NEUROBEHAVIOURAL EFFECTS OF INORGANIC LEAD EXPOSURE IN BATTERY WORKERS IN SELANGOR

BY

DR. MUHAMMAD NASIR BIN SULIAMAN

Dissertation Submitted in Partial Fulfillment
of the Requirements for the Degree
of Master of Community Medicine
(Occupational Health)

UNIVERSITI SAINS MALAYSIA

UNIVERSITI SAINS MALAYSIA
2007

PREFACE

"Health and safety decisions have two components – value and science.

Value refers to the amount of money society is willing to spend on protecting workers'

health while science refers to the available scientific knowledge

on which occupational health policies are based"

Jacqueline Karnell Corn, 1992

I hope my dissertation could be a contribution towards the second component.

ACKNOWLEDGEMENTS

I wish to extend my fullest gratitude and utmost appreciation to Professor (Dr.) Rusli Bin Nordin, Professor of Community Medicine and Deputy Dean, School of Dental Sciences, Health Campus, USM for his support, encouragement, understanding and cooperation towards me throughout my work in making this study possible.

A special gratitude to the Department of Occupational Safety and Health headquarters and Selangor branch especially En. Hamzah without whom the selection of factories would be an impossible task.

My special appreciation to Dr. Aziah Daud as my co-supervisor, Dr. Tengku Mohd. Ariff, Dr Razlan Musa and Dr. Nor Azlina Abd. Rahman for their assistance.

To the Department of Community Medicine School of Medical Sciences, USM and the Research and Ethics Committee, thank you for approving a short term grant making this study feasible. Sincere thanks also to Biochem Laboratories Sdn. Bhd. for the analysis of blood samples and environmental lead. Sincere thanks to NORMS Group for allowing me to use the NCTB equipment.

My undividing love to my family for their unconditional support throughout my Masters programme. Not forgetting Dr. Aidi Mohamed, Fathi and Faris for helping me out in my research. Thanks also to Ms. Nurul Ainun Hamzah and Ms. Haizan, and for those who have given me the support to make this study possible, directly or indirectly, my thanks goes to all of you too. Last but not least to all my classmates who have supported me throughout the years, "THANK YOU ALL".

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

ANCOVA	-	Analysis of Covariance
CI	-	Confidence Interval
DOSH	-	Department of Occupational Safety and Health
df	-	Degree of Freedom
EMM	-	Estimated Marginal Means
IQR	-	Inter-quartile Range
Lpm	-	Liter per minute
µg/dL	-	Microgram per Decilitre
NCTB	-	Neurobehavioural Core Test Battery
OSHA	-	Occupational Safety and Health Act
PEL	-	Permissible Exposure Limit
PS	-	Power and Sample Size
PVC	-	Polyvinyl Chloride
SD	-	Standard Deviation
TWA	-	Time Weighted Average
TLV	-	Threshold Limit Value
WHO	-	World Health Organisation
XRF	-	X-ray fluorescence
ZPP	-	Zinc Protoporphyrin

LIST OF APPENDICES

ABSTRAK

TAJUK: KESAN PENDEDAHAN KEPADA PLUMBUM BUKAN ORGANIK TERHADAP SISTEM SARAF DAN TINGKAH LAKU PEKERJA KILANG BATERI DI SELANGOR

Penggunaan plumbum semakin meningkat dengan kemajuan industri dan peningkatan ini semakin mendadak dengan berkembangnya penggunaan kenderaan bermotor pada abad ke dua puluh. Pada masa ini penggunaan plumbum tertumpu kepada pembuatan bateri asid dengan anggaran penggunaan tahunan sebanyak 76% dari penggunaan primer dan sekunder plumbum. Manusia boleh terdedah kepada plumbum di udara persekitaran dan di tempat kerja. Tetapi pendedahan di tempat kerja lebih menjadi tumpuan kerana 95% dari keracunan disebabkan plumbum di kalangan golongan dewasa adalah dari tempat kerja (Shwartz, 2001). Antara organ yang mendapat kesan dari pendedahan terhadap plumbum adalah kardiovaskular, ginjal, sistem reproduktif, darah, usus, hepar dan sistem saraf. Kesan awal plumbum terhadap sistem saraf adalah subklinikal and ujian terhadap sistem saraf dan tingkah laku (*neurobehavioural*) adalah satu kaedah untuk mengesan kesan subklinikal ini. Walaupun industri membuat bateri adalah pengguna utama plumbum, data mengenai tahap pendedahan dan kesannya terhadap sistem saraf dan tingkah laku pekerja kilang bateri di Malaysia masih lagi terhad.

OBJEKTIF: Objektif kajian ini adalah untuk menilai kesan pendedahan kepada plumbum terhadap sistem saraf dan tingkah laku di kalangan pekerja kilang bateri di Selangor.

METODOLOGI: Ini adalah kajian irisan lintang melibatkan 44 pekerja yang terdedah dan 33 pekerja yang tidak terdedah kepada plumbum di kilang pembuatan bateri dan

pembaikian dan penggunaan semula bateri terpakai. Pendedahan dinilai melalui permonitoran peribadi (*personal monitoring*) di kawasan berbeza di dalam kilang bateri; tahap plumbum dalam darah digunakan sebagai tahap penyerapan plumbum; gejala-gejala dan kesan terhadap system saraf dan tingkah laku dinilai dengan menggunapakai borang soalselidik piawai Pertubuhan Kesihatan Sedunia (WHO) dan *Neurobehavioural Core Test Battery.*

