

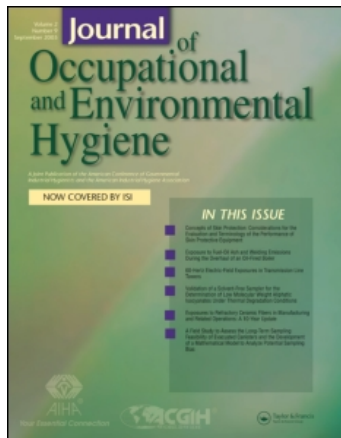
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Publisher Taylor & Francis

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Journal of Occupational and Environmental Hygiene

Publication details, including instructions for authors and subscription information:

<http://www.informaworld.com/smpp/title~content=t713657996>

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First published on: 04 March 2011

To cite this Article Gibb, Herman , Haver, Cary , Kozlov, Kostj , Centeno, Jose A. , Jurgenson, Vera , Kolker, Allan , Conko, Kathryn M. , Landa, Edward R. and Xu, Hanna(2011) 'Biomarkers of Mercury Exposure in Two Eastern Ukraine Cities', Journal of Occupational and Environmental Hygiene, 8: 4, 187 – 193, First published on: 04 March 2011 (iFirst)

To link to this Article: DOI: 10.1080/15459624.2011.556984

URL: <http://dx.doi.org/10.1080/15459624.2011.556984>

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Biomarkers of Mercury Exposure in Two Eastern Ukraine Cities

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This study evaluates biomarkers of mercury exposure among residents of Horlivka, a city in eastern Ukraine located in an area with geologic and industrial sources of environmental mercury, and residents of Artemivsk, a nearby comparison city outside the mercury-enriched area. Samples of urine, blood, hair, and nails were collected from study participants, and a questionnaire was administered to obtain data on age, gender, occupational history, smoking, alcohol consumption, fish consumption, tattoos, dental amalgams, home heating system, education, source of drinking water, and family employment in mines. Median biomarker mercury concentrations in Artemivsk were 0.26 µg/g-Cr (urine), 0.92 µg/L (blood), 0.42 µg/g (hair), 0.11 µg/g (toenails), and 0.09 µg/g (fingernails); median concentrations in Horlivka were 0.15 µg/g-Cr (urine), 1.01 µg/L (blood), 0.14 µg/g (hair), 0.31 µg/g (toenails), and 0.31 µg/g (fingernails). Biomarkers of mercury exposure for study participants from Horlivka and Artemivsk are low in comparison with occupationally exposed workers at a mercury recycling facility in Horlivka and in comparison with exposures known to be associated with clinical effects. Blood and urinary mercury did not suggest a higher mercury exposure among Horlivka residents as compared with Artemivsk; however, three individuals living in the immediate vicinity of the mercury mines had elevated blood and urinary mercury, relative to overall results for either city. For a limited number of residents from Horlivka (N = 7) and Artemivsk (N = 4), environmental samples (vacuum cleaner dust, dust wipes, soil) were collected from their residences. Mercury concentrations in vacuum cleaner dust and soil were good predictors of blood and urinary mercury.

Keywords blood, dust, hair, mercury, nails, soil, urinary

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INTRODUCTION

Mercury (Hg) is recognized as toxic, principally in relation to its effects on humans following acute or prolonged high-level occupational exposures and from a number of environmental incidents. Concern has grown, however, about the potential risks to the human population from current background levels.⁽¹⁾ The Donets Basin in southeastern Ukraine is an area of geologic and industrial sources of Hg. Arsenic, lead, zinc, and cadmium have also been identified as pollutants of concern in this area.⁽²⁾ The Nikitovka mines, the largest source of Hg for the former Soviet Union until they closed in 1991, are located in the city of Horlivka in the Donets Basin.

Kolker et al.⁽³⁾ examined Hg-rich coals in the Donets Basin and collected four samples of coal from the Nikitovka Hg mines. The authors found Hg concentrations in these samples to range from 12.8 to 25.5 ppm. These concentrations are more than 100 times higher than the average Hg concentration of coal mined in the United States.⁽⁴⁾ The Hg content of other coal samples in the Donets Basin were four times the average Hg content of coal in the United States.

