the Control Group and also for Experimental Group 2 (although to a lesser extent). However, scores increased from Time 1 to Time 2 for Experimental Group 1. Therefore it was not considered a significant enough interaction to be representative of anything meaningful. As discussed, there were some participants who were tested at Time 1 and had just finished a night shift. Given that these sorts of factors were not controlled for when determining ‘Time 1’ and ‘Time 2’, then it is quite probable that there was simply too much ‘noise’ to be able to take anything from this result.
Based on this, it was decided to average the scores for each test at Time 1 with those from Time 2. This enabled the analysis to be ‘cleaner’, as well as reducing the limitations that the small sample sizes of the groups would have on the Doubly Multivariate Analysis that would then need to be conducted (i.e. if we included Time as a within-subjects variable).

9.2.3 Assumption testing: Multivariate Normality

The Shapiro-Wilks test was significant (i.e. indicating a distribution that deviated significantly from normal) for:

- Experimental Group 1 on the Trails test ($p = 0.021$),
- the Control Group on the Pegboard test ($p = 0.002$) and
- Experimental Group 1 on the Pegboard test ($p = 0.011$).

MANOVA is robust to modest violation of normality if the violation is created by skewness rather than outliers. In addition, the assumption of normality is of less concern when the cell size is 30 or more. Since the sample size here is much less, then consideration of this assumption is more critical. However, looking over the distribution plots, it would seem that these violations are due to skewness rather than outliers. As such, it was decided to proceed with the analysis with the assumption of multivariate normality confirmed. However, it was considered wise to keep these particular condition-test groups in mind before drawing too many conclusions directly from them (i.e. if they turn out to be significant).
9.2.4 Assumption testing: Homogeneity of variance-covariance matrices

Box’s Test of Equality of Covariance Matrices was not significant ($p = 0.005$) at an alpha level of .001 and therefore this assumption has not been violated. However, the Levene’s Test of Equality of Error Variances is significant for both the Depression and Anxiety tests. This means that if either of the univariate F-test is significant for either of these variables, this finding should be interpreted at a more conservative alpha level.

9.2.5 Multivariate Tests of Significance:

There are a number of test statistics that can be used here, but Pillai’s Trace Criterion, was selected since it is considered to have acceptable power and to be the most robust statistic against violations of assumptions (of which there are some concerns regarding the normality). As shown in the table below, the Pillai’s Trace Criterion is significant ($p = 0.008$). This demonstrates that there are significant group differences across the DVs.

<p>| TABLE XII |
| Pillai’s Trace Criterion |
| --- | --- | --- | --- | --- |</p>
<table>
<thead>
<tr>
<th>Pillai'sTrace</th>
<th>Value</th>
<th>F</th>
<th>Hypothesis df</th>
<th>Error df</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.583</td>
<td>2.192</td>
<td>18.000</td>
<td>96.000</td>
<td>0.008</td>
<td></td>
</tr>
</tbody>
</table>

9.2.6 Univariate Test of Significance:

This demonstrates which individual DVs contribute to the significant multivariate effect. Since these tests are exactly the same as just running several ANOVAs, it is usually advised to use a Bonferroni-type adjustment. This means that an alpha level of $0.006 (.05/9)$ must be used. From the table below, it is evident
that the groups only differ significantly on the Depression (p = 0.0005) and Digit Symbol (p = 0.0005) tests. However, some researchers choose to ignore this safeguard and still use the standard alpha level of .05. Using this alpha, significant effects of Depression (p = 0.0005), Anxiety (p = 0.023), Digit Symbol (p = 0.0005) and CALCAP (p = 0.045) were observed. Although these might be accepted as significant, one must be wary that we are risking Type I error (i.e. accepting it as significant when it is not).

**TABLE XIII**

Dependent Variables which Contribute Significantly

<table>
<thead>
<tr>
<th>Dependent Variable</th>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
<th>Observed Power(a)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>DEP</strong></td>
<td>154.668</td>
<td>2</td>
<td>77.334</td>
<td>8.873</td>
<td>0.000</td>
<td>.965</td>
</tr>
<tr>
<td></td>
<td>479.371</td>
<td>55</td>
<td>8.716</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>ANX</strong></td>
<td>97.824</td>
<td>2</td>
<td>48.912</td>
<td>4.021</td>
<td>0.023</td>
<td>.695</td>
</tr>
<tr>
<td></td>
<td>669.073</td>
<td>55</td>
<td>12.165</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>TRAILS</strong></td>
<td>1633.825</td>
<td>2</td>
<td>816.912</td>
<td>1.791</td>
<td>0.176</td>
<td>.359</td>
</tr>
<tr>
<td></td>
<td>25086.730</td>
<td>55</td>
<td>456.122</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>FAS</strong></td>
<td>1902.564</td>
<td>2</td>
<td>951.282</td>
<td>2.545</td>
<td>0.088</td>
<td>.488</td>
</tr>
<tr>
<td></td>
<td>20561.682</td>
<td>55</td>
<td>373.849</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>PEGBOARD</strong></td>
<td>668.457</td>
<td>2</td>
<td>334.229</td>
<td>.991</td>
<td>0.378</td>
<td>.214</td>
</tr>
<tr>
<td></td>
<td>18548.033</td>
<td>55</td>
<td>337.237</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>DIGSYMB</strong></td>
<td>3072.241</td>
<td>2</td>
<td>1536.120</td>
<td>9.886</td>
<td>0.000</td>
<td>.979</td>
</tr>
<tr>
<td></td>
<td>8545.729</td>
<td>55</td>
<td>155.377</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>DIGSPAN</strong></td>
<td>31.120</td>
<td>2</td>
<td>15.560</td>
<td>1.520</td>
<td>0.228</td>
<td>.310</td>
</tr>
<tr>
<td></td>
<td>563.155</td>
<td>55</td>
<td>10.239</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>PAL</strong></td>
<td>42.542</td>
<td>2</td>
<td>21.271</td>
<td>1.953</td>
<td>0.151</td>
<td>.388</td>
</tr>
<tr>
<td></td>
<td>598.889</td>
<td>55</td>
<td>10.889</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>CALCAP</strong></td>
<td>415833.362</td>
<td>2</td>
<td>207916.681</td>
<td>3.291</td>
<td>0.045</td>
<td>.601</td>
</tr>
<tr>
<td></td>
<td>3475086.630</td>
<td>55</td>
<td>63183.393</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table XIV below provides a summary of the individual means of each group for each DV. However, since there are three levels of the group, an examination of these means does not indicate which of the levels are significantly different for the individual test.