KEPUTUSAN: Tiga belas dari 20 bacaan plumbum dalam udara menunjukkan tahap melebihi had pendedahan yang dibenarkan (julat dari <1μg/m³ ke 768.88 μg/m³). Lokasi(no.) yang mempunyai tahap pendedahan melepasi had yang dibenarkan adalah *grid casting* (2), *grid pasting* (2), kawalan mutu (3), *assembly lines* (2), *battery cutting* (1), *furnace-melt* (1), *battery smelting* (1) dan kerja pembersihan (1). Median tahap plumbum dalam darah bagi pekerja yang terdedah adalah 11.10 μg/dL manakala bagi yang tidak terdedah adalah 9.45 μg/dL. Pekerja yang terdedah mempunyai peratusan yang lebih bagi gejala kelupaan (29.5%), berpeluh yang berlebihan (13.6%), cirit birit (15.9%), lemah anggota badan bahagian bawah (25.0%) dan perubahan pada deria rasa taste (9.1%) tetapi tiada yang signifikan. Pekerja yang terdedah mencapai markah yang lebih rendah dalam ujian *Benton Visual Retention, Digit Span, Pursuit Aiming, Digit Symbol* dan *Santa Ana Manual Dexterity Non-dominant Hand.* Hanya *Pursuit Aiming Test* didapati signifikan (p=0.018). Didapati juga bahawa kaitan di antara pencapaian ujian system saraf dan tingkah laku di kalangan pekerja di dalam kumpulan kadar plumbum lebih tinggi (≥12.2μg/dL) adalah berkadar songsang jika dirujuk kepada kumpulan pekerja di dalam kumpulan tahap plumbum yang lebih rendah (≤8μg/dL) bagi

ujian *Pursuit Aiming, Simple Reaction Time, Profile of Mood States (total score), Tension-Anxiety, Depression-Dejection* dan *Vigour*

DISKUSI: Bahagian yang berbeza di dalam kilang bateri menunjukkan tahap pendedahan yang berbeza dari yang rendah kepada yang terlalu tinggi.Walaupun terdedah kepada tahap yang tinggi, tahap plumbum dalam darah pekerja kilang bateri masih di bawah tahap tindakan (*action level*). Ini adalah disumbangkan oleh kaedah perlindungan diri, cara kerja selamat yang diamalkan dan kepatuhan majikan terhadap undang-undang yang telah melindungi pekerja. Tanda-tanda dan markah ujian tingkah laku dan system saraf tidak menunjukkan perbezaan signifikan di kalangan pekerja kilang bateri yang selari dengan keputusan tahap plumbum dalam darah yang tidak signifikan.

KESIMPULAN: Pekerja-pekerja di kilang bateri yang diuji adalah terdedah kepada plumbum pada tahap yang berbeza bergantung kepada bahagian kerja. Walaubagaimanapun, melaui kaedah pelindung diri yang sesuai, cara kerja selamat dan kepatuhan majikan kepada undang-undang telah melindungi pekerja-pekerja ini. Tiada kaitan berkadar songsang yang signifikan di antara tahap plumbum dalam darah dan pencapaian ujian siatem saraf dan tingkah laku pekerja–pekerja kilang bateri.

KATA KUNCI: Pekerja kilang bateri, tahap plumbum dalam darah, ujian pencapaian sistem saraf dan tingkah laku, tahap plumbum persekitaran.

ABSTRACT

TITLE: NEUROBEHAVIOURAL EFFECTS OF INORGANIC LEAD EXPOSURE IN BATTERY WORKERS IN SELANGOR

INTRODUCTION: The usage of lead progressively increased with industrialisation and rose dramatically with the widespread use of automobile in the twentieth century. Nowadays, it is predominantly used in the lead-acid batteries with estimated 76% of annual primary and secondary lead usage. Human can be exposed to lead through the general environment and occupations but it is the latter that poses major concern because almost 95% of all adult lead intoxication is of occupational in origin (Shwartz, 2001). Among the organs affected by lead are of lead are cardiovascular, renal, reproduction, haematology, gastrointestinal, hepatic and central nervous system. Early effects of lead on the central nervous system can be subclinical and test of neurobehavioural is one method to detect these effects. Although battery manufacturing is the major user of lead, currently, there is very limited data available on the level of lead exposure and its neurobehavioural effects on battery workers in Malaysia.

OBJECTIVE: The objective of this study is to assess the neurobehavioural performances of battery manufacturing plant workers.

METHODOLOGY: This is a cross sectional comparative study comparing the neurobehavioural effects of lead among 44 exposed and 33 non-exposed from three battery manufacturing plants and one battery reclamation and recycling plant. Exposure was assessed through personal monitoring of exposure to lead at different sections of the plants; blood lead level was checked as a biomarker and symptoms and neurobahavioural

outcome was assessed using standard WHO questionnaire and Neurobehavioural Core Test Battery respectively.

RESULTS: Thirteen of twenty points of monitoring showed level above Permissible Exposure Limit (Range <1μg/m³ to 768.88 μg/m³).The sections (no.) with the level above the Permissible Exposure Limit were grid casting (2), grid pasting (2), quality control (3), assembly lines (2), battery cutting (1), furnace-melt (1), battery smelting (1) and housekeeping (1). Median blood lead levels for exposed and non-exposed workers were 11.10 and 9.45 μg/dL respectively. Exposed workers were noted to have higher proportion of forgetfulness (29.5%), excessive sweating (13.6%), diarrhea (15.9%), weakness of lower body (25.0%) and change of sense of taste (9.1%) but none was significant. Sixty three percents of exposed workers wore face mask while working but only 6.8% change their cloth before going home. Only small proportion of exposed workers eat and smoke while working (4.5% and 13.6% respectively). Exposed workers scored lower in Benton Visual Retention, Digit Span, Pursuit Aiming, Digit Symbol, and Santa Ana Manual Dexterity Non-dominant Hand. Only Pursuit Aiming Test was significant (p=0.018). There were inverse associations in workers in the higher blood lead level category (≥12.2μg/dL) in the tests of Pursuit Aiming, Simple Reaction Time, Profile of Mood States (total score), Tension-Anxiety, Depression-Dejection and Vigour, in reference to workers in the category of lower blood lead level (≤8μg/dL) but these associations were not significant.