Kolker et al.⁽³⁾ reported that there is unrestricted access to the Nikitovka mine, and Hg-rich coals are sometimes collected for domestic use by local residents.

In a previous study of occupationally exposed workers and local residents, blood and urinary Hg, but not hair or nail Hg, were found to be strongly correlated with occupational exposure at a Hg recycling facility in Horlivka.⁽⁵⁾ Although the mean urinary Hg level of the exposed workers did not exceed the World Health Organization-recommended urinary Hg level for occupational exposure of 50 µg/g-Cr,⁽⁶⁾ some workers had urinary Hg levels in the range where subtle neurological effects and proteinuria have been observed.⁽⁵⁾

The purpose of this study is to examine biological indices of community exposure in Horlivka, a city of almost 300,000 and to compare the results with biological samples from Artemivsk, a city of approximately 80,000 population located about 30 km north of Horlivka. Artemivsk is demographically similar to Horlivka but lacks geologic Hg enrichment and does not have a history of Hg production. Human exposure to Hg in Horlivka, a city with a high geologic concentration of Hg, is expected to be primarily that of elemental Hg.

METHODS

The study protocol was approved by an Institutional Review Board at the Institute for Occupational Health, Academy of Medical Science of Ukraine in Kiev. Biological samples (hair, toenails, fingernails, blood, and urine) were collected from 31 residents of Horlivka and 30 residents of Artemivsk to evaluate Hg exposures from different sources. The participants from each city were primarily nurses identified by contact through public health nursing agencies. Some participants were also identified through contact with the nurses (e.g., relative of a nurse). The biological samples were analyzed at the Armed Forces Institute of Pathology in Washington, D.C.

The methods of collection of the biological samples and the Hg analysis of the samples are described in Gibb et al.⁽⁵⁾ Briefly, blood and urine samples were analyzed for total Hg by inductively coupled plasma mass spectrometry with dynamic reaction collision cell (DRC-ICP-MS) (Model Elan 6100 DRC-ICP-MS; Perkin Elmer, Norwalk, Conn.). Hair and toenails were analyzed by cold vapor atomic fluorescence spectrometry (CVAFS) (QuickTrace M-8000 Hg Analyzer; CETAC Technologies, Omaha, Neb.). Questionnaires were administered to each individual to collect information on age, gender, education, home heating source, fish consumption, alcohol consumption, occupational and residential history, smoking history, source of drinking water, tattoos, dental amalgams, and family employment history at coal and Hg mines. Red tattooing ink often contains cinnabar (mercuric sulfide) as pigment, hence, the question on tattoos. Home heating system type was considered to be coal fueled if the respondent specified that their current home heating source was a "coal furnace;" all other heating systems, or nonspecified fuels, were considered to be noncoal. Questionnaires were administered by the study team in Russian, the primary language spoken in eastern Ukraine. The results of the questionnaire were translated and entered in Excel spreadsheets for analysis.

Environmental samples (dust wipes from window panes, both inside and outside; vacuum cleaner dust; and soil) were collected from in and around the homes of four Horlivka residents and four Artemivsk residents. These residences were considered to be generally representative of the residences in the respective cities. The primary difference with respect to residential Hg exposure in Horlivka would be the proximity to the Nikitovka mines.

Three of those who worked at the Hg recycling plant studied by Gibb et al.⁽⁵⁾ but who were not directly involved in the recycling activity also had environmental samples collected from their homes. The environmental results from these three homes were not reported by Gibb et al.; they are reported here as Apartments 1, 2, and 3. These three residents lived within 0.5 km of the Nikitovka mines and recycling facility. The other four Horlivka homes sampled were located 1 to 2.5 km from the mines and recycling facility. Some participants had multiple interior or exterior dust wipe samples taken from their homes. For regression analyses, the Hg concentrations for these samples were averaged to create one value for each medium (interior or exterior dust wipes).