<table>
<thead>
<tr>
<th>Condition</th>
<th>Mean</th>
<th>Std. Deviation</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>DEP</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>control</td>
<td>1.9412</td>
<td>1.18430</td>
<td>17</td>
</tr>
<tr>
<td>Exp 1</td>
<td>3.4167</td>
<td>2.59666</td>
<td>18</td>
</tr>
<tr>
<td>Exp 2</td>
<td>5.8261</td>
<td>3.94453</td>
<td>23</td>
</tr>
<tr>
<td>Total</td>
<td>3.9397</td>
<td>3.33519</td>
<td>58</td>
</tr>
<tr>
<td>ANX</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>control</td>
<td>5.0294</td>
<td>2.15400</td>
<td>17</td>
</tr>
<tr>
<td>Exp 1</td>
<td>5.1389</td>
<td>2.42418</td>
<td>18</td>
</tr>
<tr>
<td>Exp 2</td>
<td>7.7391</td>
<td>4.74310</td>
<td>23</td>
</tr>
<tr>
<td>Total</td>
<td>6.1379</td>
<td>3.66801</td>
<td>58</td>
</tr>
<tr>
<td>TRAILS</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>control</td>
<td>85.6285</td>
<td>14.36815</td>
<td>17</td>
</tr>
<tr>
<td>Exp 1</td>
<td>98.8767</td>
<td>28.76637</td>
<td>18</td>
</tr>
<tr>
<td>Exp 2</td>
<td>95.1172</td>
<td>18.72779</td>
<td>23</td>
</tr>
<tr>
<td>Total</td>
<td>93.5028</td>
<td>21.65137</td>
<td>58</td>
</tr>
<tr>
<td>FAS</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>control</td>
<td>118.2059</td>
<td>20.57081</td>
<td>17</td>
</tr>
<tr>
<td>Exp 1</td>
<td>103.5000</td>
<td>15.81046</td>
<td>18</td>
</tr>
<tr>
<td>Exp 2</td>
<td>111.5652</td>
<td>20.82574</td>
<td>23</td>
</tr>
<tr>
<td>Total</td>
<td>111.0086</td>
<td>19.85219</td>
<td>58</td>
</tr>
<tr>
<td>PEGBOARD</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>control</td>
<td>127.0594</td>
<td>13.56203</td>
<td>17</td>
</tr>
<tr>
<td>Exp 1</td>
<td>134.4558</td>
<td>21.22996</td>
<td>18</td>
</tr>
<tr>
<td>Exp 2</td>
<td>134.5648</td>
<td>19.00130</td>
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<tr>
<td>Total</td>
<td>132.3311</td>
<td>18.36114</td>
<td>58</td>
</tr>
<tr>
<td>DIGSYMB</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>control</td>
<td>77.0000</td>
<td>11.20407</td>
<td>17</td>
</tr>
<tr>
<td>Exp 1</td>
<td>61.1389</td>
<td>11.79707</td>
<td>18</td>
</tr>
<tr>
<td>Exp 2</td>
<td>60.9130</td>
<td>13.76974</td>
<td>23</td>
</tr>
<tr>
<td>Total</td>
<td>65.6983</td>
<td>14.27670</td>
<td>58</td>
</tr>
<tr>
<td>DIGSPAN</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>control</td>
<td>18.7647</td>
<td>3.30302</td>
<td>17</td>
</tr>
<tr>
<td>Exp 1</td>
<td>16.9444</td>
<td>2.74338</td>
<td>18</td>
</tr>
<tr>
<td>Exp 2</td>
<td>17.4348</td>
<td>3.44207</td>
<td>23</td>
</tr>
<tr>
<td>Total</td>
<td>17.6724</td>
<td>3.22892</td>
<td>58</td>
</tr>
<tr>
<td>PAL</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>control</td>
<td>24.2941</td>
<td>3.29801</td>
<td>17</td>
</tr>
<tr>
<td>Exp 1</td>
<td>22.3611</td>
<td>2.41810</td>
<td>18</td>
</tr>
<tr>
<td>Exp 2</td>
<td>22.4565</td>
<td>3.84623</td>
<td>23</td>
</tr>
<tr>
<td>Total</td>
<td>22.9655</td>
<td>3.35458</td>
<td>58</td>
</tr>
<tr>
<td>CALCAP</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>control</td>
<td>1774.3185</td>
<td>256.42991</td>
<td>17</td>
</tr>
<tr>
<td>Exp 1</td>
<td>1837.1439</td>
<td>247.36978</td>
<td>18</td>
</tr>
<tr>
<td>Exp 2</td>
<td>1972.3826</td>
<td>250.70129</td>
<td>23</td>
</tr>
<tr>
<td>Total</td>
<td>1872.3587</td>
<td>261.26951</td>
<td>58</td>
</tr>
</tbody>
</table>
9.2.7 Analysis of CALCAP Sub-Tests

SPSS Variable Names

SRTa = Average RT between Test 1 & Test 2 on the SRT
CRTa = Average RT between Test 1 & Test 2 on the CRT
SEQRT1a = Average RT between Test 1 & Test 2 on the SEQRT1
SEQRT2a = Average RT between Test 1 & Test 2 on the SEQRT2

Assumption Testing

All assumptions for the MANOVA were met:
Shapiro-Wilks test for Normality was significant for Experimental Group 1: SRTa and CRTa and Experimental Group 2: CRTa. Inspection of frequency histograms and Q-Q Plots suggests these violations were due to outliers and otherwise the distributions appeared normal. Box’s Test of Equality of Covariance Matrices was not significant (p = 0.008) and therefore this assumption is not violated. Levene’s Test of Equality of Error Variances was not significant for any of the conditions.

