

Behavioral interventions to reduce nickel exposure in a nickel processing plant

Krassi Rumchev, Helen Brown, Amanda Wheeler, Gavin Pereira & Jeff Spickett

To cite this article: Krassi Rumchev, Helen Brown, Amanda Wheeler, Gavin Pereira & Jeff Spickett (2017) Behavioral interventions to reduce nickel exposure in a nickel processing plant, Journal of Occupational and Environmental Hygiene, 14:10, 823-830, DOI: [10.1080/15459624.2017.1335402](https://doi.org/10.1080/15459624.2017.1335402)

To link to this article: <https://doi.org/10.1080/15459624.2017.1335402>



Accepted author version posted online: 22 Jun 2017.
Published online: 22 Jun 2017.



Submit your article to this journal [↗](#)



Article views: 254



View related articles [↗](#)



View Crossmark data [↗](#)



Behavioral interventions to reduce nickel exposure in a nickel processing plant

Krassi Rumchev, Helen Brown, Amanda Wheeler, Gavin Pereira, and Jeff Spickett

School of Public Health, Curtin University, Perth, Australia

ABSTRACT

Nickel is a widely-used material in many industries. Although there is enough evidence that occupational exposure to nickel may cause respiratory illnesses, allergies, and even cancer, it is not possible to stop the use of nickel in occupational settings. Nickel exposure, however, can be controlled and reduced significantly in workplaces.

The main objective of this study was to assess if educational intervention of hygiene behavior could reduce nickel exposure among Indonesian nickel smelter workers. Participants were randomly assigned to three intervention groups ($n = 99$). Group one ($n = 35$) received only an educational booklet about nickel, related potential health effects and preventive measures, group two ($n = 35$) attended a presentation in addition to the booklet, and group three ($n = 29$) received personal feedback on their biomarker results in addition to the booklet and presentations. Pre- and post-intervention air sampling was conducted to measure concentrations of dust and nickel in air along with worker's blood and urine nickel concentrations. The study did not measure significant differences in particles and nickel concentrations in the air between pre- and post-interventions. However, we achieved significant reductions in the post intervention urine and blood nickel concentrations which can be attributed to changes in personal hygiene behavior. The median urinary nickel concentration in the pre-intervention period for group one was $52.3 \mu\text{g/L}$, for group two $57.4 \mu\text{g/L}$, and group three $43.2 \mu\text{g/L}$ which were significantly higher ($p < 0.010$) than those measured in the post-intervention period for each of the groups with $8.5 \mu\text{g/L}$, $9.6 \mu\text{g/L}$, and $8.2 \mu\text{g/L}$, respectively. A similar pattern was recorded for serum nickel with significantly ($p < 0.05$) higher median concentrations measured in the pre-intervention period for group one $1.7 \mu\text{g/L}$, and $2.0 \mu\text{g/L}$ for group 2 and group 3 compared with the post intervention median serum nickel levels of $0.1 \mu\text{g/L}$ for all groups.

The study showed that educational interventions can significantly reduce personal exposure levels to nickel among Indonesian nickel smelter workers.

KEYWORDS

Behavioral change; exposure assessment; intervention; nickel

Introduction

Several million workers worldwide are regularly exposed to airborne fumes, dusts and mists containing nickel and its compounds.^[1] Inhalation, ingestion, or skin contact are common routes of exposure in nickel-producing industries (e.g., mining, milling, smelting, and refining), as well as in nickel-using industries and operations (e.g., alloy and stainless-steel manufacture; electroplating; welding, grinding, and cutting). Occupational exposures to nickel can result in elevated levels of nickel in blood, urine, and body tissues, with inhalation being the main route of uptake.^[2] The adverse health effects associated with occupational nickel exposures are dependent on a number of factors including chemical speciation, particle size, and solubility within biological fluids.^[3–5] In the nickel-producing industry, workers employed in

the sectors of mining, milling and smelting are frequently exposed to insoluble forms of ores, nickel oxide and nickel subsulphide (Ni_2S_3). Exposure to metallic and soluble nickel compounds in these sectors is less common and more likely to be found in the refining sector where workers are predominantly exposed to nickel oxide, nickel sulphide, nickel metallic, and soluble nickel salts.^[5] In its review, the International Agency for Research on Cancer^[1] concluded that there is sufficient evidence that mixtures containing nickel compounds and nickel metal are carcinogenic. These agents may have the potential to cause cancer of the lung, nasal cavity and paranasal sinuses.^[3,5–7] In a study by Mastromatteo,^[8] it was identified that there is an increased risk of gastric cancer and sarcoma; chronic irritation of the upper-respiratory tract manifested by rhinitis, sinusitis, perforation of the nasal

septum, and loss of the sense of smell; pulmonary irritation and pulmonary fibrosis; pneumoconiosis; bronchial asthma; increased susceptibility to respiratory infections; and dermatitis. According to Raithel,^[9] latency periods for the induction of malignant diseases in the nose and lung may be 20 years and more. The World Health Organization^[2] has also raised the possibility of oral nickel compound exposure as a promoter of digestive tract cancers.