Statistical Analyses

STATA 10 (StatCorp, College Station, Texas) was used to generate descriptive statistics. Mann-Whitney/Wilcoxon rank-sum tests were used to evaluate biomarker differences between cities and between categorical variables. Nonparametric tests were conducted due to the small study size (61 study participants in total) and the convenience sampling selection of study participants. Simple linear regressions were used to evaluate the relationship of environmental samples to the biological samples. Only participants having both environmental and biological data of interest were used in regression analyses.

RESULTS

Table I lists demographic and fish consumption data for the study subjects. No difference between the Horlivka and Artemivsk participants was found with respect to fish meals consumed or their education. Significant differences were found with respect to age and years lived in the city. Study participants from Horlivka had resided there for a significantly longer time than had the Artemivsk participants lived in Artemivsk, reflecting the older age of the participants in Horlivka.

Table II reports median urine and blood Hg by categorical exposure variables for each city. Only two participants had tattoos, so the results for tattoos were not included in the table. In Horlivka, the median Hg levels in urine and blood did not differ significantly by any of the categorical variables. In Artemivsk, the median blood Hg level did not differ significantly by any of the categorical variables, but the median urinary Hg level differed significantly by gender, smoking status, source of water, and alcohol consumption.

The number, mean, median, and range of Hg concentrations in fingernails, toenails, hair, blood, and urine are reported by city in Table III. Individuals in Horlivka had significantly higher fingernail and toenail Hg measurements than those in Artemivsk ($p < 0.001$). Residents of Artemivsk, however, had significantly ($p < 0.01$) higher levels of Hg in hair and urine. The difference between the two cities with respect to blood Hg was not significant.

TABLE I. Median Values for Demographic and Fish Consumption Data for Study Subjects

Continuous Variables	Total	Artemivsk	Horlivka	Mann-Whitney p-value
Age (years)	43.0	37.0	47.0	0.005
Range	16–71	16–57	16–71	
N	61	30	31	
Education (years)	12.0	12.0	12.0	0.59
Range	9–19	9–19	11–17	
N	57	30	27	
Fish meals consumed/week (among those consuming > 1 fish meal/week)	1.0	1.0	1.0	0.57
Range	0–7	0–7	0–5	
N	60	30	30	
Years resided in city	34.0	27.5	40.0	0.0014
Range	7–65	7–51	10–65	
N	61	30	31	

TABLE II. Median Hg Concentrations in Urine and Blood Samples

Categorical Variables	Artemivsk			Horlivka		
	N	Urine (Hg) ($\mu\text{g/g-Cr}$)	Blood (Hg) ($\mu\text{g/L}$)	N	Urine (Hg) ($\mu\text{g/g-Cr}$)	Blood (Hg) ($\mu\text{g/L}$)
Males	4	0.14	1.42	3	0.27	1.20
Females	26	0.29 ^A	0.90	28	0.15	0.99
Smokers (current or previous)	6	0.19	0.93	5	0.09	1.11
Nonsmokers	24	0.29 ^A	0.86	26	0.18	0.99
Had dental amalgams	5	0.30	1.08	4	0.18	1.41
No dental amalgams	25	0.24	0.85	27	0.15	0.99
At least one fish meal/wk	17	0.29	0.90	18	0.14	0.89
Less than one fish meal/wk	13	0.24	0.92	13	0.18	1.20
Current coal furnace	2	0.13	1.25	19	0.18	0.82
Other heat	28	0.28	0.92	12	0.15	1.29
Self or family member ever worked at coal mine	5	0.36	0.93	26	0.16	1.07
Self or family member never worked at coal mine	25	0.24	0.92	5	0.15	1.01
Consumed tap water	27	0.29	0.91	24	0.16	1.00
Consumed well water	3	0.15 ^A	0.94	6	0.16	1.14
Reported alcohol consumption each week	17	0.21	0.91	17	0.14	1.14
Did not report alcohol consumption each week	13	0.41 ^A	0.93	14	0.17	0.72

^AMedians are significantly different based on Mann-Whitney tests, $p < 0.05$.