Multivariate Test of Significance

As shown in the table below, Pillai’s Trace Criterion is not significant (p = 0.201). This tells us there were not any significant group differences across the scores on the CALCAP subtests at a multivariate level.

<table>
<thead>
<tr>
<th>TABLE XV</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Pillai’s Trace Criterion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Value</td>
</tr>
<tr>
<td>-------</td>
</tr>
<tr>
<td>0.192</td>
</tr>
</tbody>
</table>
**Univariate Test of Significance**

As described in the previous analysis summary, it is essential for these tests that adjustment is made for familywise error (since they are essentially the same as running separate ANOVAs). This means that an alpha level of 0.01 (or 0.05/4) must be used. As can be seen in the table below, the SEQRT2a is the only subtest that is significant (p = 0.007).

### TABLE XVI

**Subtest Scores and Levels of Significance**

<table>
<thead>
<tr>
<th>Dependent Variable</th>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
<th>Observed Power(a)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SRTa</td>
<td>4257.813</td>
<td>2</td>
<td>2128.906</td>
<td>.347</td>
<td>0.708</td>
<td>.103</td>
</tr>
<tr>
<td>CRTa</td>
<td>337267.904</td>
<td>55</td>
<td>6132.144</td>
<td>.213</td>
<td>0.809</td>
<td>.082</td>
</tr>
<tr>
<td>SEQRT1a</td>
<td>2288.429</td>
<td>2</td>
<td>1144.215</td>
<td>3.402</td>
<td>0.040</td>
<td>.617</td>
</tr>
<tr>
<td>SEQRT2a</td>
<td>295421.578</td>
<td>55</td>
<td>5371.301</td>
<td>5.488</td>
<td>0.007</td>
<td>.831</td>
</tr>
</tbody>
</table>

### TABLE XVII

**Summary of Subtest Scores for each Group**

<table>
<thead>
<tr>
<th>Condition</th>
<th>Mean</th>
<th>Std. Deviation</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>SRTa</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>338.6765</td>
<td>53.22533</td>
<td>17</td>
</tr>
<tr>
<td>Exp 1</td>
<td>359.3889</td>
<td>95.15260</td>
<td>18</td>
</tr>
<tr>
<td>Exp 2</td>
<td>355.3730</td>
<td>79.20705</td>
<td>23</td>
</tr>
<tr>
<td>Total</td>
<td>351.7255</td>
<td>77.40594</td>
<td>58</td>
</tr>
<tr>
<td>CRTa</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>403.4218</td>
<td>84.85740</td>
<td>17</td>
</tr>
<tr>
<td>Exp 1</td>
<td>403.0775</td>
<td>57.48315</td>
<td>18</td>
</tr>
<tr>
<td>Exp 2</td>
<td>416.0824</td>
<td>75.08656</td>
<td>23</td>
</tr>
<tr>
<td>Total</td>
<td>408.3355</td>
<td>72.27021</td>
<td>58</td>
</tr>
<tr>
<td>SEQRT1a</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>480.5150</td>
<td>120.06012</td>
<td>17</td>
</tr>
<tr>
<td>Exp 1</td>
<td>493.5861</td>
<td>101.52915</td>
<td>18</td>
</tr>
<tr>
<td>Exp 2</td>
<td>559.9130</td>
<td>95.06656</td>
<td>23</td>
</tr>
<tr>
<td>Total</td>
<td>516.0570</td>
<td>109.18350</td>
<td>58</td>
</tr>
<tr>
<td>SEQRT2a</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>551.1471</td>
<td>91.19309</td>
<td>17</td>
</tr>
<tr>
<td>Exp 1</td>
<td>580.6361</td>
<td>102.73569</td>
<td>18</td>
</tr>
<tr>
<td>Exp 2</td>
<td>642.0870</td>
<td>75.37040</td>
<td>23</td>
</tr>
<tr>
<td>Total</td>
<td>596.3612</td>
<td>95.94924</td>
<td>58</td>
</tr>
</tbody>
</table>
The univariate tests demonstrated that there was only a significant difference occurring between the groups within the SEQRT2a subtest. Therefore it was considered necessary to determine where this significant difference was occurring.

When pairwise comparisons of the means were observed (using the Bonferroni-adjustment), it appeared that the only significant difference that was occurring was between the Control Group and Experimental Group 2. That is, participants in the Control Group scored significantly lower on average on the SEQRT2a than participants in Experimental Group 2 (p = 0.007).

An alternative is to use t-tests for these comparisons. A Bonferroni-adjustment to the alpha level means significance is tested at 0.017 (.05/3). The results of the t-tests were as follows:

Participants in the Control Group scored significantly lower on average on the SEQRT2a than participants in Experimental Group 2 (t (38) = -3.450, p = 0.001).

Participants in the Control Group did not score significantly lower on the SEQRT2a on average than participants in Experimental Group 1 (t (33) = -0.896, p = 0.377).

Participants in Experimental Group 1 did not score significantly lower on the SEQRT2a on average than participants in Experimental Group 2 (t (39) = -2.210, p = 0.033). In this case the p-value was not significant at the Bonferroni-adjusted alpha level. As was mentioned in the previous summary, one may
choose to nonetheless assess significance at an alpha level of .05, in which case this difference would be significant. From this one could safely conclude that there were significant differences between the Controls on the SEQRT2a subtest of the CALCAP and the Experimental Groups. However, in contrast to previous research, there were definitely not any significant differences on the other CALCAP subtests.