Personal hygiene behavior can affect the occupational intake of a toxic chemical.^[10] Bavazzano^[11] suggests that nickel compound exposure of workers is probably related not only to airborne nickel compounds, but also to personal habits such as cigarette smoking, food or beverage consumption in the working area, misuse of work clothing, and not washing/having showers at the end of the work shift.

Workplace educational intervention studies targeting exposures to hazardous substances have been carried out in a range of contexts including food handlers in India,^[12] farmworkers in the U.S.,^[13] and arc welders in Nigeria.^[14] The most common measurements of effectiveness of workplace educational interventions are interviews or questionnaires conducted in pre- and post-intervention periods. Questions typically measure workers' knowledge, attitude, and reported behavior related to potential health impacts of exposure to workplace hazards and appropriate control measures. Although increases in workers' knowledge, attitude, and reported behavior are assumed to translate to the reduced exposure to workplace hazards, measurements of health outcomes provide more robust evidence of reduced exposures. Monitoring health outcomes increases confidence in the evaluation of the educational intervention programs and provides direct evidence of an impact. In the case of nickel, surveillance of health outcomes is impractical due to the long latency periods between exposure to nickel and health outcomes, biological monitoring offers a suitable measure of impact of interventions upon exposure.

The aim of this study was to investigate the efficacy of different educational intervention approaches to improve personal hygiene behavior among refinery workers by using atmospheric and biological monitoring.

Methods

Study population

We conducted an intervention study to evaluate the effectiveness of different educational intervention programs to improve personal hygiene behavior. The study was carried out in Indonesia at a nickel-smelter plant that produced nickel subsulfide. The nickel process plant

operation employed 386 workers (18.4% of the total workforce at the plant). Workers directly operating the nickel production plant including those working in the Dryer, Reduction Kiln, Furnace, Converter, and Packaging, were required to wear a mask or respirator all the time during the work-shift and were regarded as eligible to be study subjects. Workers employed in the control room, management lines, transport crews of nickel ore preparation, and worker supervisors did not meet the inclusion criteria and were not invited to participate in the study. Since the level of education of study subjects ranged from primary to senior high school we applied the following two additional inclusion criteria: (i) participants must have worked a minimum of 24 hr within an 8-day rotation; and (ii) their education level must reflect the ability to read Indonesian and speak the language fluently. Based on the above inclusion criteria, 103 participants were invited to participate in the study. During the study, 4 subjects dropped out and the final sample size of this study was 99. Study participants were male aged between 26–51 years with tenure between 2–30 years.

The study subjects had different exposure to nickel dust and those who worked in the units of Dryer, Reduction kiln, Furnace and Converter were rotated in three work-shifts (07.00 am to 15.00 p.m., 15.00 to 23.00 p.m., and 23.00 p.m. to 07.00 am) and each worker was expected to work at each shift for two days, and then moved to the next shift for two days and so forth with the total of eight days and followed by one work-shift off. In the Packaging unit, however, there were two work-shifts per-day (morning from 07.00 am to 15.00 p.m. and afternoon from 15.00 to 23.00 p.m.), from Monday to Saturday, and a day off on Sunday. Thus, the total number of days for work-shift rotation was seven.

Approval for the study was granted by the Curtin University Research Ethics Committee and a signed informed consent was obtained from all participants before commencing the study.

Intervention

This was a pre- and post-intervention study of workers' personal hygiene behavior change through education. The pre-intervention sampling was followed by a 3-month intervention period and subsequent post-intervention measurements. We developed three intervention strategies to raise awareness and knowledge of nickel exposures and its potential health impacts among workers.

According to the type of preventive measures we randomly assigned the study subjects in one of the following groups.

- Group One (n = 35) — educational booklet about nickel, its potential adverse health effects and preventive measures by following basic hygiene behavior.
- Group Two (n = 35) — educational booklet (as above) PLUS a class presentation and discussions of the booklet's content with workers.
- Group Three (n = 29) — educational booklet, class presentation (as above) PLUS personal feedback to participants in relation to their urine and blood test results.

The aim of the educational booklet was to improve knowledge and hygienic behavior of workers towards exposure to nickel in dust and consisted of six sections. The educational materials first included information related to routes of exposure to nickel dust, potential adverse health effects associated with nickel dust exposure, nickel absorption in the body, and concluded with preventive measures. Preventive measures considered in the booklet included: (i) Personal Hygiene such as washing/showering and changing out of work clothes prior to leaving the work site; washing hands before smoking, eating and drinking; and shaving; and (ii) Hygienic Work Behavior including wearing a mask or respirator during work; avoiding smoking, eating and drinking in the workplace.

Effectiveness of the interventions was evaluated through physical measurements of subject's urinary nickel concentrations before, during, and after the intervention and serum nickel concentrations before and after the intervention.

Data collection

Two methods of data collection were applied; biological testing and atmospheric measurements.

