行政院國家科學委員會專題研究計畫成果報告

電池廠員工鉛暴露途徑 – 以 Structural Equation Model 評估
Pathways of Lead Exposure of A Lead Battery Plant Workers - Assessment With Structural Equation Model

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中文摘要

本研究應用 Structural Equation Model 評估不同鉛暴露因素對血中鉛濃度的影響。113位在某鉛蓄電池廠組立線上工作一年以上的員工中，有96位參與本研究計畫。環境鉛暴露指標包括空氣鉛濃度，員工袖子、手套、臉頰、徒手及嘴唇上的體表鉛塵。血液樣本則在該廠年度健康檢查時配合採集。另外以結構式問卷收集個人資料、工作史、個人衛生習慣，以及個人防護具使用情形。分析結果顯示血中鉛濃度與嘴唇上鉛塵、以手拭汗的頻率，以及不經意碰觸鉛塵的因素有相當密切的關係($p<0.001$)。同時，空氣中鉛塵透過嘴唇上鉛塵這項影響途徑對血中鉛濃度有間接的影響。本研究可做以下結論：由於影響血中鉛濃度的因素眾多，Structural Equation Model 因此是一項可取的方法來評估鉛蓄電池廠作業員工的鉛暴露途徑。另外，研究的結果也顯示，未來要進一步有效地降低員工血中鉛濃度，必須從廠房環境衛生管理及員工的個人衛生習慣等方面著手加強管理。

關鍵字：　血中鉛、空氣鉛、鉛蓄電池廠、Structural Equation Model**。**

Abstract

The present study was initiated to evaluate the overall effects of lead exposure factors on the blood lead level by applying the structural equation model. Total 96 out of 113 assembly workers from a lead battery plant were recruited. Lead samples in air, on sleeves, gloves, hands, cheeks, and lips, etc. were applied as external lead exposure. Venous blood samples were obtained for lead determination during workers' annual physical examination. Structured questionnaire was administered to collect demographic data, work history, personal hygiene behaviors, use of personal protective equipment, etc. Results of structural equation model demonstrates that blood lead level was found strongly associated with lips lead loadings, sweat-wearing frequency, and inadvertent contact, while airborne lead only has indirect effect on blood lead level through lips lead loadings. Since blood lead levels might be influenced by various cofounders, it is concluded that structural equation model is an appropriate alternative

to evaluate worker's lead exposure pathways. Also, as a result of the present study, it is recommended that further efforts on lowering lead battery workers' blood lead levels must pay more attention to the management of house-keeping and workers' personal hygiene.

Key Words: blood lead, air lead, lead battery plant, structural equation model.

Introduction

Lead is widely used in the industrial manufacture and has long been recognized as a human health hazard. Many previous studies have focused on the relationship between total air lead and blood lead levels. Some have found a rough agreement between total air lead and blood lead concentrations, [1-5] while some other studies did not show such a significant relationship. [6,7] However, less studies were conducted in order to characterize the risk factors regarding occupational lead exposure, probably due to the inadequacy of surface contamination measurement methods.[8] The present study was therefore initiated to evaluate the overall effects of lead exposure on the blood lead by applying the structural equations to model the comprehensive pathways among blood lead level and worker's body surface lead loadings, air lead exposure level, as well as other personal hygiene and personality factors.[9]

Material and Method

This study focused on the specific manufacture process of battery assembly, which can be classified into subareas, such as cast-on-strap, plate-abrading, plate-inserting, electrode-rod-welding, sulfuric acid filling (Figure 1). Only workers at assembly lines greater than one year were invited to participate in the present study. Due to quit, reassignment, or no willing to cooperate, total 96 out of 113 workers were recruited as study subjects, 18 males and 78 females.

The current study applied lead samples on sleeves, gloves, hands, cheeks, etc., collected with 3M magic tape, as external lead exposures. Another one type of body surface sample was collected on lips with facial absorbent paper. Besides, personal samples for respirable airborne lead were collected for all participating workers in a half-day work shift.[10] All air samples and body surface samples were first digested in microwave prior to being analyzed for lead on graphite furnace atomic absorption spectrometer (GFAAS, Perkin Elmer AAS 5100) with a detection limit of 1.0 ug/L.[11] Detailed techniques regarding sampling processes and laboratory analysis have been reported elsewhere.[12]

Venous blood samples were collected by registered nurses from all participating workers during the annual physical examination, and analyzed for lead by the same laboratory for lead determination of air and body surface samples.