### 9.2.8 Length of Exposure

Due to an interest in comparing short and long-term exposure, an input into SPSS was made of the length of exposure for each participant as recorded on their Questionnaire.

For Experimental Group 1 (current exposure), the mean length of exposure was 8.15 years (SD = 5.88). Length of exposure ranged from 0.5 – 20 years. The frequency of each exposure score can be seen below in Figures 3 and 4.

**FIGURE 3**

*Frequency of Exposure EXP 1*

![Frequency of Exposure EXP 1](image-url)
For Experimental Group 2 (no longer exposed), the mean length of exposure was 11.06 years (SD = 7.34). Length of exposure ranged from 3 - 35 years. The frequency of each exposure score can be seen below:

**FIGURE 4**

*Frequency of Exposure EXP 2*

![Bar chart showing frequency of exposure scores for Experimental Group 2.]

Although the thesis proposal indicated that “short term exposure” would be described as exposure of 1 year or less and “long term exposure” was greater than one year, there were not sufficient participants to make this division. That is, in the Experimental Group 1 there were only 2 participants with an exposure time of 1 year or less and in Experimental Group 2 there were no participants who had been exposed for less than one year. Therefore the division was made at a different point to maximize sample size in each group (e.g. Short/Medium-term = 8 years or less; Long-term = Greater than 8 years). However, this still proved to be too small a sample size to run statistical analyses upon.
9.3 Summary Analysis of all Results

Post-hoc multiple comparisons using the Bonferroni test identify significant differences for:

Control (M = 1.94) and Experimental Group 1 (M = 5.83) for Depression (p = 0.0005)

Experimental Group 1 (M = 3.42) and Experimental Group 2 (M = 5.83) for Depression (p = 0.036)

Control (M = 77.00) and Experimental Group 1 (M = 61.14) for Digit Symbol (p = 0.001)

Control (M = 77.00) and Experimental Group 2 (M = 60.91) for Digit Symbol (p = 0.001)

It may be useful to note that comparisons are approaching significance for:

Control (M = 1774.32) and Experimental Group 2 (M = 1972.38) for CALCAP (p = 0.051)

Control (M = 5.03) and Experimental Group 2 (M = 7.74) for Anxiety (p = 0.055)

Alternatively, t-tests could have been used to make post-hoc comparisons. As mentioned earlier, it is generally advisable in this circumstance to make a Bonferroni adjustment whereby the alpha level would be set at 0.0042 (0.05/12). If this were done then one would see significant differences between:

Control and Experimental Group 2 for Depression (t (38) = -3.920, p = 0.0005)

Control and Experimental Group 1 for Digit Symbol (t (33) = 4.073, p = 0.0005)

Control and Experimental Group 2 for Digit Symbol (t (38) = 3.944, p = 0.0005)
However, it was decided not to make the Bonferroni-adjustment and therefore assess significance by an alpha level of 0.05 (bearing in mind that this could lead to potential criticism), then significant t-values were observed for:

Control and Experimental Group 1 for Depression ($t (33) = -2.141, p = 0.040$)
Experimental Group 1 and Experimental Group 2 for Depression ($t (39) = -2.237, p = 0.031$)
Experimental Group 1 and Experimental Group 2 for Anxiety ($t (39) = -2.116, p = 0.041$)
Control and Experimental Group 2 for Anxiety ($t (39) = -2.189, p = 0.035$)
Control and Experimental Group 2 for CALCAP ($t (38) = -2.446, p = 0.019$)

From these post-hoc comparisons, confident interpretations can be made of the increase in depression scores for Experimental Group 2 from the Control Group and from Experimental Group 1 to Experimental Group 2 (i.e. depression scores for Experimental Group 1 did not differ significantly from the Control Group). In addition, it can also be confidently interpreted that the increase in scores on Digit Symbol for both Experimental Group 1 and 2 when compared to the Control Group. However they did not differ significantly from one another. There could be a "weak" interpretation of the increase in Experimental Group 2 scores compared to the Control Group for the CALCAP, as well as for the increase in anxiety for Experimental Group 2 compared to the Control Group.
CHAPTER 10

Discussion on Glutaraldehyde Study

10.1 Introduction

One of the most significant results in this study was a significant difference between both Experimental Groups 1 and 2 and the Control Group on the Digit Symbol scores, which assess processing speed ($P = 0.005$).

This outcome demonstrated that the Control Group participants, who had never been exposed to the chemical Glutaraldehyde in their workplace, were faster to process information than those who had worked with the chemical for some years. The Digit Symbol test of the WAIS-III is considered to be one of the most sensitive of all the subtests to many forms of brain insult (Lezak, 2004; Tulsky, 2003).

The fact that both Experimental Groups’ scores were significantly lower than those of the Control Group on the Symbol Digit test, suggests that their processing speed has been affected by their exposure to the Glutaraldehyde in their workplace.

As there were no significant education or age differences between the three groups, the difference in the scores could not be accounted for by these factors. However, there were significant differences in FSIQ between the Controls and Experimental Group 1, but not between Controls and Experimental Group 2, yet both experimental groups performed more poorly than the Controls on the Symbol Digit test.
As there were no significant differences in Digit Symbol Test scores between Experimental Groups 1 and 2 themselves, (they were both impaired) this outcome suggests that exposure to Glutaraldehyde, be it long term or short term, current or past, had a significant effect on workers’ speed of information processing.

Another finding was a mildly significant difference between the Control Group and Experimental Group 2 scores in the overall CALCAP (California Computerized Assessment Package) test of reaction time to stimuli. (\(P = 0.019\)). However when a breakdown into individual CALCAP subtests was undertaken, there was a more significant difference between the Controls and the Experimental Group 2 on the most complex of the CALCAP subtests, SEQRT 2. This was significant at the level of \(P = 0.006\).