Biological testing — Urine and blood

Urine and blood samples were collected at the factory hospital or health clinic. Concentrations of urinary nickel were measured during three periods including the pre-intervention and intervention periods, and five months later during the post-intervention period. Spot samples were collected to measure nickel concentrations in the urine once at the end of the work-shift rotation for ten work-shifts in the pre-intervention period, nine rotations in the post-intervention period and at the end of four work-shift rotations during the intervention period. The total number of urine samples collected during the pre-intervention period was 491, and included 3–7 samples from each subject. During the intervention period a total of 300 samples were taken, with 0–3 samples from each subject, and a total of 474 samples taken during the

post-intervention period samples, each subject providing 2 to 8 urine samples. The average concentration of urinary nickel provided by each subject in the pre- and post-intervention periods was presented as the concentration of nickel in urine for each study subject. Between 4–7 mL of urine was collected from each subject in a capped polyethylene plastic container (Sarstedt-Germany). The urine collection followed the schedule of the 8-day rotating shift system, with urine collection occurring on the first day off from work. To avoid highly dilute or concentrated samples, all urine samples were corrected for creatinine concentrations. Only samples with a creatinine concentration of 0.5–3.0 mg/L or a specific gravity value of 1.005–1.035 were selected as per ACGIH.^[15] The number of urine samples fulfilling these criteria in the pre-intervention, during the intervention, and in the post-intervention periods was 462, 193, and 441, respectively. Urinary creatinine concentrations were measured using a Cobas Mira Plus (Roche Diagnostic Systems), which operated on the basis of the Jaffe method modification. Urine samples were shaken mechanically and mixed with ultra-pure nitric acid (HNO₃) reagent (J.T. Baker Ultrex, Phillipsburg, USA) added as per Sunderman et al.^[16]

As with urine sampling, blood samples were taken on the first scheduled rest day. Blood samples were collected in the pre- and after five months during the post-intervention periods with the total number of blood samples collected being 103 and 96, respectively. Samples of approximately 4–7 mL were collected using capped polyethylene plastic containers and a single use sterilised syringe. The blood samples were taken from a blood vein vessel inside the elbow area of the right or left arm and were stored carefully in sterilised plastic containers to prevent the blood red cells from breaking up. All participants were informed that they might experience some slight discomfort or pain. Serum samples were obtained from the whole blood samples by adding a lithium-heparin anti-coagulation agent, centrifuging for 30 min at 3000 rpm and then mixing with an ultra-pure HNO₃ reagent.

All nickel analyses were conducted using a Polarized Zeeman Atomic Absorption Spectrophotometer (AAS) (Hitachi, model Z-8100) according to the IUPAC reference method for analysis of nickel in serum and urine.^[17] Blank reagent and standard nickel reference material were used. In addition, each sample was analysed three times and its average reading presented.

Exposure assessment for nickel in the workplace

To determine the nickel exposure in workplace air, we conducted measurements on multiple occasions during pre- and post-intervention periods in each of the work areas (n = 77 and 83, respectively). Samples were collected and prepared according to the OSHA ID-121 method.^[18]

The measurement of nickel in air was conducted using a personal sampling pump (PDS) (Amatek Constant Flow Sampler P 2500 A, Amatek, Canada) with a flow rate of 2 L/min. Mixed Cellulose Esters membrane filters with a diameter of 37 mm and a pore size of 0.8 µm were used and before use, filters were desiccated with silica gel for 24 hr or more and then weighed using an electronic scale balance with a sensitivity of 0.01 mg (Mettler AE 163, Mettler Instrument AG, Switzerland-Swiss). The electronic scale was calibrated regularly prior to weighing the filters using the laboratory standard metric of Permas 745 (Fisher Scientific. Co., USA). The air sampling was conducted for 4–7 hours. Concentration of particulates in the air (mg/m³) was calculated from filter weights, flow rate of the personal sampling pump and duration of sampling. Nickel concentrations in air were analyzed after acid digestion of the filters and atomic absorption spectrometry with analytical detection limit of 0.0001 mg/m³.

Statistical analysis

Statistical analysis was conducted using The “R” Project for Statistical Computing (v3.2). Collected data were screened and cleaned for any errors before further analyses. Continuous variables are presented as mean (range) and median ($\pm$ standard deviation). Categorical variables are presented as frequency (%) in relevant categories. In addition to the descriptive statistics, Chi-square test for categorical variables was used to explore potential associations of interest. Linear mixed models are presented for the difference in serum nickel and urinary nickel (measured as post-pre-intervention) with a random intercept for work unit and adjustment for age (centred) and length of tenure.

Results

There were 103 study participants recruited, all male, aged 26–51 years, with the majority having senior high school levels of education, and had worked for the company for 2–30 years. There were no significant differences between each of the four working units in terms of subject's age or years of tenure. As such, all working units' data were pooled into the relevant intervention group. Only four participants were lost to follow up.