DISCUSSION: Different sections of different factories have different levels of environmental lead from very low level to a very high level. Despite being exposed to high concentration of lead at certain sections, the blood lead levels of the workers are still

below the action level. This is due to due to the protective measures practiced by the workers and compliance to the law by the employer that protects the workers. Neurobehavioural symptoms and performance score were not significant between the exposed and non-exposed which was reflected by the insignificant difference in blood lead level between these two groups.

CONCLUSION: The workers in the studied battery manufacturing plants are exposed to lead at varying level depending on the sections in the factory. However, through proper protective measures, safe work practices and employers compliance to the law, the workers were protected from this exposure. There were also no significant inverse association between blood lead levels and neurobehavioural performances in battery manufacturing plant workers.

Key word: battery workers, blood lead level, neurobehavioural performance, environmental lead level

CHAPTER 1

INTRODUCTION

Workers represent half of the global population and contribute greatly to the economic and social value of contemporary society (WHO, 2006) and between 60, 000 and 70, 000 people are employed in lead battery manufacturing (Gottesfeld, 2003).

Globally, of all toxic heavy metal, lead ranks as one of the most serious environmental poisons (Herman *et al.*, 2006). There has been an accumulating and incremental evidence of the effects of lead, the most ubiquitous toxic metal, whose health effects were known as early as the second century BC (Walker, 2000).

Bellinger *et al.* (2005) have studied children even with low-level lead exposure, and found that it is a significant public health problem in India. This shows that lead exposure also affects the children at home.

There is undisputable evidence to show that lifestyle factors are significant in their contribution to illness and injury at the workplace leading to an increasing costs, absenteeism and low productivity and performance at the worksite (Guharajan, 2004).

Through this study I intend to investigate the exposure of lead in the selected battery factories in Selangor, workers' hygiene practices and the neurobehavioural effects due to lead exposure among these workers. It is my fervent hope that the data obtained from this study can benefit towards ensuring workers' health particularly in the battery manufacturing industry in Malaysia. The name of the factories involved in this study will not be exposed to respect their request for confidentiality. The findings from this study will be distributed to the factories involved for their reference.

1.1 Lead

Lead is a soft, metallic blue-gray element with atomic number 82 and weight 207.19 atomic mass unit and occurs naturally in soils and rock (Swartz, 2001). Lead has found widespread application in the society. Its low melting point of 327°C, overall malleability, high density and resistance to corrosion has led to its wide usage. Lead is found at low concentration in the earth's crust predominantly as lead sulfide (galena), but the widespread occurrence of lead in the environment is largely the result of anthropogenic activity. It can enter the environment at any stage from its mining to its final use. The utility of lead and lead compounds was discovered in prehistoric times and its usage increased progressively with industrialisation and rose dramatically with the widespread use of automobile in the twentieth century. The predominant use of lead now is in the lead-acid batteries, and to lesser extent, in construction materials and lead-based chemicals (International Agency for Research on Cancer, 2006). The total intake of lead by adults and children in the general populations varies greatly as to the relative contributions from individual sources (air, water, food, soil/dust and others) and is partly dependent on lifestyle and socioeconomic status (WHO, 1995).

In United Kingdom, Health and Safety Executive (HSE) has reported that in 2003/04 period, three industry sectors account for the majority of males working with lead, being the lead battery industry (22%0, smelting, refining allotting and casting (17.5%0 and work with metallic lead and lead containing alloys (9.5%).

Despite its benefits to the industry, lead is also recognized as an environmental and occupational pollution (Ravichandran *et al.*, 2005). Inorganic lead is undoubtedly one of the oldest occupational toxins and evidence of lead poisoning can be found dating back to roman times (Gidlow, 2004).

1.2 Lead in human body

Lead is non-essential to human and has no useful biological function (Swartz, 2001). Human exposure to lead occurs in two settings:

1. General environmental exposure
2. Occupational setting (Workplace exposure)

The use of lead in pipes, paints and gasoline additives have resulted in substantial introductions of lead into the environment and human exposure, and are being phased out in many countries. In the past, lead was used extensively as an additive to automotive fuel but now this use represent less than one percent of the total world consumption (Gottesfeld, 2003).

Many countries worldwide have eliminated the usage of leaded gasoline. Occupational exposure to lead which results in poisoning, both moderate and clinically symptomatic, still occurs in many countries of the world (WHO, 1995). In China, a nationwide survey from 1979 to 1981 showed that the prevalence of lead poisoning was 1.77 percent in 355,000 lead workers examined (Russell *et al.*, 1990). Research has also shown that 95% of all adult lead intoxication is occupational in origin (Swartz, 2001).

Occupations with high potential exposure include mining, primary and secondary smelting, production of lead-acid batteries, pigment production, construction and

demolition. In developing countries, exposure attributed to this type of environment is more significant than the universal (general environment) exposure (Tong *et al.*, 2000). Lead acid battery industry being the most predominant use of lead, consumes 76% of global annual primary and secondary lead (Gottesfeld, 2003).

The route of exposure also differs between these two groups of people. In the general public, exposure to lead occurs primarily through the oral route, with some contribution from inhalation. In contrast, inhalation of inorganic lead in the form of fumes, mists, dusts and vapours is the major route of exposure in the occupational settings (Bull, 2006).

Although personal hygiene is the most important determinant of an individual blood lead level, it has also been shown that genetic polymorphism may also has an impact. It was shown that studied subjects with vitamin D receptor allele had significantly higher levels of lead in the blood and bone than those with vitamin D receptor bb allele (Gidlow, 2004).

1.3 Kinetic and metabolism of lead

Inhaled lead particles will be deposited in the respiratory tract and the absorption and clearance from the respiratory tract into the circulation. The rate of absorption of these particles depends on their aerodynamic diameter. Large particles are deposited in the upper respiratory tract and absorption occurs via the ingestion route. Fifty to seventy percent of inhaled particles smaller than 1 μm are absorbed into the circulation. Smaller particles, such as those generated in exhaust fumes are almost completely absorbed (>90%) (Bull, 2006).