Not only were there significant differences in reaction times between the Control Group and Experimental Group 2 participants on the CALCAP test scores, but also there was a significant difference between the Control Group and the Experimental Group 2 in accuracy of responses in the two most complex subtests of the CALCAP, the SEQRT 1 and SEQRT 2 tests.

These two sets of CALCAP data suggested that the Experimental Group 2 were both slower to react to the stimuli and also were less accurate in their responses to the presented stimuli than the Controls.
The Total Interview Score, which estimated the two Experimental Groups’ extent of exposure to Glutaraldehyde and the protective measures used by them, indicated that Experimental Group 2 had a significantly greater exposure to the chemical than Experimental Group 1. This may perhaps explain the differences between their scores on some of the tests.

The participants in the Experimental Group 2, who no longer worked with Glutaraldehyde, appeared to have more significant health problems associated with Glutaraldehyde exposure than those in Experimental Group 1, so this could also have been a contributing factor to their poor scores. Unfortunately no data was collected on the time which had elapsed since participants in Experimental Group 2 ceased working with Glutaraldehyde. There could well have been some recovery effects over these periods of time which were not taken into account. This may have added further significant data to the study.

Regarding the emotional state of the participants; there was a highly significant difference between the Control Group and Experimental Group 2 on the Depression component of the Hospital Anxiety and Depression Scale (HADS) (P = 0.0005). However the difference between the Control Group and Experimental Group 1 on the Depression component was only mildly significant (P = 0.04).

On the Anxiety component of the HADS, there was only a mildly significant difference between the Control Group and the Experimental Group 2 (P = 0.035) and also between the two Experimental Groups 1 and 2 (P = 0.041). However
there were no significant differences between the Anxiety Scores of the Control Group and those of the Experimental Group 1.

To summarise, based on the above findings, it can be postulated that Experimental Group 2, consisting of participants who had higher levels of exposures to Glutaraldehyde and used less protective measures than Experimental Group 1, demonstrated slower information processing speed; were slower in reaction time to complex stimuli; were more inaccurate in their responses to the stimuli presented; had a significantly higher levels of depression; and were slightly more anxious than the participants of the Control Group.

Surprisingly, Experimental Group 1, who had less severe exposure to Glutaraldehyde and used better protective measures than Experimental Group 2 were equally as slow to process information as the Experimental Group 2 participants. However their reaction times to stimuli on the CALCAP tests were not significantly slower than those of the Control Group participants, nor were they any less accurate in their responses than the Control Group.

10.2 Hypothetical Reasons for Findings
The findings in this study could reflect the lack of sensitivity of many of the tests utilized, where no significant differences were found. Some of the reaction time tests utilized via CALCAP were expected to be sensitive in detecting the effects of chemical exposure, as they had been in other studies, but the results were only mildly conclusive. It may be that impairments in cognitive functioning, as
measured by the CALCAP reaction time tests are only recognizable when the test is complex and the degree of impairment has reached a significantly high level. However the study did reflect the sensitivity of processing speed tests, such as Digit Symbol, in determining subtle cognitive impairments in Glutaraldehyde exposed workers.

Hence, as Tulsky et al stated “Processing speed tests such as the Symbol Digit Coding test, give a more accurate indication of brain impairment, even after only mild insults to the brain”. Therefore it is suggested that any future neurotoxicity studies should focus more on this particular dimension of cognitive functioning, and perhaps incorporate another WAIS-III component of the Processing Speed Index, the Symbol Search test, which was not included in this study (Tulsky et al., 2003).

It may be argued that higher levels of depression could account for the poor processing speed scores of the two Experimental Groups, when compared to participants in the Control Group. This notion could be refuted on the basis that although Experimental Group 2 had very significantly higher levels of depression compared with the Control Group (P = 0.005), Experimental Group 1 had only mildly significant levels of depression compared with the Control Group (P = 0.04), yet both Experimental Groups had very significantly impaired processing speed scores when compared with the Controls. Results indicated that there was only a mildly significant difference between Experimental Group 1 and Experimental Group 2 on their HADS Depression scores, (P = 0.036) yet
both groups had very significantly slower processing speed scores when compared with the Control Group participants (P = 0.0005).

According to researchers Rohling, Green, Allen and Iverson in their comprehensive study, depression does not necessarily adversely affect an individual’s cognitive performance. In their study, there were no significant correlations between measures of depression and the various clusters of neurocognitive tests administered (Rohling et al., 2002).

It is often considered that where an individual’s performance is affected by depression, it generally has a global effect on all test measures, however in the above study, the participants in Experimental Group 1 and Experimental Group 2 performed reasonably well on most tests, except those which are considered to be sensitive to neurotoxic insults, i.e. processing speed and reaction time to stimuli.
CHAPTER 11

Critical Evaluation of the Present Glutaraldehyde Study

11.1 Introduction

The results of this study demonstrated some significant deficits in processing speed for the two Experimental Groups which had been exposed to the chemical Glutaraldehyde. However the only other mildly significant findings were those of reaction time to stimuli and accuracy of response to stimuli among the Experimental Group 2 participants, when compared with the Controls. This perhaps demonstrates the overall lack of sensitivity of the test battery to exposure to chemicals such as Glutaraldehyde.

Perhaps if other speed of information processing speed tests had been employed, such as the Symbol Search test of the WAIS-III, the results may well have been more conclusive. Similarly, more complex reaction time tests could have been employed to more closely examine the slowed reaction times of the Experimental Groups compared with the Control Group, thereby adding more weight to the study.

The Hospital Anxiety and Depression Scale was used as a brief measure of emotional distress and did provide some significant and meaningful results for Experimental Group 2 on the Depression factor. However, the anxiety component did not demonstrate such differences.

