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Relationship of Blood Lead Levels to Personal Hygiene Habits in Lead Battery Workers: Taiwan, 1991–1997

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Background: *The blood lead concentrations of workers in lead battery factories are more than 4 times higher than those of the general population in Taiwan. Therefore, efforts are needed to reduce lead exposure in this high-risk population. A health promotion program on personal habits that reduce lead exposure has been carried out in a lead battery factory since 1991. This study investigated the longitudinal relationship of workers' blood lead concentrations and personal hygiene habits from 1991 through 1997.*
Methods: *In each of the 7 years of the study, occupational physicians questioned workers regarding nine personal hygiene items, personal information, and medical history before their annual health examination. The relationship between blood lead concentrations and personal hygiene habits was analyzed by longitudinal multiple regression in a mixed effect model with adjustment for potential confounders. In addition, the risk ratio of a blood lead concentration exceeding 40 µg/dL in men and 30 µg/dL in women (the action levels set by the Department of Health, Taiwan) was estimated by generalized estimating equations.*
Results: *Blood lead levels decreased significantly in the first 5 years of the study. The personal habits most closely related to blood lead concentrations were smoking at work sites (estimated coefficient = 3.13, $P < 0.001$), and eating at work sites (estimated coefficient = 1.38, $P = 0.069$). The risk ratio for workers with both these habits exceeding the action level of blood lead was 2.93 (95% CI 1.27–6.77). Difference in job titles, however, accounted for a major portion of the variance in blood lead. For example, working in "pasting" and "plate-cutting" was associated with blood lead elevations >20 µg/dL in comparison to the "low- or no-exposure jobs."*
Conclusions: *Health promotion programs can decrease exposure of lead workers; reducing the practices of smoking and eating at work sites should be the core of such programs. However, a major reduction in lead exposure for some jobs (e.g., "pasting" and "plate-cutting") in lead battery factories in Taiwan is unlikely to occur without major engineering changes.* Am. J. Ind. Med. 35:595–603, 1999.

***KEY WORDS:* blood lead; lead battery; health promotion; personal hygiene**

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INTRODUCTION

Workers in lead battery factories constitute one of the highest lead-exposed populations in Taiwan. A 1991 survey of the entire island revealed that more than 2,000 workers were employed in lead battery factories. The average blood lead concentration among 1,726 workers with available data was 37.1 μg/dL (SD = 16.7) and 37.5% of the workers had blood lead concentrations over 40 μg/dL [Chao et al., 1995]. In contrast, the mean concentration of blood lead in the general population was 7.7 μg/dL (SD = 5.23) in a 3-year survey of Taiwanese adults [Liou et al., 1996]. Thus, the average blood lead concentration of lead battery factory workers is over 4 times higher than that of the general population, and lead exposure needs to be reduced in this high-risk group.

It is well known that poor personal hygiene at work sites increases the level of lead exposure and absorption into the human body [Askin and Volkmann, 1997]. In particular, hand-to-mouth movements and hand-washing practices significantly influence blood lead concentrations [Far et al., 1993]. Several studies have demonstrated the effectiveness of employee education in reducing lead exposure-related behaviors [Maples et al., 1982; Lewis, 1983; Porru et al., 1993]. However, most of the previous studies were cross-sectional in design and of relatively small sample sizes [Far et al., 1993; Askin and Volkmann, 1997]. Porru et al. reported that a health education program led to decreased blood lead levels among lead workers in a prospective study and Maples et al. reported that an employee training and motivation program with bimonthly follow-up measurements of blood and urine lead levels for 1 year led to a decline in workers' blood and urine lead levels. However, there were no direct measurements of personal hygiene changes over time in these studies. Thus, there are few longitudinal studies of changes of blood lead levels which are related to personal hygiene habit changes fostered by health education or promotion programs.

For workers in lead battery factories, health promotion efforts should focus on changing relevant personal hygiene habits, including reducing hand-to-mouth movements; decreasing the frequency of smoking and eating at work; and washing hands, face, and hair before eating. The aim of this study was to investigate the changes in workers' blood lead concentrations in relation to these personal hygiene habits using a prospective longitudinal design.