Absorption of lead from the gastrointestinal tract (mainly in the non-occupational settings) comes from intake of lead from food, drink and soil/dust. In adults, approximately 5 – 15% of ingested lead is absorbed in the gut. Dermal absorption of inorganic lead compounds is generally quite low (Bull, 2006).

Absorbed lead is transported primarily in the red blood cells bound to plasma protein. It is then distributed to the mineralizing systems (bone and teeth) and soft tissue (liver). Ninety percent of body burden of lead is in the bone (Swartz, 2001).

The half life of lead in blood, soft tissue and bone is approximately 36 days, 40 days and 27 years respectively. Lead is readily transferred via the placenta from the mother to the developing fetus during pregnancy with cord blood concentration of 80 – 90% of maternal blood, hence posing a risk for the fetus. Therefore, a more stringent monitoring and blood lead standard for occupationally exposed women in reproductive age is imposed. Inorganic lead is not metabolized, although conjugation with glutathione may occur. Approximately 90% of ingested inorganic lead is eliminated unabsorbed through the faeces. Absorbed lead is primarily excreted in the urine (75%) and faeces (25%), independent of route of exposure. In the case of chronic exposure, as exposure continues, the amount stored will also increase if the body absorbs more leas than it can excrete (Herman D. S. *et al.*, 2006).

Rabinnowitz *et al.* (1976) did a kinetic analysis of lead metabolism in healthy human and came with similar result as Herman *et al.* (2006). They came up with simplified diagrammatic representation of lead metabolism model (Figure 1).

The lead which is stored in the tissue slowly starts affecting the tissue causing irreversible damage. A measure of the amount of lead at the site of toxic action would be

an ideal approach. However, this is impractical in many situations. Hence, the measurement of dose and the environmental concentration could reflex the concentration of lead in the tissues. In addition, biological effect monitoring can be performed with the assumption that biochemical alteration precedes structural damage (Walker, 2000). Biological monitoring of lead can be done through measurement of blood lead level or bone lead. X-ray fluorescence (XRF) system has been developed for easier attainment of lead levels in the bone (Dorsey *et al.*, 2006).

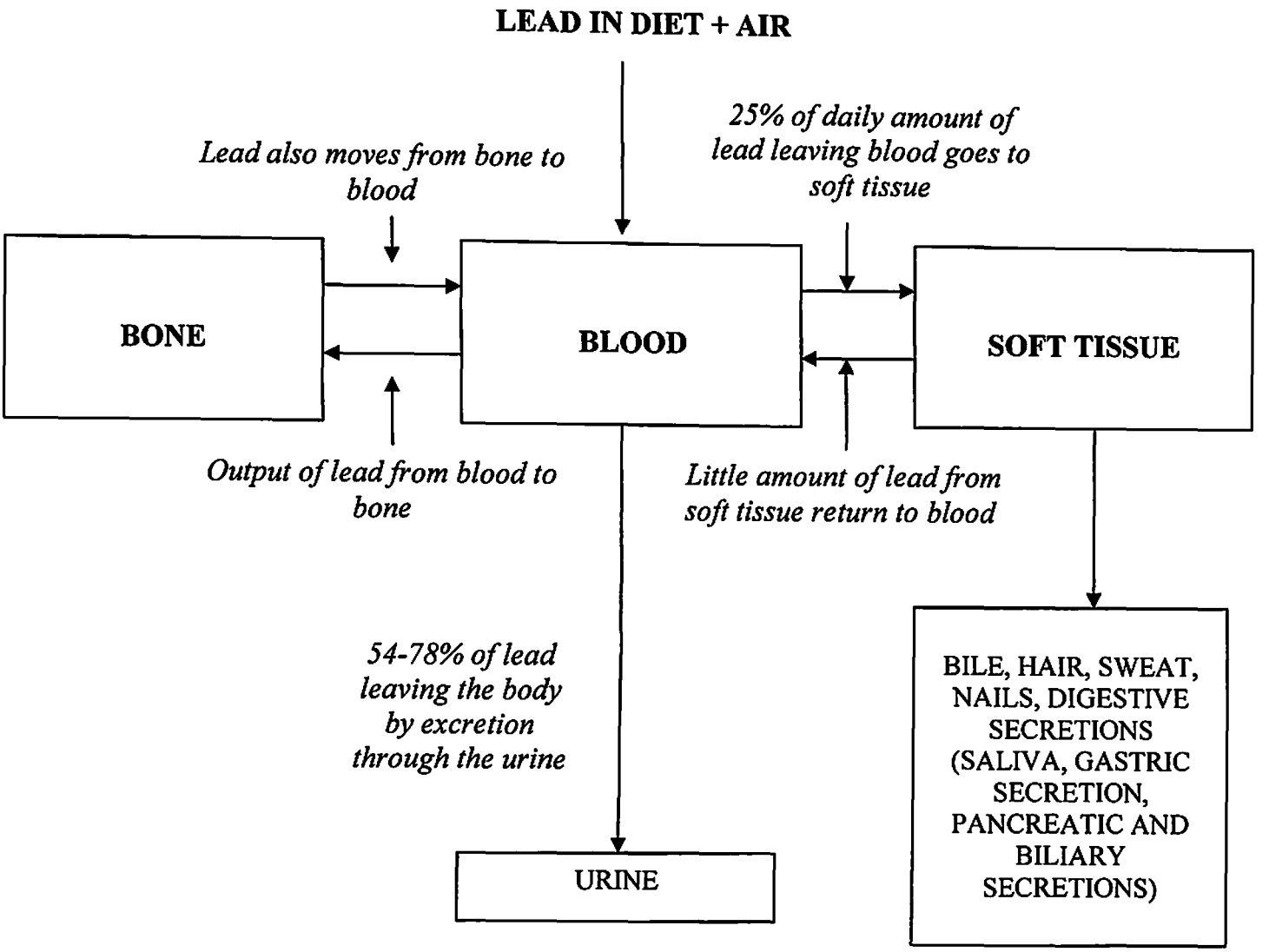


Figure 1 Lead metabolism model (Rabinowitz *et al.*, 1976)

1.4 Health Effects

Lead poisoning is among the most common environmentally induced disorder seen by primary care physicians serving urban populations (Walker, 2000) and it continues to be a significant public health problem in developing countries (Tong *et al.*, 2000). Results of epidemiological and toxicologic studies have associated lead exposure with a number of disorders and disease processes, including learning and behaviour

disorders, cardiovascular and kidney diseases, decreased fertility, and cancer. On an individual level, the effect of lead on these disorders and disease processes may be subtle (Lustberg and Silbergeld, 2002). In addition, there is no exposure level below which lead appears to be safe (United Nations, 1998).