Environmental samples

The median concentration of particles in air was not significantly different ($p = 0.9$) between the pre-intervention (4.22 mg/m³) and post-intervention periods (5.13 mg/m³). The pre-intervention median nickel concentration in the air was 0.02 mg/m³ which was the

Table 1. Concentrations of atmospheric dust and nickel by work-unit (mg/m³).

Period	Work Unit (n)	Median Dust Concentration $\pm$ SD	Median Nickel Concentration $\pm$ SD
Pre-Intervention	Dryer (18)	2.76 $\pm$ 2.86	0.02 $\pm$ 0.01
	Kiln (18)	7.59 $\pm$ 6.09	0.02 $\pm$ 0.01
	Furnace (23)	2.72 $\pm$ 2.73	0.02 $\pm$ 0.01
	Converter (18)	4.22 $\pm$ 3.94	0.02 $\pm$ 0.01
	Total (77)	4.22 $\pm$ 4.43	0.02 $\pm$ 0.01
Post-Intervention	Dryer (20)	7.63 $\pm$ 13.16	0.02 $\pm$ 0.02
	Kiln (24)	5.34 $\pm$ 4.76	0.02 $\pm$ 0.02
	Furnace (24)	3.58 $\pm$ 4.85	0.02 $\pm$ 0.02
	Converter (15)	4.96 $\pm$ 9.30	0.02 $\pm$ 0.01
	Total (83)	5.13 $\pm$ 8.37	0.02 $\pm$ 0.02

same as measured in the post-intervention period, see Table 1. Thus, any changes in nickel levels in worker's blood or urine can be attributed to changes in personal hygiene behavior and not to any changes in the workplace environment.

Biological samples

For the pre-, during, and post-intervention periods multiple urine samples were collected on the first scheduled rest day from each participant of the intervention groups (pre- $n = 462$, during $n = 193$, post $n = 441$). The median and range of the urinary nickel concentrations in the pre-intervention period of 50.1 µg/L (25.3–78.9 µg/L) was significantly higher ($p < 0.01$) than those measured during the post intervention period with median levels of 8.5 µg/L (3.0–4.2 µg/L) (Figure 1, Table 2). Figure 1 demonstrates that the variability in urinary nickel levels was greater for both the pre- and during intervention periods when compared with the post-intervention period. This is also evident for the serum nickel measures shown in Figure 2.

In total, 103 and 96 study subjects gave blood samples in the pre- and post-intervention periods, respectively. The median serum nickel concentration in the pre-intervention period for all groups was 2.0 µg/L and ranged from 0.13–18.30 µg/L. This was significantly ($p < 0.05$) higher than the median serum nickel levels of 0.1 µg/L (range 0.01–2.7 µg/L) recorded in the post-intervention period (Table 2). As with the urine samples, the linear mixed model results showed that the reductions

Table 2. Median and range of nickel in serum and urine for study subjects in the pre and post intervention periods (µg/L).

Intervention Post-Group	Serum Pre-Intervention	Serum Post-Intervention	Urine Pre-Intervention	Urine Post-Intervention
One	1.7 (0.1–17.6)	0.1 (0–1.0)	52.3 (25.3–69.8)	8.5 (3.0–12.4)
Two	2.0 (0.4–9.1)	0.1 (0–1.0)	57.4 (38.5–78.9)	9.6 (4.9–14.2)
Three	2.0 (0.2–18.3)	0.1 (0–2.7)	43.2 (26.6–78.3)	8.2 (5.9–11.7)
All	2.0 (0.13–18.3)	0.1 (0–2.7)	50.1 (25.3–78.9)	8.5 (3.0–14.2)