MATERIALS AND METHODS

Subjects

One of the largest lead battery factories in Taiwan and the closest to Taipei was chosen as the site for a health promotion program. The program was initiated in 1991 and has been conducted continuously up through the present time. Workers who were exposed to lead were included in the program. The program includes education of all workers on lead poisoning and toxicology, protection measures, and personal hygiene practices by using handouts and multimedia education utilizing video cassettes. Health education was performed when workers entered the plant and changed job area or work shift. Generally, each worker attended the program at least once in the 7-year study. When male workers' blood lead levels were over 40 μg/dL or female workers' levels were over 30 μg/dL in the annual health examination, they had small group meetings with occupational physicians to arrange a follow-up health examination and reform their personal hygiene practices. During the period of study, some workers left and some new workers were hired. The workers in this company thus formed an open occupational cohort.

Data Collection

A physical examination and blood tests were performed on each worker during each annual health examination. From 1991 through 1997, a questionnaire on demographic characteristics, medical history, and personal hygiene was administered before the examination. Workers were asked to provide information on personal smoking status and nine personal habits for the preceding 3 months: 1) smoking at work sites, 2) eating at work sites, 3) washing hands before lunch, 4) using soap during washing hands, 5) gargling before lunch, 6) washing face before lunch, 7) taking a shower before going home, 8) washing hair before going home, and 9) changing clothes before going home. Items 1 and 2 addressed the risk of hand-to-mouth movements at work. Item 2, eating at work, only asked workers whether they ate snacks or chewed gum or betel nuts at work. Items 3 through 6 addressed aspects of hygiene practices before lunch in the context of advice given to workers through the health promotion program. Lunch was provided by the company, and the dining hall was located outside the plant. Items 7 through 9 addressed personal hygiene practices before going home, which were also recommended by the health promotion program to protect workers' families. Work clothes which were changed before going home were cleaned in the plant. For each item, workers were asked to respond according to frequency: never, less than or equal to 3 days per week, and more than 3 days per week. The questionnaire was reviewed and checked for completeness by an occupational physician when the annual health exam was performed.

Blood Lead Test

At every annual health exam, we collected venous blood samples by standard procedures. Each worker first washed his/her forearms with soap and fresh water. The antecubital area was then cleaned with 70% ethanol and cotton balls (no wipe package was used to avoid lead-containing foil) and a 5-ml whole blood sample was collected (by venipuncture) in a lead-free vacuum tube (Monoject, Sherwood Medical) containing ethylenediamine tetracetic acid (EDTA) as the anticoagulant. After pretreatment with a 1:4 solution of 0.1% Triton X 100 (Merck, scintillation grade) and 1.25% ammonium dihydrogen phosphate (Merck, puratronic grade) in a class 100 hood to which air was supplied and cleaned by a high-efficiency particulate filter, the blood samples were analyzed by Zeeman effect graphite furnace atomic absorption spectrometry (GF-AAS, Perkin-Elmer 5100 PC with AS 60 autosampler) with intralaboratory quality controls. Using standard commercial materials (Betherning Institute, Bio-Rad), all coefficients of variation (CVs) were less than 3% for measurements at high levels (70.5–82.7 μg/dL) and medium levels (37.1–45.3 μg/dL), and were less than 5% for those at low levels (5.6–8.9 μg/dL) during these 7 years. Since 1985, the laboratory at the Institute of Occupational Medicine and Industrial Hygiene, National Taiwan University, has been participating in the interlaboratory blood-lead proficiency testing program of the Centers for Disease Control and Prevention; the results of our measurements are all within the reference ranges, indicating that our blood lead measurements are relatively accurate.

Other Laboratory Tests

Levels of serum alanine transaminase (ALT), serum creatinine, fasting blood glucose, urine protein and sugar, and complete blood counts were measured at each periodic health examination. All specimens for a given worker were taken on the same day and were immediately transported to the central laboratory of Provincial Tao-Yuan General Hospital for analysis. Workers with abnormal laboratory data, i.e., a hemoglobin level of less than 12 mg/dL for women or 14 mg/dL for men, a serum creatinine level of greater than 2.0 mg/dL, a strongly positive urine protein (+++), an ALT level of higher than 35 IU/L, a positive urine sugar or fasting glucose level of higher than 140 mg/dL, were followed up in the outpatient department of Provincial Tao-Yuan General Hospital. Workers diagnosed with abnormal renal or hepatic function or with diabetes were excluded from data analysis.