1.4.1 Acute Health Effects

Lead is classically a chronic or cumulative toxin. However, health effects of lead exposure can also be seen in acute or single exposure (Table 1). Following an acute exposure, lead-induced encephalopathy may take up to several weeks to occur. The symptoms include irritability, poor attention span, memory loss, headache, muscular tremor, ataxia, convulsions, hallucinations, drowsiness, malaise, coma, seizures and death (WHO, 2000).

Table 1 Health effects of acute/single exposure to lead on adults (Bull, 2006).

System	Toxic effects	Blood lead concentration (µg/dL)
Nervous system	Encephalopathy in children	>300
Renal system	Acute nephropathy (largely reversible) – aminoaciduria, hypophosphataemia and glycosuria	40
Cardiovascular	Hypertension	48 – 120
Gastrointestinal	Abdominal cramps, diarrhea with black stools, vomiting and anorexia.	40-60
Hepatic	The effects of lead on haem synthesis may alter function capacity of hepatic cytochrome P450 enzymes	No available data

1.4.2 Chronic Health Effects

In the case of chronic exposure, as exposure continues the amount stored will also increase if the body absorbs more lead than it can excrete. Lead will slowly start affecting the tissue causing irreversible damage, first to the individual cells, then to the organs and, finally to the whole body (Herman *et al.*, 2006). Table 2 summarises the health effects of chronic or repeated exposure to lead in adults.

Table 2 Health effects of chronic or repeated exposure to lead in adults (Bull, 2006)

System	Health effects	Blood lead concentration, (µg/dL)
Haematology	Anaemia	50
	Clinically observable anaemia	80 – 100
Nervous system	Fatigue, sleep disturbance, headache, irritability, lethargy, slurred speech and convulsion, muscle weakness, ataxia, tremors and paralysis	40 – 120
	Neurobehavioural effects (reaction time, visual motor performances, hand dexterity, IQ and cognitive performance, anxiety and mood	40 – 80
Renal	Chronic nephropathy with reduction in glomerular filtration rate, sparse nuclear inclusion bodies and irreversible atrophy of the proximal and distal tubules. Albuminuria, aminoaciduria, glycosuria, phosphaturia and renal tubular acidosis.	50 – 200
Cardiovascular	Elevated systolic blood pressure	>30
Gastrointestinal	Nausea, vomiting, anorexia, constipation and abdominal cramps	40 – 60, 100 – 400
Hepatic	The effects of lead on haem synthesis may alter function capacity of hepatic cytochrome P450 enzymes	No available data
Reproductive	Male	
	- reduced libido, low semen volume and sperm counts, increased abnormal sperm morphology and decreased sperm motility.	40 – 50
	Female	
	- spontaneous abortion, late fetal death and stillbirth	>20
	- decreased length of gestation	12 – 23

In addition, lead is also a confirmed animal carcinogen. Several studies have indicated that lead compound ingested or administered to laboratory animals at the maximum tolerable dose have caused cancer (Swartz, 2001).

1.5 Mechanisms of Lead Neurotoxicity

The confluent of evidence from toxicology and clinical neurology has shown that neurobehavioural toxicity is a significant outcome of exposure to chemicals. The possible reactions of the nervous system to lead insult vary. However, the changes are often subtle and subclinical. The lapse between exposure and the appearance of dysfunction or disease can range from years to months (Walker, 2000).

The nervous system is a primary target in adults since lead directly affects the blood brain barrier and brain tissue (Swartz, 2001). One hypothesis is that lead is toxic by disrupting calcium-dependent mechanisms. It does so by competing for the same binding sites on proteins that involves in the process of dendritic branching. Dendritic branching enables neurons to make new connections, a process that is important in learning. A study on mice had shown that lead blocks this process thus disrupt the learning process. Lead also affects Protein Kinase C. Protein Kinase C functions to tranduce signals generated by a wide variety of effectors through specific receptors. This protein requires calcium for its activity. Processes important for synaptic transmission such as the biosynthesis of neurotransmitters, ligand-receptor interactions, conductance of ion channels and dendritic branching are regulated, in part, by protein kinase C. Therefore any disruption in protein kinase C will affect these processes (Walker, 2000).

Occupational lead exposure affects neuropsychological performance primarily in the areas of verbal memory and visual-motor skills (Lindgren *et al.*, 2003) and studies have suggested that lead influences neurobehavioural test scores as a function of both recent and cumulative dose (Dorsey *et al.*, 2006).

1.6 Blood Lead in Occupationally Exposed Workers

Exposure to lead at workplace depends on the nature of work and protective measures practiced. Table 3 summarizes the findings of blood lead level in other studies that measured blood lead level in workers occupationally exposed to lead. Different occupations have different level of exposure to lead but from this table, it shows that battery workers' blood lead levels are on the higher side as compared to other occupations.