Perhaps if more comprehensive measures of anxiety and depression had been utilised, such as the Beck Anxiety Inventory, the Beck Depression Inventory, or
the Personality Assessment Inventory, then more useful data could have been extracted in this domain.

However, in its favour, the above mentioned HADS assessment method was selected for ease of obtaining data and the brief time required for test administration.

These factors were considered desirable, in the interest of brevity of the test battery, as time constraints are a significant factor when limited resources are available at the time of data collection.

The researcher was required to travel to Melbourne on a 3 monthly basis over 2 years to collect the data and also had to fit testing times into the operating hours of the Australian Nursing Federation Headquarters in the Melbourne CBD.

For these reasons, it was important that the test battery did not take longer than 30 to 40 minutes to administer. In hindsight, a more comprehensive although more time consuming test battery, comprising more lengthy, sensitive tests, may have provided the researcher with more significant and meaningful data.

However, the above mentioned testing procedures were considered the most reasonable ones at the time of the data collection, given all the above mentioned constraints. Consultation had been held with two senior neuropsychology academics from New South Wales prior to the establishment of the test battery, to ensure that it was appropriate in nature.
CHAPTER 12

Conclusions and Recommendations for Future Research

12.1 Summary of what was Achieved

12.1.1 The BAe-146 Study

The BAe-146 aircraft study of pilots and flight crew exposed to jet engine oil emissions via faulty air-conditioning seals, demonstrated impairments in information processing speed, concentration and attention span and some aspects of memory.

The outcome of this brief study was considered sufficiently concerning to warrant a wider scale research project incorporating a larger group of participants and a more extensive battery of tests.

The above paper and other more technical papers were presented at the British Airline Pilots Association’s (BALPA) Air Safety and Cabin Air Quality International Aero Industry Conference in London in 2005. Following these presentations, Neuropsychologist, Dr Sarah Mackenzie-Ross was approached by the UK Government to join an advisory committee to investigate the issue of ill health among airline pilots exposed to contaminated air. This Committee on Toxicity of Chemicals in Food, Consumer Products and the Environment (COT) is made up of scientists from diverse backgrounds. These are; Molecular Toxicology, Pathology, Endocrinology, Epidemiology, Pharmacology, Immunology, Nutrition and Neuroscience.
The COT was asked to review the available evidence and form an opinion as to whether a significant problem existed for airline pilots. They considered that there were only limited data available to enable them to review the situation and none of the COT members had any experience in assessing aircraft crew, despite submissions being made to COT by the presenters at the BALPA International Conference in London in 2005, including that of Coxon (2005). However, neuropsychologist, Mackenzie-Ross, who had subsequently assessed aircrew in UK for clinical purposes, was asked to submit her findings in a report, as part of their review. Mackenzie-Ross collaborated with Coxon regarding the neuropsychological test battery used in the BAe-146 2002 project.

Among the questions asked of Mackenzie-Ross were:
How do BAe-146 pilots compare to Boeing 757 pilots?
Are cabin crew affected?
Are passengers affected?
Could ill health be the result of lifestyle and not exposure?
Any similarities with farmers exposed to Organophosphates?

The above Mackenzie-Ross project was conducted via the University College in London, and the results obtained verified those found in the brief Coxon study in Western Australia (Coxon, 2002; Mackenzie-Ross, 2006).

Hence the above mentioned Coxon and Mackenzie-Ross projects played a role in initiating further research to highlight the difficulties faced by pilots attempting to operate aircraft while affected by the inhalation of contaminated air.
Further research is likely to be conducted in this important area of workplace health and safety in the future. Already, air monitors and bleed air cleaning technologies are being introduced to monitor and improve air cabin quality. (Rowe, 2007; Aerotoxic Association UK, 2009).

In September 2009, BAe Systems introduced the new “AirManager” air cleaning system which it had developed with Quest International. With the installation of this unit, the ventilation air passes through an electric field generated by plasma which inactivates viruses, bacteria and mould and oxidises gaseous contaminants that contain volatile organic compounds (VOCs), such as ethanol and benzene. This system was touted as a response to fears of SARS, Avian Flu, Swine Flu and “market perception” of poor cabin air quality, and was installed in the BAe-146 and Boeing 757 aircraft in 2009. These were the two aircraft with the most frequently reported fume events over the past decade or more (Aerotoxic Association Newsletter, October 2009).

12.1.2 F-III Deseal/Reseal Spouse Study
This study, which investigated the impact on spouses caring for individuals affected by neurotoxic chemicals in their workplace highlights the far reaching effects of neurotoxicity problems to areas that are beyond those of the workers themselves.

Studies such as this give impetus to providers of health and safety programs to be more mindful of the extent of the burden of care thrust upon chemically affected workers’ partners and spouses. Hopefully this will lead to more
stringent use of safety measures which are being utilized in all workplaces involving chemical exposure, universally.

Such studies may also facilitate the early reporting of chemically induced symptoms so that workers do not reach such a disabled state before being identified. This would reduce the enormous burden placed on their carers and spouses, which has in the past been largely ignored by employers.

Hopefully the outcomes of this study will also lead employers to provide appropriate treatments and respite facilities for the spouses of the affected workers who carry the burden of care through no fault of their own.

12.1.3 Glutaraldehyde Study

From this study, it was revealed that lengthy and excessive exposure to the chemical Glutaraldehyde, particularly where few protective measures have been utilized, can have deleterious effects on the cognitive functioning and the emotional state of health care workers handling this chemical.

These effects, although only evident in discrete areas of cognitive functioning, such as; speed of information processing, reaction time to stimuli and accuracy of responses to stimuli, may have significant effects on the day to day performance of such individuals. In terms of their work performance, they would be likely to respond and react more slowly to workplace demands, which in emergency situations could prove dangerous, and could render them a liability in their work environments.
A general slowing of speed of information processing may also render them less efficient in their day to day duties, thus wasting valuable time, which is all important in modern hospital settings.