Structured questionnaire was administered for demographic data, work history, personal information such as eating at work sites, smoking, alcohol use, medications, painting, etc. Besides, the use of personal protective equipment, and individual personality were also recorded in this questionnaire.

Structural equation model was employed to establish the relationships among the blood lead, airborne lead level, body surface lead loadings, individual behavior, activities, and personality.[9, 13]

Results

Results of demographic data showed that male workers averaged 35.7 years old, 5.3 years younger than the female workers. Nevertheless, male workers were generally more advanced-educated and had longer duration of employment than female workers. Assembly workers were mostly composed of female workers, i.e. 84.8%, who primarily worked in the sub-areas of cast-on-strap, resin filling, electrode-rod-welding, while most male workers acted as supervisors and were in charge of the task of trouble-shooting.

Results of personal biological and environmental measurements for lead are summarized in Table 1 by five sub-groups as shown in Figure 1. Geometric mean of blood lead level of all assembly workers was 27.6 ug/dl. Supervisors had the highest average blood lead level of 44.5 ug/dl, followed by those of the plate processing sub-group, 36.8 ug/dl, and the cast-on-strap sub-group, 29.6 ug/dl. Regarding the respirable air lead concentration, the highest levels were present at the sub-groups of cast-on-strap, plate processing, and supervisors, i.e., 0.032 mg/m^3, 0.029 mg/m^3, and 0.027 mg/m^3, respectively.

The geometric means of these six measures of body surface lead loading are also presented in Table 1. The heaviest lead loading was found in the sub-group of plate processing. For instance, the geometric means of lead loadings were 66.4 $u g/cm^2$ on glove, 4.94 $u g/cm^2$ on sleeve cover, 0.80 $u g/cm^2$ on cheek and, 3.33 $u g/cm^2$ and 0.79 $u g/cm^2$ on bare hands before and after hand washing, respectively. Relative high lead loadings on body surface were also observed for workers of the cast-on-strap sub-group, such as 62.4 $u g/cm^2$ on glove and 2.35 $u g/cm^2$ on sleeve cover. In general, supervisors had obviously elevated lead loadings on their body surface.

In the structural equation model, numerous potential risk variables were included. Table 2 shows correlation coefficients between the endogenous variables, and the corresponding candidate predictor variables of each endogenous variable in the model. Also a latent variable representing the unmeasured effect of inadvertent contact was included in this model. These predictor variables described the nature and extent of study subjects' hygiene behaviors, and other factors which might increase or decrease the impact of environmental lead on their blood lead levels. A total of 8 exogenous variables plus the 4 endogenous variables were used in the initial empirical model (Figure 2). A high Goodness of Fit Index (GFI) of 0.946 indicates that this initial model fit the multivariate distribution of the endogenous variables well.[14]

In order to find a more parsimonious

structural equation model, only significant pathways (with t values > 1.96) and some other specified pathways were retained in the model. Figure 3 presents the reduced model and delineates the relationships among these significant and dedicated pathways. Blood lead level was found strongly associated with lips lead loadings, sweat-wearing frequency, and inadvertent contact, while moderate associations were observed for blood lead level with personality of carefulness and whether washing work clothes at home. Strong associations were also found between lips lead loadings and air lead level, and between inadvertent contact and right hand finger lead loadings (after hand-wash), respectively. A Chi-square value of 11.9(d.f.=5) with a Goodness of Fit Index of 0.974 for the goodness of fit test indicates that this reduced parsimonious model adequately accounted for the prediction of blood lead level through these comprehensive multi-pathways. [14]