Job Titles

Because no data on personal air-lead concentrations were available, job titles served as surrogates for lead exposure in different work zones. Workers with different jobs are located in different areas and buildings. During the 7-year study period, there were no major changes in work devices or designs or in engineering controls in the factory. On the basis of work time and work zone, six specific job titles—lead oxide powder making, pasting, grid casting, plate formation, plate cutting and assembly—involving direct exposure to lead-contaminated environments during the entire work day were identified and termed ''full-exposure jobs.'' Four other job titles—engineering, machine maintenance, quality control and testing, and packing—involving exposure to contaminated environments for part of the time and work in an office or laboratory (where lead exposure is lower) part of the time were identified and termed ''partial-exposure jobs.'' Administrators, managers, and office workers made up the group with the lowest level of lead exposure or no exposure; these were named ''low- or no-exposure jobs.''

Data Analysis

Blood lead concentrations in each year of the study were normally distributed. Personal hygiene habits, gender, job title, and education level were treated as categorical variables. Responses to the questions regarding personal hygiene habits were based on three categories of frequency: never, less than or equal to 3 days per week, and more than 3 days per week.

We first examined the calendar years 1991 through 1997 for secular trends in mean concentrations of blood lead. For each year, we also compared the mean concentrations of blood lead for subgroups of workers who left the factory after annual health examination to those who stayed at the factory. We plotted and examined trends in personal hygiene habits and mean blood lead in job classifications over the 7 years of observation.

Since blood lead concentrations are continuous variables, generalized linear mixed models were used to analyze the longitudinal relation of repeated blood lead concentrations to potential predictors (job classification, demographic characteristics, and personal hygiene habits). For each subject, *i*, the blood lead concentration in the annual health examination $Y_i = (Y_{1991}, Y_{1992}, Y_{1993}, Y_{1994}, Y_{1995}, Y_{1996}, Y_{1997})$, with the covariate matrix X_{ij} were modeled by the PROC MIXED procedure of the SAS computer package (SAS Inc., Cary, NC). This method fits a regression model between blood lead concentrations and covariates for each subject, taking into account the inherent variability of slope estimates from individual subjects [Cnaan et al., 1997; Wolfinger, 1997]. In studies of the relation of personal hygiene habits to blood lead concentrations, education levels and gender might conceivably confound and interact with the results. This possibility was assessed by testing the interaction terms against each other. We put these potential confounders into the generalized linear mixed model. Each personal hygiene item was entered into separate models with potential confounders, including gender, dummy variables for job titles, dummy variables for education levels, and percent of life span in the work in order to examine that item's individual effect. Each worker's percent of life span spent working in the battery plant was calculated by his/her working duration divided by age. Use of this variable allowed us to avoid the collinearity between age and working duration. Using the same statistical procedure, we then included the personal hygiene habits that were found to have potential associations ($P < 0.10$) in the individual models and the potential confounders in a multivariate model.

Finally, we related this analysis to practical decisions that must be made in administering lead exposure regulations by estimating the risk of exceeding the maximum allowable blood lead criteria of the Department of Health, Taiwan [Wu et al., 1995] (40 µg/dL for men and 30 µg/dL for women) as a result of poor personal hygiene habits and the other covariates. Blood lead concentrations were dichotomized to categories above or below the relevant criteria, a new binary variable. Because the data contain repeated observations, instead of logistic regression, we used the generalized estimating equation (GEE) approach to derive odds ratios of blood lead concentrations exceeding the criteria with respect to personal hygiene habits [Zeger and Liang, 1986; Diggle et al., 1994]. The computer package SAS 6.12 GENMODE procedure was used.

RESULTS

The workers' mean blood lead concentrations at each annual health examination are shown in Table I. The mean concentration decreased from 34.7 µg/dL in 1991 to 23.9 µg/dL in 1997, with a particularly steep decline in the first 5 years. In addition to listing figures on workers hired and those leaving their jobs, the rates of participation in annual health examinations varied from 72.7–99.2%. As is evident from Table II, the mean blood lead concentration of workers who left the factory in 1993 was significantly lower than that of workers who did not leave, but no significant differences between the two groups were noted in other years.