Table 3: Blood lead level of different occupations/industry

Study	**Subjects Occupation/ Industry**	**Mean Blood Lead level (SD), µg/dL**
J.S. Lai *et al.*, 1996	Lead battery workers (Plant A)	65.8 (28.5)
	Lead battery workers (Plant B)	50.7 (20.9)
Kovala *et al.*, 1997	Lead battery workers	1.3µmol/l (0.4)
SF Ho *et al.*, 1998	Lead-acid storage battery workers	32.51 (8.01)
	PVC Compounding industries	23.91 (13.06)
TN Wu *et al.*, 1998	Battery recycling and production(1994)[1]	31.8 (18.9)
	Battery recycling and production (1995)[1]	31.1 (22.6)

Table 3 continue

Study	Subjects Occupation/ Industry	Mean Blood Lead level (SD), µg/dL
Schwartz *et al.*, 2001	Air condition assembly plant	5.3 (1.8)
Norlen, 2003	Male policemen	2.5 (1.0)
Nazhari, 2004	Car spray painters	10.19 (5.64)
	Car mechanics	7.39 (4.44)
Mazrura and Hassim, 2005	Battery Manufacturing Workers	40.5 (16.8)
Ravichandran *et al.*, 2005	Lead Acid Battery Industry Unit	
	Administration	17.77 (4.2)
	Grid casting	28.17 (8.09)
	Grid pasting	29.8 (9.14)
	Assembly	32.9 (11.5)
	Quality control	22.0 (9.30)
Ruzita H, 2005	Female electronic factory operators	6.12 (4.61)

[1]Year of blood investigation recorded

1.7 Battery Manufacturing

The battery industry is by far the principle consumer of lead, using an estimated 76% of annual primary and secondary lead (mined and recycled metallic lead) production (United States Geological Survey, 2001). Lead acid batteries are primarily used in automobile for starting, lighting and ignition purposes, but also used as back-up power supplies. Battery composition by weight is as follows: 50% lead salts and oxide, 24%

acid, 17% metallic lead, 5% plastics and 4% ebonite and separators (Gottesfeld, 2003). A steady growth in the world car market is expected to underpin the growth the growth in demand for lead-acid batteries. The battery manufacturing involves the following process (Kelley, 2006).

(Figure 2)

1. Oxide manufacture
2. Grid production
3. Pasting
4. Formation, plate cutting and assembly

1.7.1 Oxide Manufacture

This is the process of oxidizing pigs of lead (masses of lead from smelting furnaces) to form lead oxide (PbO). There are two available methods of lead oxidation process. They are Barton Pot process or milling process. In the Barton Pot process, air is blown over molten lead to produce a fine stream of lad droplets. The droplets react with oxygen in the air to form the oxide, which consists of a core of lead with a lead oxide coating.

In the milling process, solid lead is fed into a rotating mill. The tumbling action of the lead generates heat and the surface of the lead oxidizes. As the particles roll around in the drum, the surface layers of oxide are removed to expose more clean lead for oxidation. The air stream carries the powder to a bag filter, where it is collected.

1.7.2 Grid Production

The grids are produced mainly by casting or expansion from wrought or cast lead alloy.

1.7.3 Pasting

Battery paste is made by mixing the oxide with water, sulphuric acid and a range of proprietary additives. The paste is pressed by machine or hand into the grid lattice, and the plates are flashed-dried in a high-temperature oven. Pasted plates are cured by storing them in ovens under carefully controlled conditions of temperature, humidity and time. Free lead in the paste converts to lead oxide.

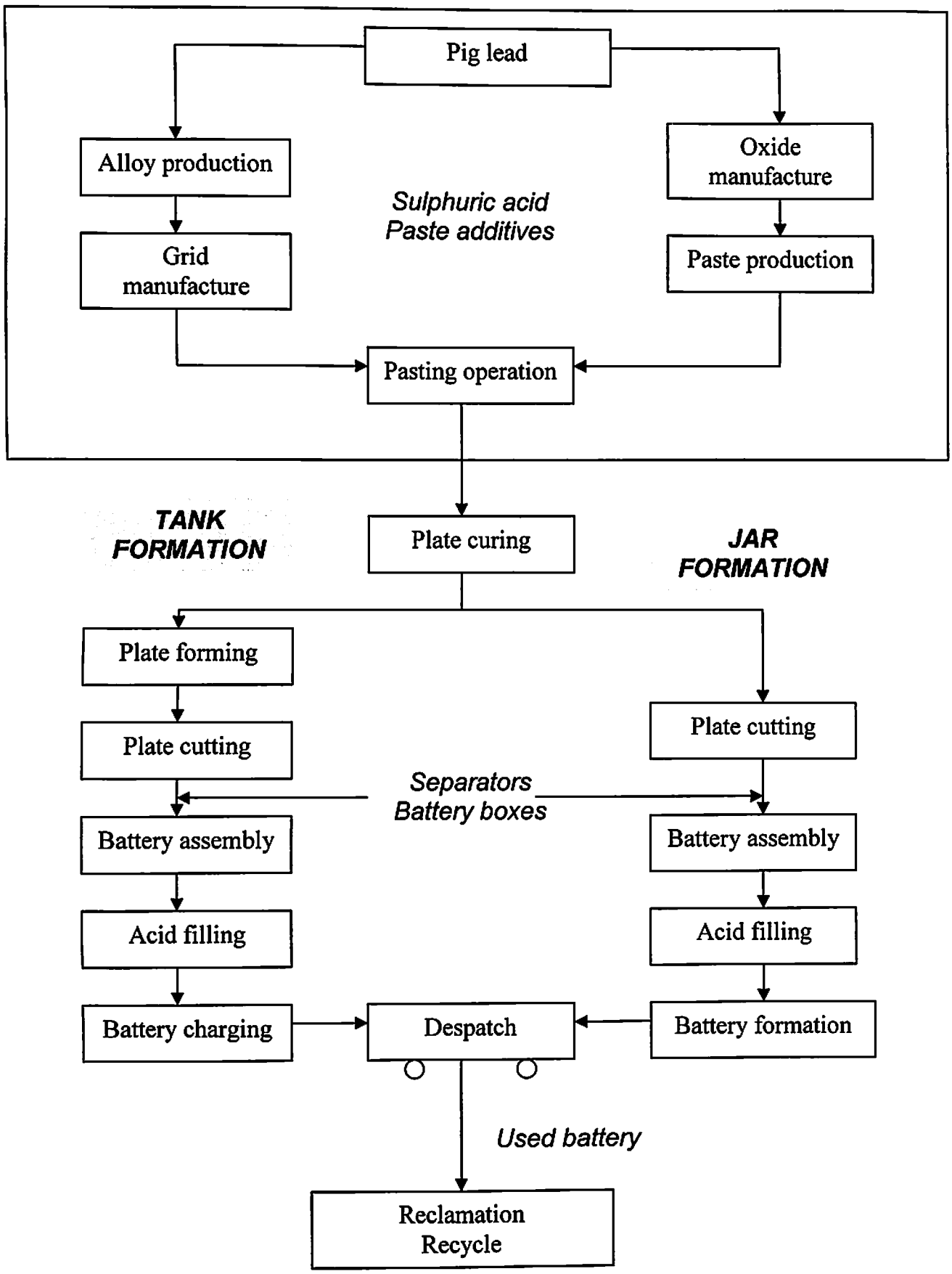
1.7.4 Formation, plate cutting and assembly