Discussion

The present study was a population-based exposure survey directly measuring environmental exposures and their impacts on the workers' blood lead levels. By focusing on the assembly lines workers, their lead exposure levels coming from the same working environment were relatively stable and fell within the permission exposure level of 50 $\mu g/m^3$. At such moderate lead exposure in this typical battery plant, results of the structural equation model demonstrated that lead dust depositing on the workers' bodies, and the workers' personality and hygiene behavior had more important effects on the blood lead level. Although the airborne lead did influence the blood lead level, it must be exerted through other body lead dust variable, i.e., lips lead loadings. This indicated that the traditional reliable on airborne threshold limit values as the criteria for evaluating the extent of occupational lead exposure is not always mandatory, especially at the moderate occupational lead exposure. Since blood lead levels might be influenced by various cofounders, it is concluded that structural equation model is an appropriate alternative to evaluate worker's lead exposure pathways. Also, as a result of the present study, it is recommended that further efforts on lowering lead battery workers' blood lead levels must pay more attention to the management of house-keeping and workers' personal hygiene.

Self-Evaluation

The present study shows that the well-known social science methodology, structural equation model, might be appropriately applied in the occupational exposure assessment to help to comprehensively identify the most urgent risk factors in working environment. Furthermore, the findings of the present study could be applied to substantiate the recommendations for industrial hygiene and effectively to reduce the blood lead levels of lead battery workers. Also, a draft of article resulting from the present study, entitled 'Lips lead as an alternative measure for lead exposure assessment of lead battery assembly workers', has been submitted to the American Industrial Hygiene Association Journal for the consideration of publication.

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Table 1. Lead levels in personal biological and environmental samples by sub-group[a]

Sub-Groups	Blood Lead, ug/dl	Respirable Air Lead,[b] Mg/m^3	Lead Loading, ug/cm^2					
			Glove	Sleeve Cover	Cheek	Lips	Hands, Before Washing	Hands, After Washing
Cast-on-strap	29.6(1.3)	0.032(1.9)	62.4(1.5)	2.35(2.1)	0.24(2.4)	0.0012(3.2)	0.85(2.1)	0.27(1.9)
Plate Processing	36.8(1.1)	0.029(2.4)	66.4(1.5)	4.94(2.3)	0.80(3.7)	0.0019(4.3)	3.33(2.6)	0.79(3.2)
Battery Cell Setting	22.6(1.8)	0.013(2.4)	9.9(2.8)	1.26(2.2)	0.15(3.1)	0.0012(4.0)	0.49(3.0)	0.18(2.5)
Finish Processing	22.4(1.3)	0.009(2.0)	7.8(2.1)	0.68(2.3)	0.08(4.8)	0.0015(4.4)	0.32(2.2)	0.10(2.5)
Supervisors	44.5(1.3)	0.027(1.9)	22.7(1.8)	1.02(2.0)	0.44(1.5)	0.0052(4.1)	2.79(2.5)	0.47(2.4)
Total	27.6(1.5)	0.019(2.5)	24.1(3.2)	1.52(2.6)	0.19(3.6)	0.0015(3.9)	0.74(3.0)	0.22(2.6)

[a] Present as geometric mean (GSD).

[b] Lead in airborne particulate with aerodynamic size less than 5 um.

Table 2. Correlation coefficients between endogenous variables and candidate predictor variables for the structural equation model

	Endogenous Variables			
	Blood Lead Level	Lips Lead Loadings	Cheek Lead Loadings	Right Hand Finger Lead Loadings, After Hand-Wash
Endogenous Variables				
Lips LeadLoadings	0.27 (0.007)			
Cheek Lead Loadings				
Right Hand Finger Lead Loadings (After Hand-Wash)				
Candidate Predictor (Exogenous) Variables in Model				
Gender	0.47 (<0.001)		-0.01 (0.953)	
Personality of Carefulness	0.25 (0.016)	0.10 (0.328)		
Hand-Wash Frequency	-0.16 (0.125)			
Wash Work Clothes at Home, Yes/No	0.29 (0.004)			
Sweat-Wiping with Hands/Arms, Fre-Quency	0.27 (0.008)			-0.01 (0.945)
Air Lead Level	0.20 (0.049)	0.28 (0.006))		
Mask-Wearing, Yes/No		0.02 (0.858)		
Mask-Change Frequency		-0.07 (0.501)		

Note: 1. Causal pathway variables selected based on study hypothesis.