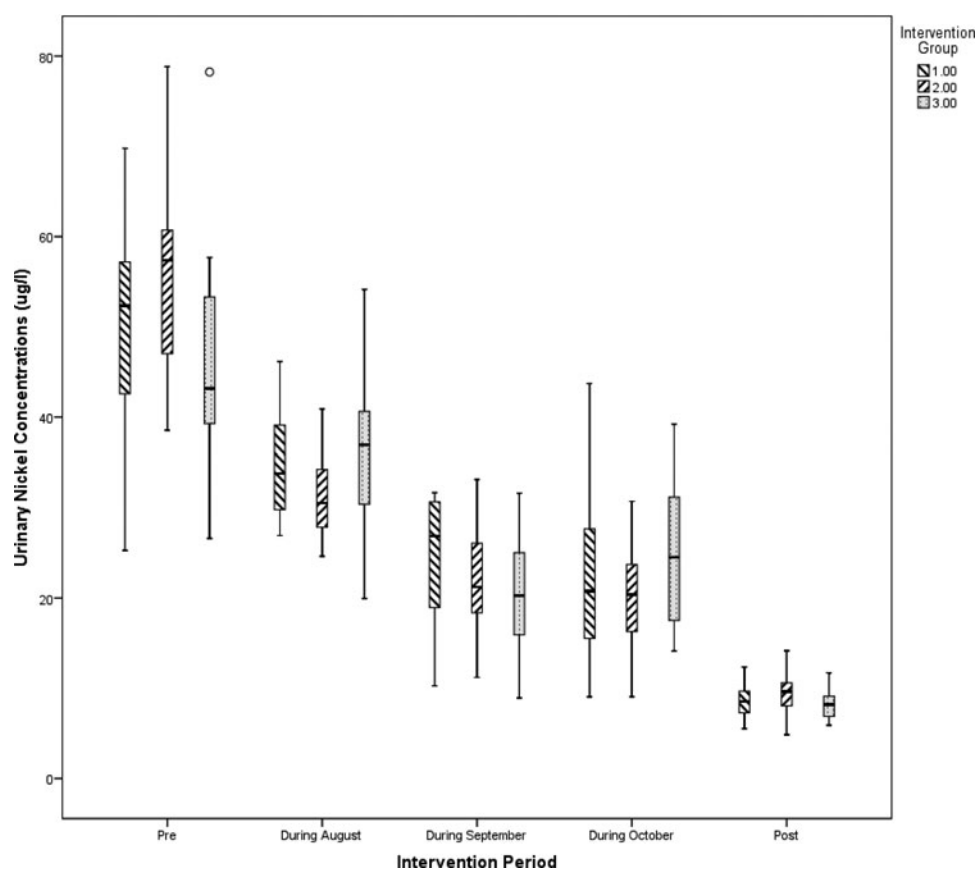


Figure 1. Pre- and post-intervention median urinary nickel concentrations by intervention group.

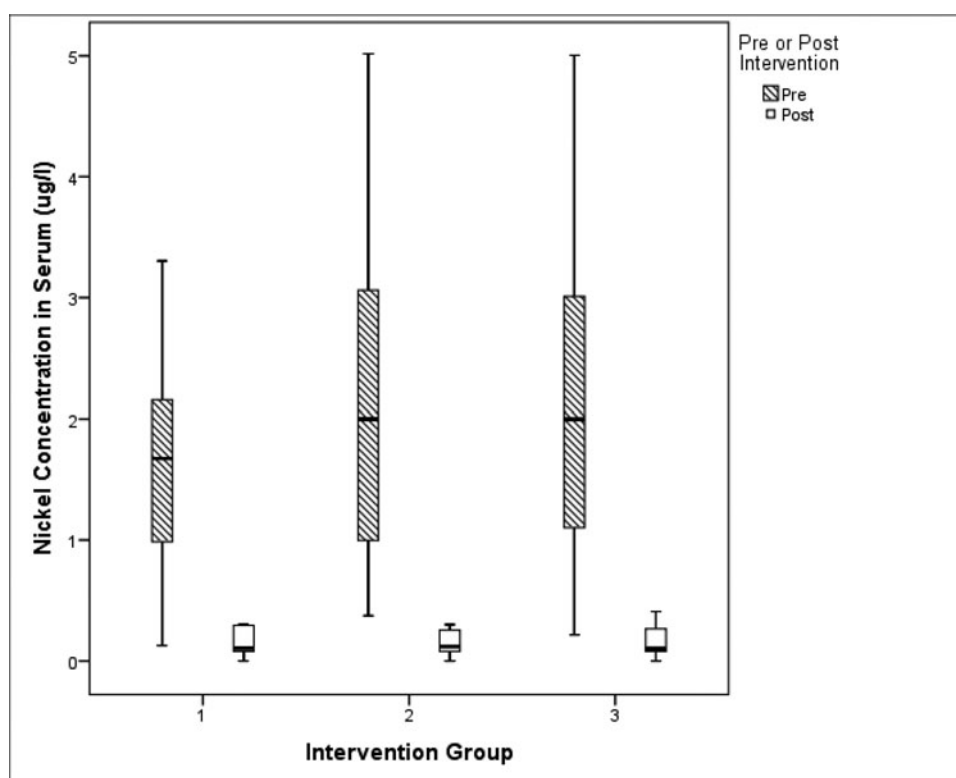


Figure 2. Pre- and post-intervention median serum nickel concentrations by intervention group. (Group 1 – Booklet only; Group 2 – Booklet and presentation; Group 3 – Booklet, presentation and feedback on biological results.)

Table 3. Adjusted* improvement in urinary and serum nickel concentrations by intervention group ($\mu\text{g/L}$).

Intervention Group	Urine		Serum	
	Improvement	(95% CI)	Improvement	(95% CI)
One	41	(47–35)	2	(3–1)
Two	47	(53–41)	3	(4–1)
Three	37	(43–32)	2	(3–1)
All	42	(47–37)	2	(3–2)

*Adjusted for age, tenure and a random intercept for unit.

of serum nickel concentrations were not significantly different between the three intervention groups, (Figures 1 and 2). In addition, the linear mixed model was adjusted for age and tenure (Table 3) and the result showed no evidence for any interaction between length of tenure and improvements in urinary nickel concentrations.