TABLE III. Hg Biomarker Concentrations in the Total Study Population

		Mercury Concentration				
		Fingernails ($\mu\text{g/g}$)	Toenails ($\mu\text{g/g}$)	Hair ($\mu\text{g/g}$)	Blood ($\mu\text{g/L}$)	Urine ($\mu\text{g/g-Cr}$)
All	N	59	57	61	58	61
	Mean	0.30	0.25	0.42	1.13	0.27
	Median	0.20	0.18	0.24	0.95	0.21
	Min	0.00	0.00	0.00	0.17	0
	Max	2.63	1.14	5.82	7.72	1.28
Artemivsk	N	28	26	30	29	30
	Mean	0.18	0.12	0.64	0.96	0.37
	Median	0.09	0.11	0.42	0.92	0.26
	Min	0.00	0.00	0.08	0.25	0.09
	Max	1.18	0.58	5.82	1.93	1.28
Horlivka	N	31	31	31	29	31
	Mean	0.41	0.35	0.22	1.31	0.18
	Median	0.31	0.31	0.14	1.01	0.15
	Min	0.01	0.00	0.00	0.17	0
	Max	2.63	1.14	1.15	7.72	0.51
Mann-Whitney p-value comparing medians for Horlivka and Artemivsk		0.0001	0.0013	0.0001	0.41	.0027

Figure 1 shows the average Hg concentrations of environmental samples from the homes of four residents of Horlivka and four residents of Artemivsk in the current study, and the three residents of Horlivka (Apartments 1, 2, and 3) from the Gibb et al. study.⁽⁵⁾ Figure 1 also reports average urinary and blood Hg concentrations for the residents from each group. Average Hg concentrations of the environmental, urinary, and blood samples for the four residents from Horlivka were elevated in comparison to those from the four residents of Artemivsk.

The three residents of Apartments 1, 2, and 3 (all female) had the highest average urinary Hg. All three worked at the recycling plant but were not directly involved in the recycling operation. Two individuals worked as cooks; one worked in the human resources department. All three individuals lived within 0.5 km of the Nikitovka mines and recycling facility. The other four Horlivka residents lived 1–2.5 km from the facility.

Simple linear regressions of the various environmental concentrations found that Hg concentration in vacuum dust was significantly associated ($R^2 = 0.99$, $p < 0.001$) with urinary Hg based on nine participants. Soil Hg concentration was also significantly associated with urinary Hg ($R^2 = 0.55$, $p < 0.05$) based on eight participants. The Hg concentration in vacuum dust was of borderline significance with respect to blood Hg ($R^2 = 0.44$, $p = 0.07$). Table IV reports the urinary and blood

