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Emotions and personality traits in former mercury miners

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Abstract: The aim of this study is to evaluate the impact of long-term occupational exposure to elemental mercury vapor (Hg°) on the personality traits of ex-mercury miners. The study groups included 53 ex-mercury miners previously exposed to Hg° and 53 age-matched controls. Their previous occupational exposure, as well as some biological indices of actual non-occupational exposure, were evaluated. Miners and controls completed the self-reporting Eysenck Personality Questionnaire (EPQ) and the Emotional States Questionnaire (ESQ). Group differences were analyzed through the application of ANOVA software. The relationship between the indices of previous occupational exposure and the observed personality traits was evaluated by machine learning methods (regression trees). The mercury miners were intermittently exposed to Hg° in intervals – cycles for a period of 7-31 years at air Hg° concentrations ranging from 0.14 to 0.45 mg/m3. The miners' mean cycle urine mercury (U-Hg) level (range 20–120 μg/L) and cumulative U-Hg level (range 1286–21390 μg/L) were very high. The present non-occupational exposure to mercury was very low in both groups. The low extraversion and lie scores shown by ESQ suggest that miners are more introverted and sincere. The results obtained from ESQ indicate that mercury miners tend to be more depressive, more rigid in expressing their emotions (indifference), and are likely to have more negative self-concepts than the controls. The tendency towards emotional rigidity, negative self-concept, and partly also introversion seems to be associated with some biological indices of occupational Hg° exposure, but not the lower score of lie found in miners. Higher occupational Hg° exposure (cycles U-Hg level > 38.7 mg/L) in interaction with moderate alcohol consumption (<26 ml/day) seems to have had a decisive influence on the development of miners' depression. Despite the limitations, long-term intermittent, substantial exposure to Hg° in interaction with alcohol remains a plausible explanation for depression, disposition to emotional rigidity, and negative self-concept found in mercury miners in the period after exposure.

Key words: mercury, occupational exposure, personality traits, emotions

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Čustva ter osebnostne lastnosti bivših rudarjev v rudniku živega srebra

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Povzetek: Namen študije je ugotoviti vpliv dolgotrajne izpostavljenosti elementarnemu živemu srebru na osebnostne poteze nekdanjih rudarjev, ki so delali v rudniku živega srebra. Raziskava vključuje 53 nekdanjih rudarjev, ki so bili predhodno izpostavljeni živemu srebru in 53 udeležencev, ki sestavljajo kontrolno skupino in so izenačeni po starosti in spolu. Ugotavljali so se pretekla izpostavljenost in nekateri biološki kazalci izpostavljenosti, ki niso povezani z delom. Obe skupini sta izpolnili Eysenckov osebnostni vprašalnik (EPQ) in Lestvico emocionalnih stanj (ESQ). Razlike med skupinama so avtorji ugotavljali z ANOVO, povezanost med kazalci pretekle delovne izpostavljenosti in merjenimi osebnostnimi potezami pa z ti. »machine learning« metodami (regresijska drevesa). Rudarji so bili v presledkih izpostavljeni živemu srebru, in sicer v obdobju 7 do 31 let, pri koncentracijah živega srebra, ki so znašale med 0.14 do 0.45 miligramov na kubični meter. Povprečni cikli vrednosti živega srebra v urinu (U-Hg; 20-120 mikrogramov na liter) in kumulativni nivo U-Hg (1286-21390 mikrgramov na liter) so bili zelo visoki. Trenutna izpostavljenost živemu srebru, ki ni povezana z delom, je bila pri obeh skupinah udeležencev nizka. Nizki ekstravertnost in lestvica laži pri rudarjih nakazujeta, da so rudarji bolj iskreni in introvertirani kot njihovi vrstniki iz kontrolne skupine. Rezultati na lestvici emocionalnih stanj pa kažejo, da rudarji bolj težijo k depresivnostni naravnanosti, so bolj rigidni in bolj ravnodušni v čustvovanju. Tendence k emocionalni rigidnosti, negativnejši samopodobi, delno pa tudi nakazana introvertnost so verjetno povezane z nekaterimi biološkimi kazalci poklicne izpostavljenosti živemu srebru. Zdi se, da sta višja poklicna izpostavljenost živemu srebru in interakcija z zmernim uživanjem alkohola odločilnega vpliva za razvoj depresivnostne naravnanosti pri rudarjih, ki se navezujeta tudi na emocionalno rigidnost in negativnejšo samopodobo.