Associations between the nickel in air samples, urinary nickel and serum nickel in both the pre- and post-intervention periods were evaluated using Spearman correlations (ρ). The only associations identified in the study were between the pre-intervention urine samples with the corresponding air samples ($\rho = 0.29$; $p = 0.032$). None of the post-intervention urine or serum samples were associated with the air samples.

Discussion

In this study, we demonstrated that each of the applied behavioral intervention programs successfully changed the worker's hygiene behavior. This result in significant reductions in the worker's post-intervention nickel exposures in both urine and blood. For each work-unit, the particulates and nickel concentrations in air were not significantly different between the pre- and post-intervention periods indicating that workers were consistently exposed to nickel for the duration of the study. In addition, according to observations and discussions with the supervisors, production capacity and processes did not change during the study. Therefore, the reduced exposure to nickel can be attributed to the change in worker's personal hygiene behavior evaluated by the physical measurements of urine and serum nickel levels before and after the interventions. Our results are consistent with the findings of previous studies. Hopkins et al.^[19] showed that workers who practiced poor personal hygiene behavior were exposed to higher levels of chemical agents than those that consistently practiced better hygiene behavior. Therefore, improvements in personal hygiene behavior may significantly reduce the uptake and reduce the concentrations of nickel in the body.

When comparing the three different intervention methods and their impact upon the workers' biological

samples there were no significant differences in the outcomes of the three interventions. This was unexpected as it was hypothesized that the three different intervention strategies of booklet, booklet and content explanation, and booklet, content explanation, and feedback on worker's urine and serum nickel levels would demonstrate that greater interactions with workers would be more effective at reducing nickel concentrations in serum and urine compared to the strategy of booklet only. This suggests that just providing a booklet to workers and explaining the significant health impacts of poor personal hygiene behavior can prove to be sufficient to change behavior in relation to chemical exposures. Other occupational settings have successfully investigated the impact of providing safety education material to workers to reduce exposures to hazardous situations. Sam et al.^[20] provided agricultural workers with educational materials on safe applications of pesticides and were able to demonstrate a significant improvement in knowledge, as measured by a questionnaire. Unlike our findings, other studies^[8,10,21] demonstrated that the knowledge received by workers through both a booklet and in class booklet presentations was significantly higher compared to those who received the booklet only. It has been suggested that knowledge is a precursor of behavior, however it has been shown that alone it may be insufficient to motivate behavior change because other variables such as attitude, beliefs and feelings can change people's behavior.^[22–24]

In this study, the nickel concentrations measured in the air were less than 0.02 mg/m^3 and lower than the limit values established by the major standard-setting bodies in Indonesia, Australia, Canada, and the U.S.,^[4] i.e., 1 mg/m^3 , however, according to other studies adverse health effects might be induced even at these low levels of exposure.^[5,7]

In a workplace, the common routes of exposure to nickel include inhalation, ingestion and skin absorption. The absorbed nickel finds its way into the blood stream and is predominantly excreted in urine.^[25] According to Morgan and Rouge,^[26] the concentrations of nickel in blood and urine are the primary tools for assessing insoluble nickel compound exposure. This is consistent with the study of Tola, Kilpio, and Virtamo,^[27] who state that blood and urine can be successfully used as indicators of nickel exposure. Concentrations of nickel in urine and blood may not reflect the actual exposure levels since insoluble nickel compounds may accumulate in the lung where their ions can be absorbed into the blood and excreted through urine. In a study of nickel kinetics by Raithel et al.,^[9] a relatively short urinary half-life of 30–53 hr among workers exposed to nickel oxide, complex oxide fumes, or fine particles of insoluble nickel was seen. In addition, Patriarca et al.^[28] demonstrated that

nickel concentrations in urine and blood have different excretion rates. Individuals provided with a dose of ^{62}Ni excreted approximately 51–82% of the dose through urine over a five-day period. Blood levels peaked 1.5–2.5 hr after ingestion and were diminished to background levels within 96 hr.^[28] This may explain why not all workers in this study had similar reductions in urinary nickel concentrations and Figure 1 shows variability across workers which may reflect the timing between the end of their shift and the collection of the urine sample the following day.

The lack of significant associations between serum and urinary nickel concentrations found in this study might be a result of the different collection methods. The nickel concentrations in urine were individual average concentrations of spot urine samples collected during each of the 8–10 week-shift rotations, while the serum nickel concentrations were from an individual serum sample collected once per week-shift rotation. In addition, nickel levels in the serum and urine can vary considerably due to the time of collection.^[4]

Previous studies have also reported that the hygiene behavior of workers can lead to a poor relationship between environmental and biological exposures. For example, Ulenbelt et al.^[29] reported that workers' hygiene behavior was a modifier of environmental and biological exposure in workers exposed to lead. Aitio^[30] stated that differences in personal working habits and personal hygiene of workers exposed to nickel might play a role in the discrepancies between both exposures.

We acknowledge that this study has some limitations including the potential for cross-group discussions around the learning materials and their implementation. However, it is expected that this would be likely to occur across all groups and therefore unlikely to influence one intervention over another.