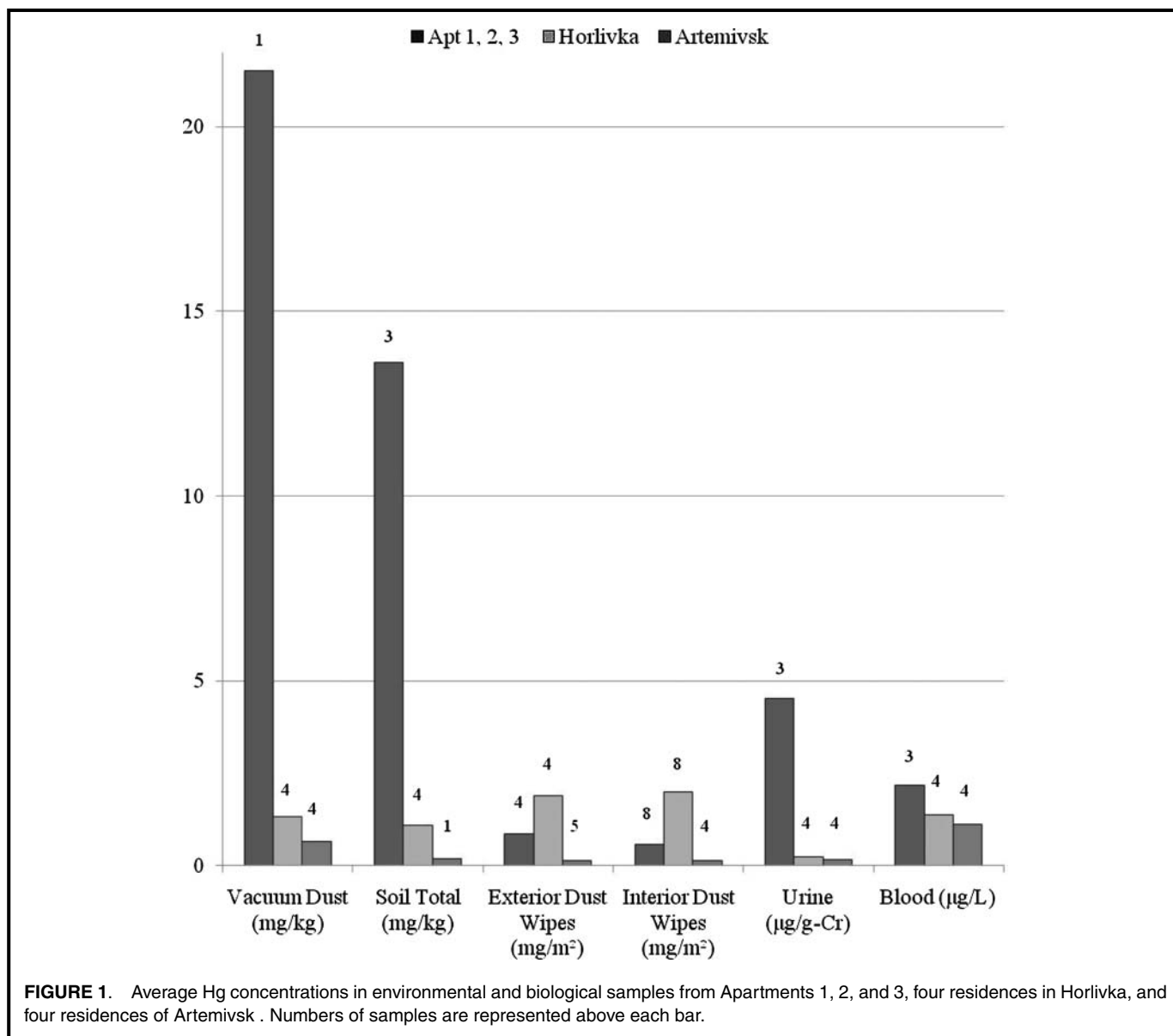
Hg levels and environmental concentration for all subjects included in the regression analysis.

DISCUSSION

Residents of Horlivka were expected to have more exposure to Hg based on their proximity to a former industrial complex, which included a Hg processing facility, the Nikitovka mines, and tailings piles located around the city, compared with Artemivsk. Contrary to expectation, urinary Hg levels in Artemivsk were significantly higher than those in Horlivka. Urinary Hg is considered the best biomarker of elemental and inorganic Hg exposure,⁽⁶⁾ which is the primary environmental exposure that would be expected in Horlivka given its industrial and geologic sources of Hg. Urinary Hg in Artemivsk residents was significantly elevated among those who consumed tap water vs. those who consumed well water and was significantly elevated over those who consumed either well or tap water in Horlivka. If Hg contamination of the tap water supply is occurring in Artemivsk, it could explain the difference between the two cities. Another reason for the surprising results may be that the study participants, primarily nurses, were not representative of the populations of Artemivsk and Horlivka with respect to factors affecting Hg exposure.

TABLE IV. Environmental and Biological Mercury Concentrations Included in Linear Regression Analysis

Group	ID	Vacuum Dust Hg (mg/kg)	Total Soil Hg (mg/kg)	Average Hg		# Exterior Dust Wipe Samples	Average Hg		# Interior Dust Wipe Samples	Blood Hg ($\mu\text{g/L}$)	Urinary Hg ($\mu\text{g/g-Cr}$)
				Exterior Dust Wipes (mg/m^2)	Interior Dust Wipes (mg/m^2)		Interior Dust Wipes (mg/m^2)	Interior Dust Wipes (mg/m^2)			
Apts. 1,2,3	1	21.50	29.00	1.80	0.26	1	0.26	0.26	2	2.63	5.59
	2	—	7.44	0.16	0.50	1	0.50	0.50	3	1.37	2.52
	3	—	4.42	0.61	0.96	2	0.96	0.96	3	2.58	5.48
Artemivsk	22	0.37	0.20	0.13	0.02	1	0.02	0.02	1	1.54	0.24
	24	0.70	—	0.18	0.07	1	0.07	0.07	1	0.96	0.10
	25	0.67	—	0.16	0.12	1	0.12	0.12	1	1.10	0.22
	29	0.86	—	0.12	0.05	2	0.05	0.05	1	0.94	0.15
Horlivka	31	1.42	0.77	0.99	0.98	1	0.98	0.98	2	0.68	0.12
	32	0.82	0.97	0.75	0.53	1	0.53	0.53	3	2.41	0.39
	33	2.18	0.69	—	6.20	—	6.20	6.20	2	.	0.18
	35	0.88	2.00	3.94	0.25	2	0.25	0.25	1	1.01	0.27