Electrical formation process can be done in two ways. In *tank formation,* plates are loaded into large baths of dilute sulphuric acid and a direct current is passed to form the positive and negative plates. After drying, the plates are cut and assembled, with separators between them, into battery boxes. Plates of like polarity are connected by welding together the plate lugs. In *jar formation*, the plates are electrically formed after being assembled into battery boxes. The batteries are then distributed and ready to be used. The used batteries are then collected and undergo reclamation process for recycling of lead.

1.7.5 Reclamation

In this process, lead and plastic contents are reclaimed. The metallic lead plates coated with lead oxide and lead sulfate are removed from the plastic cases. The decasing requires manual labour and mechanical activities to cut open the batteries and remove their contents (Center for Disease Control and Prevention Morbidity and Mortality Weekly Report, 1992). The raw material (rails, iron scrap, limestone, cokes) will then undergo *Cupola* process where they will become molten. From here lead molten will be separated from waste material (slag, solid waste, dust, gas and fumes) and will be formed into a bullion which consists of 98% lead (Anonymous, 2006).

Figure 2 Flow Chart of Battery Manufacturing Process (Kelley, 2006)



1.8 Occupational Lead Poisoning Among Battery Workers

Recalling the process of battery manufacturing, the workers are exposed to lead dust and fumes at every step of this work process. The potential for hazardous exposure to lead during lead smelting and refining are well recognized, particularly when molten lead and alloys are poured, resulting in the vapourisation of metal (WHO, 1995). A survey of literature has identified almost 30 studies from 1986 to 2002 of lead poisoning in workers manufacturing as well as in workers, and their dependents, employed in battery salvaging in China, Columbia, the Dominican Republic, Germany, India, Iraq, Israel, Jamaica, Nicaragua, Russia, Taiwan and the United States (Penrose, 2003).

United States' Morbidity and Mortality Weekly Reports, May 1992 reported that battery workers in the United States remained amongst the most at risk of occupational lead poisoning. They also reported that 12 out of 15 battery reclamation workers in Alabama showed blood lead level of greater than 60μg/dL. Fourteen out of 15 workers showed zinc protoporphyrin (ZPP) of greater than 100μg/dL (reference range: 0 – 79). Seven of the total worker showed creatinine clearance rate greater than 90 mL/min.

Allen and Newton (2004), found that lead battery industry represented the greatest exposure risk to lead and accounted for 91% of all high blood lead results. They also found that a significant negative correlation between the haemoglobin and blood lead concentrations among the female workers and a strong significant positive correlation between the blood ZPP and lead concentrations.

Exposure to lead can have toxic effects on the nervous system. A neurophysiology study among 60 battery workers had shown that there was an abnormal

conduction variable (6 subjects), local slowing of the conduction velocity of the median nerve (2 subjects) and a decrease in vibratory sensibility (12 subjects). There were also negative correlations between indicators of exposure to lead (calcaneal lead, tibial lead and blood lead) and the conduction velocities and sensory amplitudes of the median, radial, peroneal, and sural nerve (Kovala *et al.*, 1997). Russell *et al.* (1990), reported that there was a significant reduction in test score for mood state, intelligence, memory, perception, vigilance and psychomotor when they compared between battery workers and food product manufactures in China.

Exposure is the key element in the chain of events that lead from the release of a neurotoxicant-which may occur at any point in the manufacturing including processing, storage transport, usage or disposal (Walker, 2000).

Despite the mentioned effects of lead exposure in the occupational settings, with the good control and health promotion programmes, the effects of lead exposure can be reduced. This was shown by Hsiao *et al.*(2002) in his study long term exposure over 10 years alongside the improvement of control and health promotion programmes in Taiwan over the same period, had shown positive correlation of blood lead level (BLL) and red blood cells (RBC) This occurred due to dynamic relationship between BLL and bone. As bone lead decreases over time, the production of RBC which takes place in the marrow, increases.

In summary, many studies worldwide had shown that lead has many adverse effects on the human. Occupational settings, especially the battery manufacturing industry, shown to have the highest exposure. However, with good control and health promotion programmes these effects can be avoided. In Malaysia, there is still very

limited data on the lead exposure among battery workers. By studying the level of exposure, safe work practice and the health effects of battery workers, we can determine the current status of lead exposure among battery workers in Malaysia. To study the whole spectrum of lead toxicity among battery workers in Malaysia is very costly. Therefore, in my study I will only focus on the neurobehavioural effects of lead among battery workers. Appropriate recommendations will be provided based on the finding of this study and I hope this study will add to the pool of data of lead toxicity in Malaysia and provide a useful reference to the relevant parties.

1.9 Rationale of study

1. To provide more scientific evidence on the neurobehavioural effects of inorganic lead exposure in battery workers in Malaysia.
2. To document environmental lead levels in battery manufacturing factories in relation to accepted standards according to Occupational Safety and Health Act (1994).

CHAPTER 2

OBJECTIVES

2.1 General Objectives

The general objective of my study is to assess the neurobehavioural performances of battery manufacturing plant workers.