Another potential limitation of this study is the collection of a spot urine sample to measure urinary nickel concentrations. For the accurate monitoring of urinary nickel concentrations, it is preferable to collect a 24-hr urine sample. However, the collection of such samples is impractical in an occupational setting. Hence, random collection or spot urine samples of pre- or post-shift exposure is the most common method used for routine examination. The use of urine samples is preferred over blood samples since the collection of urine samples is not an invasive technique. Also, urinary nickel concentrations are higher than concentrations in other biological media, thus improving analytical sensitivity, accuracy, and precision.^[25]

The main routes of exposure to nickel include inhalation followed by skin contact and ingestion however due to limited resources, in this study we only assessed occupational exposures through ingestion and skin absorption which is acknowledged as a limitation.

No long-term follow-up was completed as part of this study to evaluate the effectiveness of the interventions on long-term worker behavior. Future studies should consider including such measures. Educating employees to reduce their exposures to toxic chemical agents has great benefits. Education about the relationship between behavior at work and potential adverse health effects may motivate workers and result in long lasting effects in the improvement of personal hygiene behavior associated with the prevention of the uptake of chemical agents into the body. Significant variations with respect to realistic options for workplace interventions can occur between countries. For example, economic factors and limitations in knowledge have been cited as barriers to effective control of occupational hazards in low-income countries.^[31] This study highlights that relatively simple and inexpensive training methods to improve worker knowledge on how personal hygiene behavior can lead to significant benefits to workers. Given the widespread availability of information on occupational hazards such as nickel, the development and implementation of educational programs such as those used in this study should be considered as part of an integrated approach to potentially reduce workplace exposure to other hazardous substances.

Acknowledgment

The authors would like to acknowledge the support of the nickel refinery and its workers. We would also like to acknowledge the contribution of N. Furqaan who assisted with data collection.

References

- [1] **International Agency for Research on Cancer (IARC):** "A Review of Human Carcinogens. Part C: Arsenic, Metals, Fibres, and Dusts/IARC Working Group on the Evaluation of Carcinogenic Risks to Humans (Lyon, France)," (2012). Available at: <http://monographs.iarc.fr/ENG/Monographs/vol100C/mono100C.pdf> (accessed February 23, 2016).
- [2] **World Health Organization (WHO):** *Environmental Health Criteria 108: Nickel, International Joint Sponsorship Publication of United Nations Environment Programme.* International Labour Organisation and WHO (1991).
- [3] **Goodman, J., R.L. Prueitt, S. Thakali, and A.R. Oller:** The nickel ion bioavailability model of the carcinogenic potential of nickel-containing substances in the lung. *Crit. Rev. Toxicol.* 41(2):142–174 (2011).
- [4] **Nickel Institute and Nickel Producers Environmental Research Association (NiPERA):** "Health Guide: Safe Use of Nickel in the Workplace, third edition, Nickel Institute Canada & NIPERA." (2008). Available at: <https://www.nickelinstitute.org/~media/Files/NIPERA/Health%20Guide%20Third%20Edition%20June%202008.ashx?la=en> (accessed February 23, 2016).
- [5] **Oller, A.R., G. Oberdorster, and S.K. Seilkop:** Derivation of PM_{10} size-selected human equivalent concentrations of inhaled nickel based on cancer and