The higher hair Hg levels in Artemivsk suggest greater fish consumption in Artemivsk, since hair Hg is considered to be approximately 90% methylmercury (fish mercury).⁽⁷⁾ Table II indicates that the percentage of study participants consuming *at least* one fish meal per week was about the same in Artemivsk and Horlivka; however, study participants in Artemivsk still could have consumed more fish meals per week than participants from Horlivka. Differences in the type of fish consumed (predator fish would contain more methylmercury), the amount consumed, and the source of fish (e.g., local or commercial) could also explain the difference in hair concentrations.

As evidenced by the small sub-sample, environmental samples such as soil and vacuum cleaner dust can be important factors in identifying those with higher exposures. Interpretation of biological measures of mercury was made more difficult

due to the lack of environmental information for all survey respondents.

Urinary Hg concentrations in Horlivka residents in the present study were lower than in Horlivka residents who were not employees of the recycling facility studied in Gibb et al.⁽⁵⁾ Horlivka residents not employed at the recycling facility in Gibb et al., however, lived within 0.5 km of the Nikitovka mines. Other than the four residences where environmental samples were collected (all were 1–2.5 km from the mines), no attempt was made to record location of the residences of the participants from Horlivka in the current study. Horlivka is a relatively large city (approximately 300,000 residents), and study participants may have lived as far as several km away from the Nikitovka mines and the recycling facility.

In the present study, the highest blood Hg concentration (7.7 µg/L) was found in a 38-year-old female from Horlivka whose

husband was a coal miner for 10 years. She reported eating less than one fish meal per week. This blood Hg concentration is higher than the median blood concentration of 2.58 $\mu\text{g/L}$ for those directly involved with Hg recycling in Gibb et al.⁽⁵⁾ Given that Hg concentrations in coal found in the Donets Basin can be unusually high, it is possible that the woman experienced domestic Hg exposure as a result of the husband's employment.

For the few individuals who also had environmental samples collected at their homes, results were generally consistent with expectations. Average Hg concentrations for environmental, blood, and urine samples were higher for the seven Horlivka residents than for the four Artemivsk residents. For the limited number of environmental samples collected, Hg concentrations in soil and vacuum cleaner dust were found to be the best environmental predictors of blood and urinary Hg and better predictors of blood and urinary Hg than demographic and lifestyle factors.

Results of wipe samples did not show a correlation with either blood or urinary Hg. Wipe samples, both inside and outside, were taken from window panes. Cleaning of the windows could have affected the amount of dust present. It would be harder to reduce the Hg concentration in house dust and soil, particularly when the Hg in the soil is constantly being tracked into the house. Similar to the results of Gibb et al.,⁽⁵⁾ Hg exposure in Horlivka appears to be more strongly associated with blood and urinary Hg than with hair and nail Hg. Results of the current study are based on few samples, however, and further study should be undertaken to confirm the results.

Jarosińska et al.⁽⁸⁾ found no association between urinary Hg and living near a Hg-bed chloralkali facility. The authors did find that dental amalgam, chewing on amalgam, and fish consumption were positively associated with urinary Hg. The current study did not find an association of dental amalgam or fish consumption with urinary Hg. However the number of samples in the current study is considerably smaller than that of Jarosińska et al., and a reduced ability to detect modest relationships was expected. The effects of variables such as dental amalgam and fish consumption may make it difficult to discern the contribution from environmental exposures unless efforts such as soil and dust sampling are made to gauge the environmental contribution.