On the home front, their inefficiencies could also prove troublesome for other family members, especially if they were in a position of responsibility, such as taking care of young children, grandchildren or elderly parents.

The Depression scores of the Experimental 2 Group participants which were significantly higher than those of the other two groups, pose two questions “Do their cognitive deficits and health problems cause their depression?” or “Does their depression contribute to their cognitive dysfunctions?”.

This latter question could essentially be ruled out because the Experimental 1 Group were not very significantly depressed, yet their reaction times to stimuli and their processing speeds were equally as impaired as those of the Experimental 2 Group, who were highly significantly depressed.

This phenomenon was reported in a study by Rohling, Green et al., as mentioned previously, where they found non significant correlations between measures of depression and various clusters of neurocognitive tests. This was a robust study involving 420 patients with heterogeneous referral diagnoses, from head injury to neurological diseases, plus well-matched non depressed control participants. Contrary to expectation, their data suggested that
depression has no impact on objective neurocognitive functioning (Rohling, Green et al., 2002).

Future studies in the area of neurotoxicity involving Glutaraldehyde may consider employing other more sensitive tests of cognitive functioning ability, perhaps those incorporating working memory components. There was evidence of such deficits on one of the CALCAP subtests (SEQR 2) where Experimental 2 Group participants were not only the slowest to respond but obtained the least accurate scores. This task requires the individual to hold numbers in their memory, while searching for the next consecutive ascending number and respond to it as quickly as possible. If other similar such tasks had been included, there may have been a richer bank of data collection for analysis.

Another important inclusion for future studies would be a more comprehensive collection of details of each group’s exposure to Glutaraldehyde. Although this information was collected in the present study via questionnaire, there was not sufficient detail to provide more useful data.

Although some participants in Experimental Group 2 had provided additional information on their questionnaire sheets, this could not be fully utilized as the same information had not been extracted from the remaining participants of this group. The information which had been supplied in this manner included; descriptions of wide scale chemical spills; faulty equipment which leaked chemicals onto the floor; situations where Glutaraldehyde soaked cloths were
hung out to dry in the preparation rooms, thus emitting a constant flow of fumes into the closed environment; and faulty or non operational extractor fans which failed to remove fumes from the sterilizing rooms.

Had this data, listed above, been extracted from both experimental groups, and separated out, then the data obtained may have been reasonably robust and a valuable inclusion.

In this study, the history of exposure to Glutaraldehyde; safety measures used; and health problems associated with Glutaraldehyde exposure; were all combined into an “Exposure History” factor. Although this appeared to be a reasonable approach at the time, in hindsight, it rendered some valuable data less useful than it may have been.

Additionally, the study could have been more conclusive, had there been greater numbers of participants in each group. This could have been achieved by employing a more comprehensive recruitment campaign using newspaper advertisements, or radio programs on community issues. If more than two states in Australia had been included, the study would have been richer in data collection and perhaps more meaningful conclusions could have been drawn. This would also have enabled state by state comparisons to be made, which would have proved useful in terms of national chemical usage and safety standards being established on the basis of the results obtained.
In this study only Western Australian and Victorian nurses participated, because that is where the interest was generated. The New South Wales and South Australia Branches of the Australian Nursing Federation had been contacted, but their limited interest did not warrant the collection of data from these states. Perhaps if a more personal approach had been made to the Australian Nursing Federation offices in South Australia, New South Wales, Queensland and Tasmania, then the number of participants could have been doubled or trebled, thus creating a richer bank of data.

Funding was also an issue, as the experimenter funded all eight trips to Victoria and covered the expenses of both herself and her research assistants. If a substantial grant were to be made in the future to carry out further studies in this and similar workplace areas, then this research project could serve as a very useful pilot study.

12.1.4 Research Hypotheses

The research hypotheses of the three above mentioned studies were accepted.

1) Toxic jet oil emissions from faulty BAe-146 aircraft were found to negatively affect the cognitive functioning of pilots and flight crew, although the study was limited in its depth and lacked a control group.

2) The burden of caring for chronically affected aircraft workers exposed to toxins in the RAAF F-III Deseal/Reseal program was found to significantly impact on the mental health of their spouses and their burden of care was moderate to severe.
3) The occupational exposure of health workers to the chemical Glutaraldehyde resulted in some areas of significant cognitive impairment and emotional distress.

12.2 Overall Contributions and Limitations of the Studies

In the area of workplace safety in aviation, hospital and clinic settings, where chemicals are used more and more frequently, the outcomes of studies such as these highlight the need for stringent health and safety measures to be implemented. Once upper level managers and departmental heads are alerted to the long term deleterious effects of chemicals on the cognitive functioning, emotional state and overall health of workers and their spouses, one would hope that more stringent adherence to recommended guidelines would occur across all relevant settings worldwide. Such recommendations, guidelines and warnings are generally clearly outlined by the distributors of toxic products and attached to chemical labels. However, in their haste to dilute and prepare such solutions for distribution, as in Glutaraldehyde, staff members have not always heeded such guidelines. Research projects such as these present studies highlight the importance of workers adhering to manufacturers’ recommendations, and safety regulations.

Another useful aspect of studies such as these is that the current battery of tests, which demonstrated a degree of sensitivity to neurotoxic exposure in workers, could be further refined to include additional more sensitive tests as suggested above. The refined battery could be used with workers in a range of other work settings where neurotoxic chemicals are used, as even the current
battery of tests has demonstrated a degree of sensitivity to Glutaraldehyde exposure in hospitals and clinics, and jet oil fume emissions in the aviation industry. Researchers in the past have also used similar batteries (Gronwall, 1997; Shores & Simpson, 1998; Mackenzie-Ross, 2006).