- non-cancer effects on the respiratory tract. *Inhal. Toxicol.* 26(9):559–578 (2014).
- [6] **Grimsrud, T.K., S.R. Berge, J.I. Martinsen, and A. Andersen:** Lung cancer incidence among Norwegian nickel-refinery workers 1953–2000. *J. Environ. Monit.* 5:190–197 (2003).
 - [7] **World Health Organisation (WHO):** *Air Quality Guidelines*. 2nd ed. Copenhagen, Denmark: WHO Regional Publications. Regional Office for Europe, 2000. pp. 162–172.
 - [8] **Mastromatteo, E.:** Nickel. *Am. Industr. Hyg. Assoc. J.* 7(10):586–601 (1986).
 - [9] **Raithel, H.J., K.H. Schaller, T. Kraus, and G. Lehnert:** Biomonitoring of nickel and chromium in human pulmonary tissue. *Int. Arch. Occup. Environ. Health* 65:197–200 (1993).
 - [10] **Ulenbelt, P., L.G. Lumens, H. Geron, and R. Herber:** An inverse lead air to lead blood relation: the impact of air stream helmets. *Int. Arch. Occup. Environ. Health* 63:89–95 (1991).
 - [11] **Bavazzano, P., R. Bolognesi, C. Cassinelli, et al.:** Skin contamination and low airborne nickel exposure of electroplaters. *Sci. Total Environ.* 155:83–86 (1994).
 - [12] **Malhotra, R., P. Lal, S.K. Prakash, M.K. Daga, and J. Kishore:** Evaluation of a health education intervention on knowledge and attitudes of food handlers working in a medical college in Delhi, India. *Asia Pac. J. Publ. Health* 20(4):277–186 (2008).
 - [13] **Salvatore, A.L., J. Chevrier, A. Bradman, et al.:** A community-based participatory worksite intervention to reduce pesticide exposures to farmworkers and their families. *Am. J. Publ. Health* 99(Suppl. 3):S578–581 (2009).
 - [14] **Adewoye, K.R., A.O. Awoyemi, O.A. Babatunde, O.A. Atoyebe, S.K. Salami, and F.Y. Issa:** Effect of health education intervention on the awareness and use of personal protective equipment among small scale electric arc welders in Ilorin, Nigeria. *Ind. J. Occup. Environ. Med.* 18(1):3–8 (2014).
 - [15] **American Conference of Governmental Industrial Hygienists (ACGIH):** *Threshold Limit Values & Biological Exposure Indices*. Cincinnati, OH: ACGIH, 2003.
 - [16] **Sunderman, Jr., F.W., S.M. Hopper, M.C. Crisostomo, and M. Stoeppler:** Rapid analysis of nickel in urine by electrothermal atomic absorption spectrophotometry. *Ann. Clin. Lab. Sci.* 16(3):219–230 (1986).
 - [17] **Brown, S.S., S. Nomoto, M. Stoeppler, and F.W. Sunderman Jr.:** IUPAC reference method for analysis of nickel in serum and urine by electrothermal atomic absorption spectrometry. *Clin. Biochem.* 14:295–299 (1981).
 - [18] **OSHA:** Metal & metalloid particulates. In: *Workplace Atmospheres (Atomic Absorption)*. Salt Lake City, UT: Division of Physical Measurements and Inorganic Analyses, 1985.
 - [19] **Hopkins, B.L., R.J. Conard, and M.J. Smith:** Effective and reliable behavioral control technology. *Am. Industr. Hyg. Assoc.* 47(12):785–791 (1986).
 - [20] **Sam, K.G., H.H. Andrade, L. Pradhan, et al.:** Effectiveness of an educational program to promote pesticide safety among pesticide handlers of South India. *Int. Arch. Occup. Environ. Health* 81:787–795 (2008).
 - [21] **Lumens, M.E., P. Ulenbelt, R.F. Herber, and T. Meymen:** The impact of hygienic behaviour and working methods on the uptake of lead and chromium. *Appl. Occup. Environ. Hyg.* 9(1):53–56 (1994).
 - [22] **Karita, K., M. Nakao, K. Ohwaki, et al.:** Blood lead and erythrocyte protoporphyrin levels in association with smoking and personal hygienic behaviour among lead exposed workers. *Occup. Environ. Med.* 62(5):300–303 (2005).
 - [23] **Maibach, E.W., and D. Cotton:** Moving people to behavior change. In: *Designing Health Messages: Approaches from Communication Theory and Public Health Practice*. Thousand Oaks, CA: Sage Publications, Inc., 1995. pp. 7–23.
 - [24] **Porru, S., F. Donato, P. Apostoli, L. Coniglio, P. Duca, and L. Alessio:** The utility of health education among lead workers: the experience of one program. *Am. J. Industr. Med.* 23(3):473–481 (1993).
 - [25] **Sunderman Jr., F.W.:** Biological monitoring of nickel in humans. *Scand. J. Work Environ. Health* 19:34–38 (1993).
 - [26] **Morgan, L.G., and P.J. Rouge:** Biological monitoring in nickel refinery workers. In *Nickel in the Human Environment: Proceedings of a Joint Symposium*, March 1983, Sunderman, F.W., Jr., et al., (eds). Lyon, France: International Agency for Research on Cancer (IARC Scientific Publication No. 53), 1984. pp. 507–520.
 - [27] **Tola, S., J. Kilpio, and M. Virtamo:** Urinary and serum concentration of nickel as indicator of exposure to nickel in electroplating shop. *J. Occup. Med.* 21(3):184–188 (1979).
 - [28] **Patriarca, M., T.D.B. Lyon, and G.S. Fell:** Nickel metabolism in humans investigated with a stable oral isotope. *Am. J. Clin. Nutr.* 66:616–621 (1997).
 - [29] **Ulenbelt, P., M.E. Lumens, H. Geron, R. Herber, S. Broersen, R.L. Zielhuis:** Work hygienic behaviour as modifier of the lead air-lead blood relation. *Int. Arch. Occup. Environ. Health* 62:203–207 (1990).
 - [30] **Aitio, A.:** Biological monitoring of occupational exposure to nickel. In *Nickel in the Human Environment*, Sunderman, F.W., et al. Lyon, France: IARC, 1984. pp. 497–505.
 - [31] **Ramanan, L., C. Jeffrey, and A. Sonbol:** Intervention cost-effectiveness: overview of main messages. In *Disease Control Priorities in Developing Countries*. 2nd ed., Shahid-Salles, R.L. et al. Washington, D.C.: World Bank, 2006.