The biomarkers of Hg exposure for the study participants from Horlivka and Artemivsk are low in comparison with those known to be associated with clinical effects. However, there is a growing concern for low-level toxicity of Hg and its potential role in various chronic diseases. A study of children living in France, the Czech Republic, and Poland reported that heavy metals polluting the environment (arsenic, lead, cadmium, Hg) could cause subtle effects on children's renal and dopaminergic systems without clear evidence of a threshold.⁽⁹⁾ The authors found that urinary *N*-acetyl- β -D-glucosaminidase (NAGTU) increased with urinary Hg from concentrations as low as 0.06 $\mu\text{g/g}$ creatinine after adjusting for urinary cadmium. Guided by environmental measurements and questionnaire responses, a population of Hg-exposed children in Horlivka could be identified to further evaluate such effects.

CONCLUSIONS

The present study suggests that environmental samples are helpful in determining biological evidence of Hg exposure. Vacuum cleaner dust and soil Hg proved to be good predictors of urinary and blood Hg concentrations, although a larger sample size is clearly desirable to explore predictive ability in greater depth. Overall, biological markers did not indicate that Hg exposure in Horlivka was an environment with Hg contamination greater than that in Artemivsk, the control. Environmental samples were a better predictor of elevated urinary and blood Hg than was general location (Horlivka vs. Artemivsk).

ACKNOWLEDGMENTS

The authors would like to thank Boris Panov and Yuri Panov of the Donetsk National Technical University, Donetsk, Ukraine; Volodymyr Mukhin, Donetsk Institute of Hygiene and Occupational Health, Donetsk, Ukraine; Chiemeka Chine, The George Washington University, Washington, D.C.; Suzette Morman, U.S. Geological Survey, Denver, Colorado; and Joe Bunnell, U.S. Geological Survey, Reston, Virginia, for their help with this study. The authors would also like to thank the reviewers selected by the *Journal of Occupational and Environmental Hygiene*. This study was supported, in part, by a Cooperative Grant (UKG1-2633) from the U.S. Civilian Research and Development Foundation.

REFERENCES

1. Holmes, P., K.A. James, and L.S. Levy: Is low-level environmental mercury exposure of concern to human health? *Sci. Total Environ.* 408(2):171–182 (2009).
2. Panov, B., A. Dudik, Shevchenko O., et al.: On pollution of the biosphere in industrial areas: The example of the Donets Coal Basin. *Int. J. Coal Geol.* 40:199–210 (1999).
3. Kolker, A., B. Panov, Y. Panov, et al.: Mercury and trace element contents of Donbas coals and associated mine water in the vicinity of Donetsk, Ukraine. *Int. J. Coal Geol.* 79:83–91 (2009).
4. Bragg, L.J., J.K. Oman, S.J. Tewart, et al.: *U.S. Geological Survey Coal Quality (COALQUAL) Database: Version 2.0. Open File Report 97-134, CD-ROM*. Reston, Va.: U.S. Geological Survey, 1998.
5. Gibb, H.J., K. Kozlov, J.P. Buckley, et al.: Biomarkers of mercury exposure at a mercury recycling facility in Ukraine. *J. Occup. Environ. Hyg.* 5:483–489 (2008).
6. World Health Organization (WHO) and United Nations Environment Program (UNEP): *Guidance for Identifying Populations at Risk from Mercury Exposure*. Geneva, 2008.
7. National Research Council (NRC): *Toxicological Effects of Methylmercury*. Washington, D.C.: National Academies Press, 2000.
8. Jarosińska, D., M. Horvat, G. Sallsten, et al.: Urinary mercury and biomarkers of early renal dysfunction in environmentally and occupationally exposed adults: A three-country study. *Environ. Res.* 108(2):224–232 (2008).
9. de Burbure, C., J.P. Buchet, A. Leroyer, et al.: Renal and neurologic effects of cadmium, lead, mercury, and arsenic in children: Evidence of early effects and multiple interactions at environmental exposure levels. *Environ. Health Perspect.* 114(4):584–590 (2006).