2. N=96, p values in parentheses.

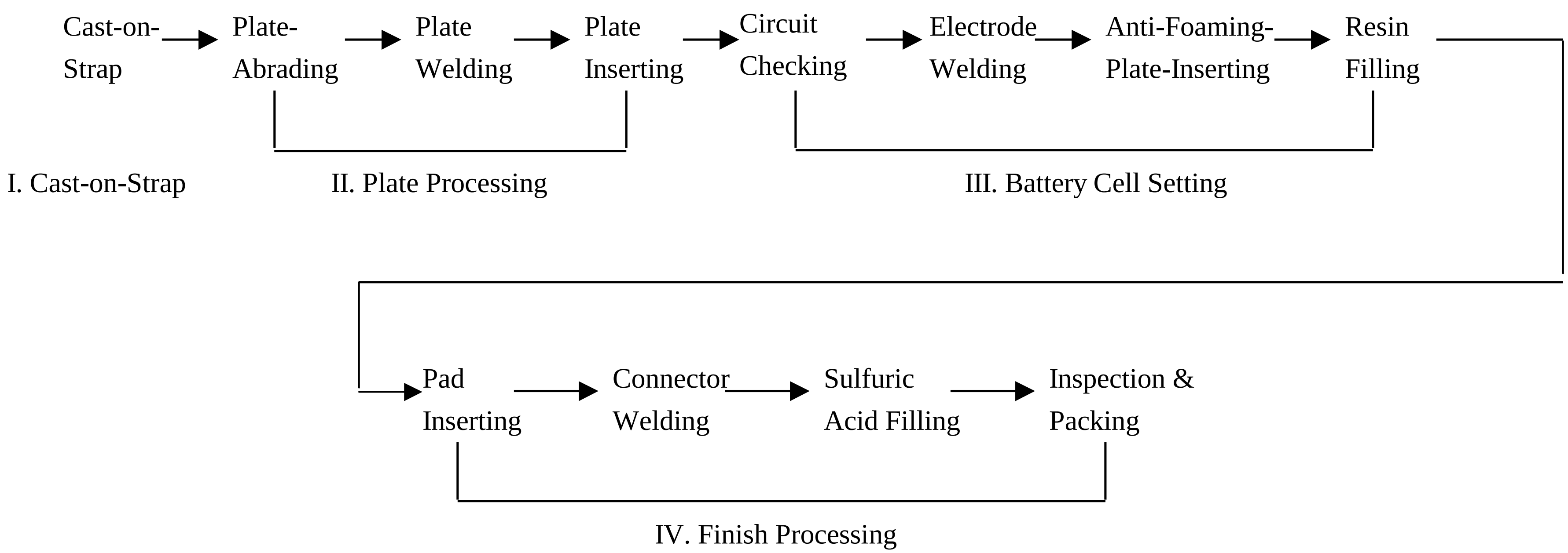
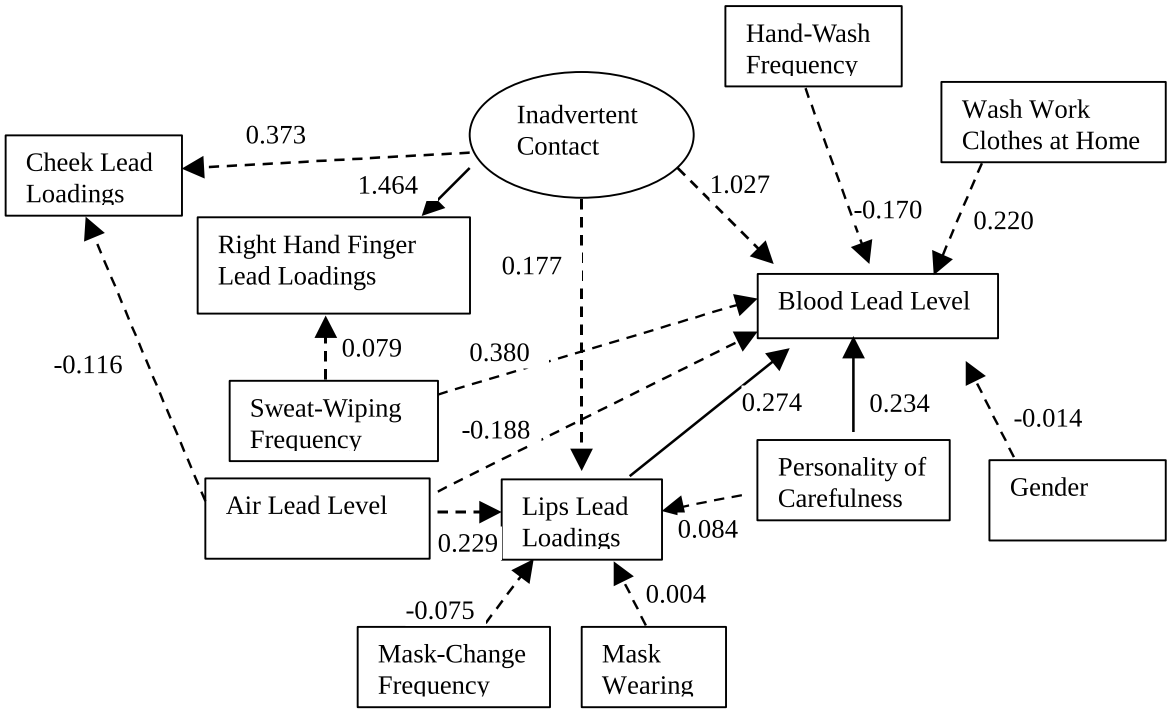
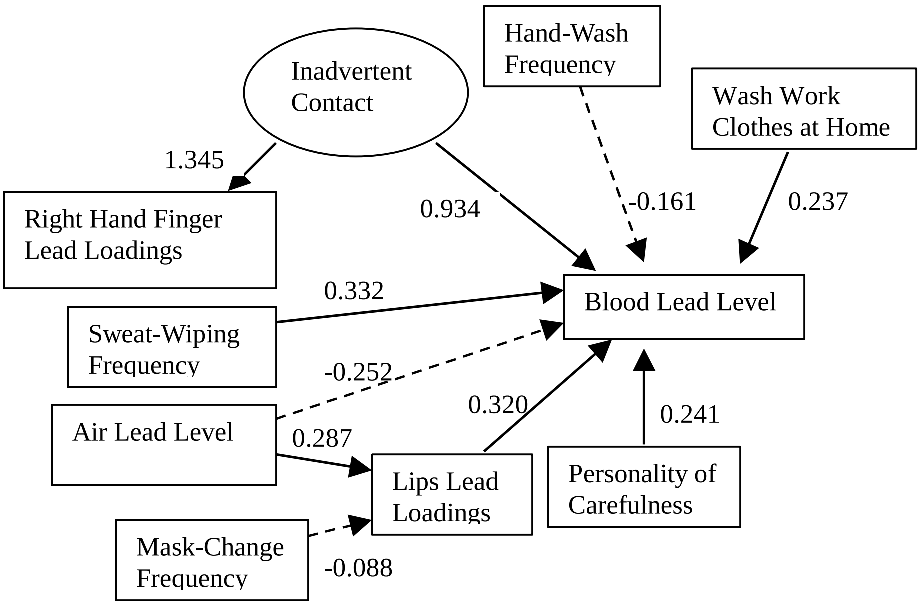


Figure 1. Flowchart of work activities at lead battery assembly line.



Note:
1. Goodness of Fit Test: Chi-square= 36.2(df=13), GFI=0.946.
2. Coefficient is shown for each pathway.
3. Solid line arrow indicates significant pathway (t>1.96, p<0.05).
4. Dotted line arrow indicates insignificant pathway.

Figure 2. Initial empirical model of lead battery workers' occupational lead exposure pathways.



Note:
1. Goodness of Fit Test: Chi-square= 11.9(d.f.=5), GFI=0.974.
2. Coefficient is shown for each pathway.
3. Solid line arrow indicates significant pathway ($t>1.96$, $p<0.05$).
4. Dotted line arrow indicates insignificant pathway.
5. Some interested pathways were retained in the model even though their coefficients were not statistically significant.

Figure 3. Reduced model of lead battery workers’ occupational lead exposure pathways.