Figure 1 displays changes in blood lead concentrations over the 7-year study period. As expected, workers in the full-exposure jobs had the highest mean concentration throughout this period, partial-exposure jobs the next highest, and low- or no-exposure jobs the lowest. Of interest is that, in contrast to the full-exposure and partial-exposure job categories, the low- or no-exposure category exhibited no decline in blood lead concentration over the 7 years of observation. Figure 2 shows the proportion of workers who reported the most frequent of each personal hygiene habit in the 7 years. The proportions of workers who reported smoking and eating at work more than 3 days per week trends toward a decline, whereas the proportions of workers who reported "more than 3 days per week" on the items "taking a shower" and "washing hair before going home" increased in the first 5 years.

TABLE I. Rates of Participation in Annual Health Examinations With Mean (SD) Blood Lead Levels and Numbers of Workers Leaving and Hired Newly by the Lead Battery Factory After the Annual Health Examinations During the 7-Year Study in Taiwan

Year	Total number	Number participants (%)	Mean (SD) µg/dL	Number newly hired	Number leaving job
1991	346	284 (82.1%)	34.7 (15.0)	25	—
1992	371	274 (73.9%)	33.0 (14.5)	56	43
1993	384	279 (72.7%)	32.7 (12.1)	24	37
1994	371	282 (76.0%)	29.9 (14.7)	47	13
1995	405	316 (78.0%)	25.7 (12.5)	27	34
1996	398	369 (92.7%)	25.3 (12.9)	21	24
1997	395	392 (99.2%)	23.9 (12.4)	—	—

TABLE II. Mean (SD) Blood Lead Levels of Workers Who Left the Battery Factory Versus Workers Who Stayed During the 7-Year Study in Taiwan

Year	Number, leaving after health exam	Mean (SD) blood lead level in departure year	Mean (SD) blood lead level of remaining workers
1992	43	35.4 (17.9)	32.7 (13.7)
1993	37	26.2 (12.9)	33.9 (12.9)*
1994	13	24.2 (10.2)	30.0 (15.0)
1995	34	23.7 (14.7)	26.3 (12.3)
1996	24	23.1 (14.4)	25.5 (12.8)

*$P < .01$.

The results of longitudinal regression analysis for each personal hygiene habit are given in Table III. Each mixed-effect model contained one habit as well as the covariates, including calendar year, gender, job title, education level, and percent of life span in the work. Only the effect of smoking at work sites was statistically significant (test of fixed effect, $P < 0.05$). More frequent smoking at work was associated with higher blood lead concentrations. Smoking at work more than 3 days per week was estimated to raise the blood lead concentration 3.08 µg/dL, in comparison to persons who never smoked at work. Eating food at work was also positively associated with blood lead concentrations ($P = 0.082$). Mean blood lead concentrations were 1.32 µg/dL higher in individuals who ate at work more than 3 days per week than in those who never did. No other personal hygiene habits were associated with blood lead concentrations in this analysis ($P > 0.1$).