2.2 Specific Objectives

The specific objectives of my study are as follows:

1. To measure the Time-Weighted Average (TWA) environmental lead level in a battery factory.
2. To compare the prevalence of symptoms suggestive of inorganic lead intoxication between exposed and non-exposed workers.
3. To assess the work practices among battery workers regarding protection against exposure to inorganic lead.
4. To compare the blood lead level between exposed and non-exposed workers.
5. To compare the neurobehavioural performance between exposed and non-exposed workers.
6. To determine the association between neurobehavioural performance and blood lead level in battery manufacturing plant workers.

2.3 Research Hypotheses:

1. There is a higher prevalence of symptoms of inorganic lead intoxication in exposed workers.
2. The work practices regarding protection against inorganic lead exposure in battery workers are good.
3. Exposed workers score lower on neurobehavioural performance compared to non-exposed workers.
4. The environmental lead level in the battery factory is above the recommended threshold limit value (TLV).
5. Exposed workers have higher blood lead levels compared to non-exposed workers.
6. There is a negative association between neurobehavioural performance and blood lead levels in exposed workers.

2.4 Conceptual Framework:

Battery manufacturing process involves 4 general processes. They are oxide and grid production, plate production and processing, battery assembly and after the batteries are distributed to the users, they will be either repair or reclaimed. All of the above processes contribute to lead being released into the factory environment which can be measured. Environmental lead can be absorbed into the body system through respiratory system and gastrointestinal system with the former being the main route. The dose of lead that enters the workers depends on the protective measures and their work practices. High level of blood lead will adversely affects many body systems namely the renal, hepatic, cardiovascular, haemopoeitic and the central nervous system. Effects of lead on the nervous system can be presented clinically or subclinically i.e. the neurobehavioural changes. Figure 3 shows the conceptual framework of exposure to lead and the neurobehavioural effects.

CONCEPTUAL FRAMEWORK OF EXPOSURE TO LEAD AND NEUROBEHAVIOURAL EFFECTS

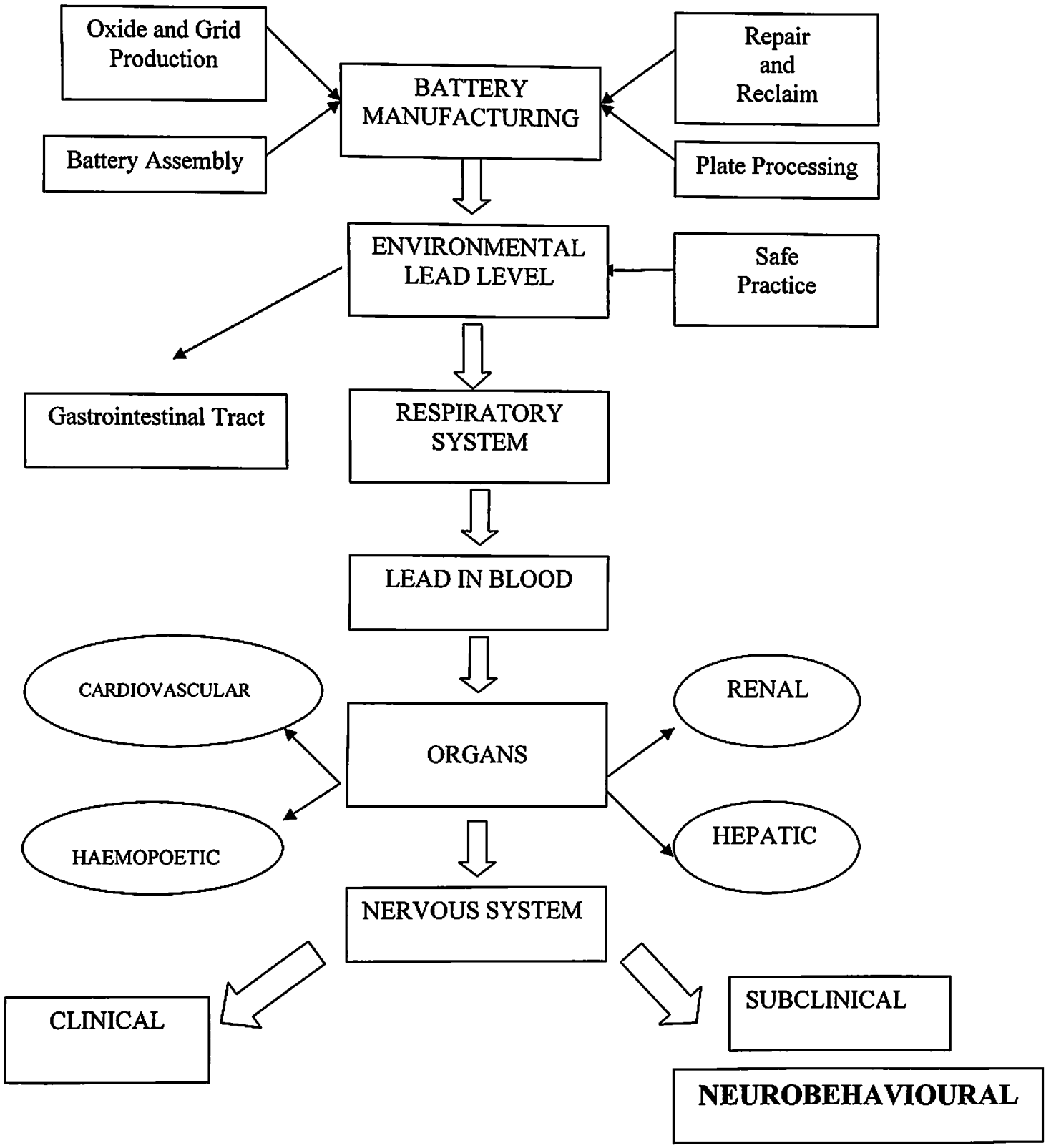


Figure 3 Conceptual framework showing the relationship of lead exposure in battery manufacturing and neurobehavioural effects