If the refined battery which included more sensitive tests, were to be applied to a more extensive range of work settings where chemicals are used, then we would be able to gather a richer bank of data. Then if the more sensitive tests were to be extracted from the test battery used in these research projects, then combined with other test batteries previously used by Mackenzie-Ross, in the United Kingdom; Heuser, in USA; Teo, and Coxon, and Winder, in Australia, then we may be able to compile a more useful test battery which could be used internationally in a variety of work settings, where workers are exposed to neurotoxic substances (Mackenzie-Ross, 2006; Heuser, 2005; Teo, 1994; Coxon, 2002; Winder, 2005).

Collaboration between all above mentioned groups has already occurred on a small scale, but wider scale research needs to occur before such batteries could be established and recognized internationally as effective modes of assessment.

12.3 Recommendations for Future Research

In this time of ever increasing use of chemicals in many workplaces, it is of vital importance that research projects such as this are ongoing so that any deficits in cognitive functioning and health problems are identified at an early stage.
during the exposure to chemicals. This would prevent devastating chemical injuries from occurring which can maim workers for life, result in their premature death, cause health problems for carers and spouses, and create genetic problems for future generations (Ford, 1998 &1999; Costa & Manzo, 1998).

However, methods of monitoring environmental and occupational exposures to organophosphates, such as chlorpyrifos have their limitations, including low specificity and sensitivity, and short time windows for detection. Unfortunately biomarkers for the organophosphate tricresyl phosphate (TCP), which can contaminate bleed air from jet engines and cause occupational exposure of commercial airline pilots, crew members and passengers, has not to date been identified. However, a research team at the University of Washington’s Department of Medicine led by Kim, Stevens, Furlong et al., have embarked on work to identify, purify and characterize new biomarkers of organophosphate exposure. Their hypothesis is that by indentifying and characterising molecular biomarkers with longer half lives, they should be able to clinically detect TCP and OP insecticide exposure after longer durations of time than are currently possible. This work is necessary and will be ongoing, in order to detect and appropriately treat poisonous organophosphate exposures to humans (Kim, Furlong et al., 2006).

Hence further research incorporating these highly sensitive testing methods and identification of specific biomarkers of organophosphate exposure in humans is urgently needed.
There is also an important role for neuro imaging, electroencephalograph, regional cerebral blood flow and genetic methods of assessment such as; SPECT and PET, AERP, rCBF, chromosome testing and fMRI, as suggested by Heuser & Mena, Teo & Naidu, & Maximilian et al & Ford. However, these are expensive diagnostic tools and their use may be prohibitive if research funds are limited (Heuser, 1999: Heuser & Mena, 1998; Teo & Naidu, 1994; Maximilian et al., 1982; Ford, 1998, 1999).

A combination of both neuropsychological test data and neuro imaging results would no doubt provide more comprehensive and meaningful data as they would demonstrate a combination of; pathological changes in brain structure, blood flow changes to various parts of the brain, chromosome changes, and also functional deficits in brain activity, as revealed by neuropsychological test data.

Therefore if neuropsychological, neurological, neuro imaging and other medical and genetics researchers could combine their areas of expertise and put effort into conducting further research studies, then the effects of a variety of frequently used neurotoxic chemicals on the human brain and body would be better understood.

We would then have a richer bank of data on which to base more precise safety standards, which one hopes would be adhered to in all work settings where toxic chemicals are employed. This hopefully would reduce the casualties caused by chemical exposure in workplaces.
A number of researchers have raised the issue of under reporting of chemical exposure events by workers, particularly those in the aviation industry, where air crew fear losing their jobs and pilots licence to fly their aircraft. Also, the industry itself tends not to take “fume events” seriously, as both Rolls Royce and British Aerospace have been documented as considering cabin air contamination as being associated with “small” or “minor” leakages. Although such events have been documented for almost 20 years, little progress had been made in identifying the source of the problem and taking action until recent years (Michaelis, 2007).

Hence it is important that workers who are exposed to chemicals in the course of their work are properly educated on the dangers associated with such chemicals and have access to comprehensive information on the particular chemicals they encounter. It is also important that they have access to occupation, health and safety personnel, who are themselves well educated in the perils of chemical exposure. Early reporting of symptoms is all important in the treatment of such individuals, as ongoing unreported symptoms can lead to permanent health problems, as reported by Costa and Manzo and Hartman (Costa & Manzo, 1998; Hartman, 1995).

Following the BALPA Air Safety and Cabin Air Quality Conference in London in 2005, a group of interested researchers from a range of disciplines and a number of countries, gathered together to discuss plans for future research on the effects of neurotoxic chemicals on the physical, cognitive, and emotional wellbeing of workers, particularly those in the aviation industry.
Communication among these groups has been well established for some 4 years, via internet connection, and hopefully will continue, so that collaboration will be ongoing and vital data shared among these concerned researchers. Hopefully this will result in changes being made to occupation, health and safety legislation internationally, not only to protect humans, but also to protect the environment.

Toxico-pathologist, Professor Vyvyan Howard, who has deep concerns about the effects of chemicals on human health and the environment considers that we need to take all the precautions we can in preventing harm to humanity and the environment, and quoted in his paper on Risk Assessment, “The Precautionary Principle” in 2008.

“When an activity raises threats of harm to human health or the environment, precautionary measures should be taken, even if some cause and effect relationships are not fully understood” (Howard, 2008).

Finally, Fengsheng He was also concerned about neurotoxic problems in general and proposed:

“Although multi-disciplinary research efforts are to be encouraged to investigate the pathogenesis, diagnosis and treatment of neurotoxic disorders, it is multi-sectoral collaboration that is urgently needed if we are to prevent the growth of occupational neurotoxic disorders world wide” (He, 1998).
REFERENCES


Matarazzo, J.D. (1972) Wechsler Measurement and Appraisal of Adult Intelligence (5th Ed) Baltimore, Williams & Wilkins.


The following appendices are not available online if you wish to obtain a copy please contact ill@murdoch.edu.au

Appendix A-F only available with hardcopy.