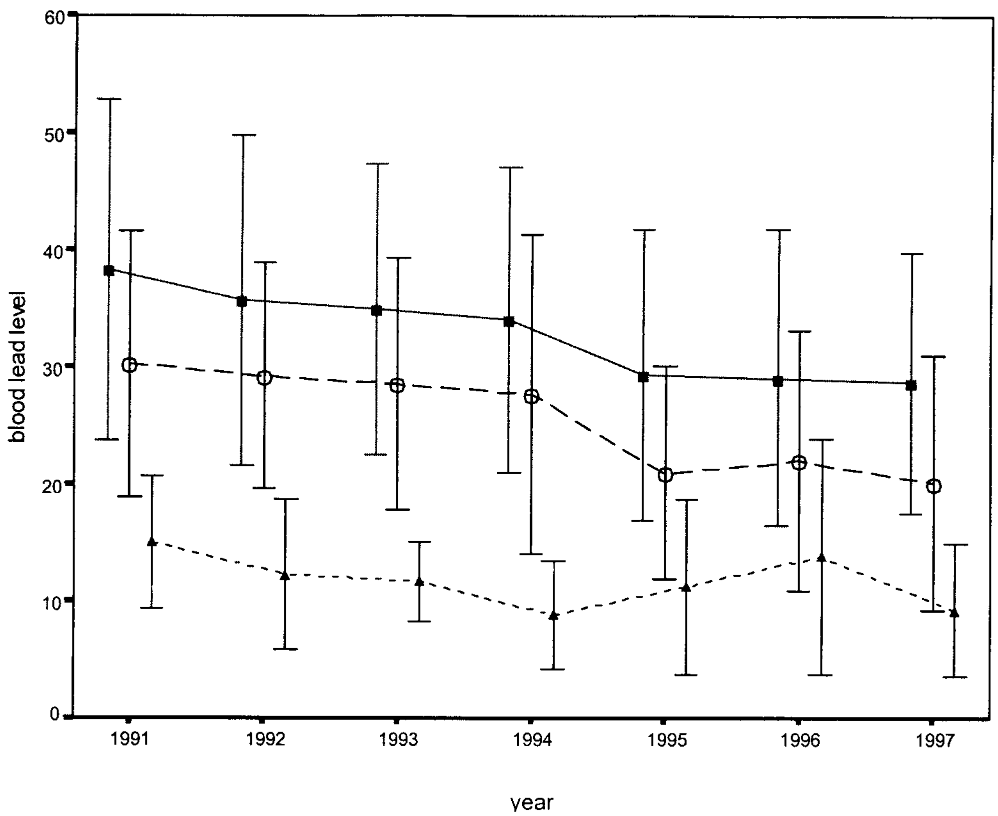

FIGURE 1. Mean and standard deviation bars of blood lead concentrations in different exposure groups of lead battery workers for 7 years in Taiwan. Squares = workers with full-exposure jobs, circles = partial-exposure jobs, triangles = low- or no-exposure jobs (see text).

When we inserted the two relevant personal hygiene habits—smoking and eating at work—in a multivariate model with other covariates, including calendar year, gender, job title, education level, and percent of life span in the work (Table IV), smoking at work remained significantly related to blood lead, with levels 3.13 μg/dL higher in workers who smoked at work more than 3 days per week than in those who never smoked at work. In this model, the blood lead concentrations of workers were significantly higher in the first 5 years than in 1997 (the reference year), but no linear decrease was evident. The job title associated with the highest blood lead levels was "pasting"; "plate cutting" work was the second riskiest job. Overall, male workers had 10.27 μg/dL higher mean blood lead concentrations than female workers with the same covariates. Education level was significantly and inversely related to blood lead concentrations. We found no significant interaction of education level with job title and education level and personal hygiene habit (data not shown). In addition, duration of working in the plant was related to blood lead levels. Mean blood lead increased by 0.06 μg/dL for each 1% increase of life span spent in the plant.

In our multivariate analysis with the GEE method (Table V) of the factors associated with a blood lead level exceeding the maximum allowable criteria (40 μg/dL for men and 30 μg/dL for women), smoking at work more than 3 days per week was associated with a significant elevation of 1.74 times risk with adjustment for calendar year, gender, job title, education level, and percent of life span in the plant. Eating at work also increased the odds of exceeding the criteria. Eating during work more than 3 days a week was associated with an odds ratio of 1.63 in comparison to those who never ate at work (with the same condition).

In a further analysis, these two personal hygiene habits were found to have synergistic effects. Workers who both smoked and ate at work more than 3 days per week were 2.93 times more likely to have blood levels exceeding the maximum allowable criteria than those who neither smoked nor ate at work sites. Workers who smoked at work more than 3 days per week and ate at work less than or equal to 3 days per week had the next highest risk, 2.09, of exceeding the criteria compared to the reference group. Workers who smoked more than 3 days per week but did not eat at work had a 1.76 times higher risk than the reference group, and those who did not smoke but did eat at work more than 3 days per week had a 1.54 times higher risk than the reference group. These results showed that the riskier personal hy-

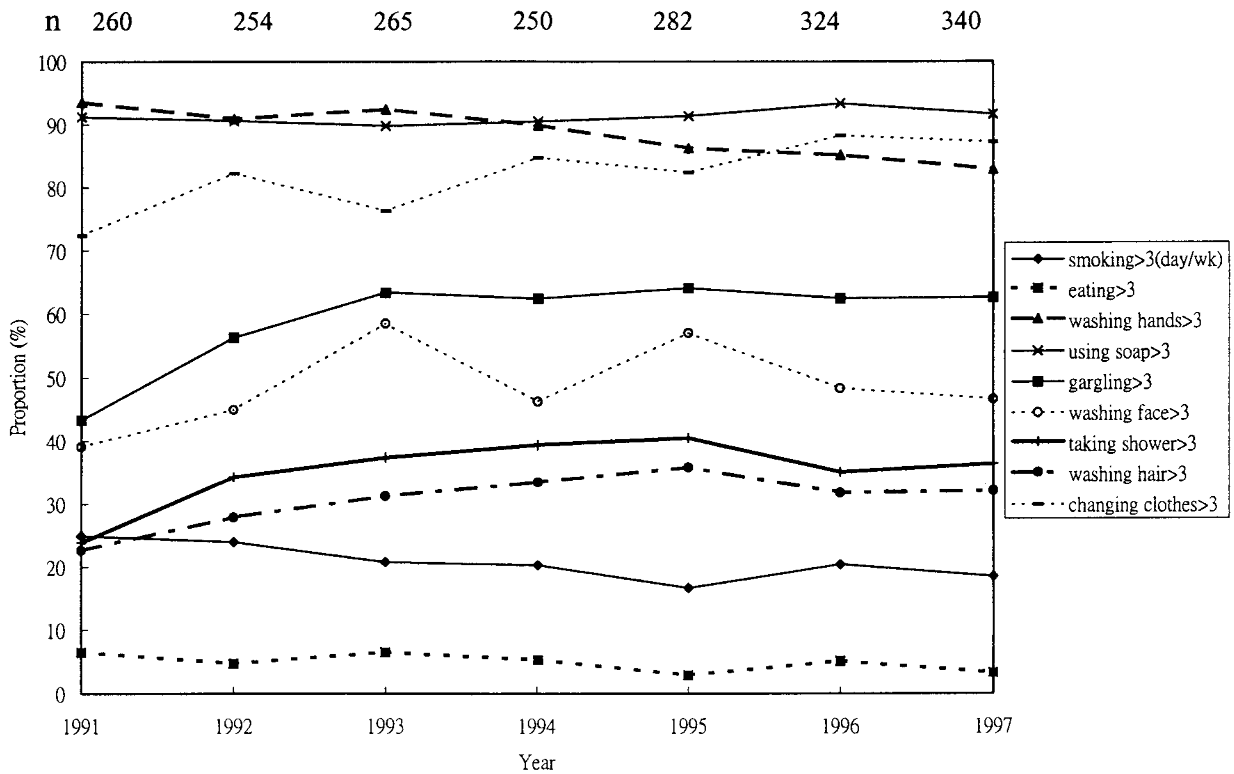

FIGURE 2. Proportions of workers participating in the health promotion program and reporting the most frequent in each personal hygiene habit in Taiwan. Each personal hygiene habit was divided into three categories (see text). The proportions shown in the figure are the categories that were more than 3 days per week.

giene habits at work, the greater the odds of exceeding recommended maximum blood lead concentrations.

DISCUSSION

Blood lead concentrations decreased significantly (by about 10 µg/dL) in the first 5 years of our study among the workers with full-exposure and partial-exposure to lead, but did not change significantly among officers and administrators who were not exposed to lead at work. The decrease among workers with full- and partial-exposure jobs probably reflects the effects of the health promotion program. However, the fact that the declining trend was not significant from the years 1995–1997 may indicate the limitations of this program. Some investigators have argued for the effectiveness of employee-based health promotion efforts [Keogh and Gordon, 1994]. Our study suggests that a health promotion program supervised by occupational physicians may reduce average level of blood lead concentrations by 10 µg/dL.

There are few longitudinal studies on the relationship between personal hygiene habits and blood lead concentrations. A strength of our study is that it is one of the longest observational and prospective studies on this topic. However, departure of workers from their jobs and workers who did not complete the periodic health exams during the 7-year study resulted in some dropouts and missing data. For the missing or incomplete data from the records of the company, we found the most frequent cause of nonparticipation to be timing conflicts of the health examinations with workers' shift schedules. In the first 5 years, almost no worker on the night shift participated in the annual health examinations. After we changed the schedule of these examinations in the last 2 years, participation rates increased to more than 92% in 1996 and more than 99% in 1997. Because no worker was permanently assigned to the night shift, i.e., all workers were rotated through day and night shifts, the source of missing or incomplete data from nonparticipation was likely randomized. Nonparticipation in health examinations was therefore not related to blood lead elevations. For workers dropping out in the prospective study, factory records showed that one of the most frequent reasons for leaving the company was that workers found jobs with better pay elsewhere. We compared blood lead concentrations of the workers who left with those of workers who stayed at the factory and found no consistent differences (Table II). Thus, nonparticipation and dropout were not a major source of bias in this study [Heyting et al., 1992; Laird, 1988].

TABLE III. Longitudinal Analysis (Mixed Models) of the Impact of Each Personal Hygiene Habit on Blood Lead Levels, With Adjustment for Calendar Year, Gender, Job Title, Education Level, and Percent of Life Span in the Plant Among Lead Battery Workers in Taiwan, 1991–1997

Habits, reported frequency	Number of observations	Estimated β (std error)	Test of fixed effect, type III F-value
Smoking at working site			6.90***
never and nonsmoker (reference)	1,666	—	
≤3 days per week	50	1.44 (1.32)	
>3 days per week	435	3.08 (0.83)***	
Eating at working site			1.68
never (reference)	1,634	—	
≤3 days per week	324	0.50 (0.51)	
>3 days per week	154	1.32 (0.76)*	
Washing hands before lunch			0.37
>3 days per week (refernece)	1,931	—	
≤3 days per week	82	−0.81 (0.95)	
never	105	0.02 (0.82)	
Washing hands with soap			1.20
>3 days per week (reference)	1,832	—	
≤3 days per week	168	−0.82 (0.77)	
never	146	−0.95 (0.73)	
Gargling before lunch			0.03
>3 days per week (reference)	1,201	—	
≤3 days per week	286	−0.06 (0.55)	
never	650	0.07 (0.45)	
Washing face before lunch			1.61
>3 days per week (reference)	966	—	
≤3 days per week	321	0.77 (0.54)	
never	824	−0.19 (0.44)	
Taking a shower before going home			1.00
>3 days per week (reference)	699	—	
≤3 days per week	137	0.59 (0.79)	
never	1,303	−0.41 (0.50)	
Washing head before going home			0.28
>3 days per week (reference)	604	—	
≤3 days per week	191	−0.48 (0.72)	
never	1,335	−0.31 (0.53)	
Changing clothes before going home			0.33
>3 days per week (reference)	1,757	—	
≤3 days per week	57	−0.37 (1.17)	
never	337	0.38 (0.55)	

*$P < 0.1$.
**$P < 0.05$.
***$P < 0.01$.

TABLE IV. Multivariate (Mixed) Model for Longitudinal Analysis of Blood Lead Changes Among Lead Battery Workers in Taiwan, 1991–1997

Independent variable	Number of observations	Estimated β (std error)	Test of fixed effect, type III F-value
Intercept		−2.07 (1.52)	—
Time (calendar year)			25.13**
1991	284	7.04 (0.65)**	
1992	274	5.45 (0.67)**	
1993	279	5.52 (0.60)**	
1994	282	5.61 (0.65)**	
1995	316	1.38 (0.52)**	
1996	369	0.87 (0.51)	
1997 (reference)	392	—	
Smoking at working sites			7.12**
nonsmoker and never (reference)	1,666		
≤3 days per week	50	1.33 (1.32)	
>3 days per week	435	3.13 (0.83) **	
Eating at working site			1.89
never (reference)	1,634		
≤3 days per week	324	0.57 (0.51)	
>3 days per week	154	1.38 (0.75)*	
Job titles			33.28**
low- or no-exposure (reference)	192		
lead powder making	22	9.76 (3.35)**	
pasting	59	23.18 (2.46)**	
grid casting	39	12.29 (2.52)**	
plate formation	104	16.02 (1.88)**	
plate cutting	77	21.68 (2.07)**	
assembly	1,177	14.70 (1.24)**	
partial exposure	533	7.14 (1.12)**	
Gender			98.53**
female (reference)	1,904		
male	1,918	10.27 (1.03)**	
Education level (year)			22.63**
primary school (1–6)	959	10.38 (1.42)**	
junior high school (7–9)	1,015	10.71 (1.37)**	
senior high school (10–12)	959	7.08 (1.32)**	
college (reference)	581		
Percent of life span in the work	3,157	0.06 (0.02)**	7.21**

*$P < 0.1$.
**$P < 0.01$.

Among the personal hygiene habits evaluated, only smoking at work and eating at work were significantly related to blood lead concentrations. These two risky habits increase hand-to-mouth movements and necessitate the removal of the disposable protective masks, although the

TABLE V. Multivariate Analysis (GEE Method) of Factors Associated With an Elevated Risk of Blood Lead Concentrations Exceeding 40 μg/dL in Male Lead Battery Workers and 30 μg/dL in Female Lead Battery Workers in Taiwan, 1991–1997

Personal hygiene category	Number of observations	Odds ratio (95% confidence interval) in model with*		
		Smoking only	Eating only	Both
Smoking at work				
$\leq$3 days/week	50	1.41 (0.74–2.73)		
$>$3 days/week	435	1.74 (1.18–2.55)		
never and nonsmoker (reference)	1,666	1.00		
Eating food at work				
$\leq$3 days/week	324		1.07 (0.82–1.38)	
$>$3 days/week	154		1.63 (1.11–2.40)	
never (reference)	1,634		1.00	
Smoking and Eating				
both $>$3 (days/wk)	13			2.93 (1.27–6.77)
smoking $>$3, eating $\leq$3	55			2.09 (1.12–3.90)
smoking $>$3, eating $=$0	354			1.76 (1.18–2.63)
smoking $\leq$3, eating $>$3	3			4.64 (0.10–238.82)
smoking $\leq$3, eating $<$3	14			1.90 (0.88–4.11)
smoking $\leq$3, eating $=$0	31			1.06 (0.44–2.61)
smoking $=$0, eating $>$3	137			1.54 (1.02–2.34)
smoking $=$0, eating $\leq$3	252			1.02 (0.74–1.38)
neither (reference)	1,244			1.00

*Indicates the model was adjusted for calendar year, gender, job title, education level, and percent of life span in the work.

effective dust-protective masks were widely used and required at work sites in the factory by labor regulations. Hand- and face-washing and gargling before lunch did not play an important role in reducing blood lead concentrations, perhaps because the dining room is separate from the working sites and lunch is eaten with utensils (chopsticks and spoons) in the Chinese culture; evidence showed the proportion of washing hands more than 3 days per week declined since 1994. In addition, only around 60% or less of workers practiced gargling or/and face-washing before lunch (Fig. 2). Thus, the effectiveness of these practices remains unclear. Although the other personal hygiene habits evaluated—taking a shower, washing hair, and changing clothes before going home—increased in frequency during the study, the goal of these habits is to avoid bringing lead contamination home and to protect workers' families, especially children, and not to reduce workers' blood lead levels primarily in the health promotion program. Thus, these items were not significantly associated with workers' blood lead concentrations. However, they should be more strongly promoted while further investigations of their impact on workers' families are conducted.

Both among lead workers [Brown et al., 1980] and in general populations [Berode et al., 1991], smokers have been shown to have higher blood lead concentrations and higher levels of bone lead were observed in male smokers [Hu et al., 1996]. These findings are consistent with our results. The mean blood lead concentrations of workers in the factory were always significantly higher among smokers than among nonsmokers. Nevertheless, mean blood lead concentrations of smokers gradually declined over the 7-year study—from 43.3 μg/dL in 1991 to 28.6 μg/dL in 1997.

Job titles representing different levels of occupational exposure played a major role in our analyses. In this factory, two of the highest-risk jobs are pasting and plate cutting. A study in Germany yielded similar results: the levels of air lead and blood lead were highest in employees from the plate formation and adjoining production areas, and were next highest for pasting, casting, and assembly [Kentner et al., 1994]. Use of different work designs and engineering controls (such as general and local ventilation), rather than an ever-greater emphasis on personal hygiene habits, would probably be the best way to lower workers' blood lead concentrations. Unfortunately, it is difficult to persuade employers to implement such measures because of the expense.

In conclusion, this study demonstrates that changing workers' hygiene habits can reduce their blood lead concentrations (even with adjustment for job title and the other potential confounders). Thus, personal hygiene is important and should be stressed in education programs. However, the improvements that can be expected to result from better personal hygiene practices are limited, and employers should institute engineering controls to reduce the blood lead concentrations in their workers.

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