Ključne besede: živo srebro, poklicna izpostavljenost, osebnostne lastnosti, emocije

CC = 3120, 3670

The central nervous system is the critical organ for Hg° vapor exposure (WHO 1976). Post mortem studies (Kosta et al., 1975; Byrne et al., 1995; Falnoga et al., 2000) have shown that the accumulation of mercury in the brains of ex-mercury miners was very high even several years after exposure. Strong mercury accumulation and retention was found, particularly in the hippocampus, cerebellar cortex, nucleus dentatus, pituitary, and also in the pineal gland.

Long-term occupational exposure to Hg° has been found to be associated with symptoms of erethism, characterized by irritability, depression, introversion, apprehension, loss of self confidence, and other non-specific symptoms (Smith et al., 1970;

Gerstner and Huff, 1977; Piikivi and Hänninen, 1989; Chapman et al., 1990; Soleo et al., 1990; Kobal, 1975a, 1991; WHO, 1976, 1991, 2003; Echeverria et al., 1995). In his work entitled "De Hydragyro Idriensi Tentamina Physico-Chymico-Medica" (1771), Scopoli precisely described the symptoms and signs of occupational poisoning with Hg°, and specifically mentions the "unusually sad mental state of these workers".

Only a few studies evaluated the residual, mostly neurological, neurophysiological and neuropsychological effects associated with remote occupational elemental mercury exposure (Albers et al., 1988; Andersen et al., 1993; Ellingsen et al., 1993; Mathiesen et al., 1999; Letz et al., 2000). To our knowledge, only the study of Letz et al. (2000) evaluated residual mood effects in workers previously exposed to Hg°, but the authors state that no changes were observed. An epidemiological study of the causes of death among miners in certain mercury mines (Boffetta et al., 1998) also revealed an increased mortality rate due to suicides among the miners of the Idrija Mercury Mine (unpublished data). Even on the basis of long-term medical monitoring of workers exposed to Hg° (Hribernik, 1950; Kobal, 1975a, 1991), a direct connection between the increased suicidalness of miners and poisoning with Hg° cannot be confirmed. On the other hand, the effects of long-term occupational exposure to Hg° on the personality traits of miners cannot be completely excluded. The purpose of the present study is to evaluate the impact of long-term occupational exposure to Hg° on the personality traits reported by ex-miners in the Eysenck Personality Questionnaire and the Emotional States Questionnaire in the period after exposure.

Method

Participants

120 males were examined in the study. After the selection procedure, the study population comprised 53 ex-mercury miners previously exposed to Hg° and 53 workers in the control group. The study group of miners comprised 33 active miners not exposed to Hg° in the preceding 8 to 60 months, and 20 retired miners who had not been exposed to Hg° before the present observations for a period from 32 to 336 months. The mean age of miners was 47 (range: 31-63), and of control workers 44 years (range: 30-62). The miners were employed in the Idrija Mercury Mine for a period ranging from 7 to 31 years. In the shafts, the miners worked in small groups (3-4 miners). The organization of work in the pit was traditionally coordinated, but nevertheless required constant mutual communication. Mercury miners were intermittently exposed to Hg° in intervals - cycles at air concentrations varying from 0.05 to over 1.00 mg/m3, depending on specific workplaces. When exposure to Hg° exceeded the occupational exposure limit of 0.1 mg/m3, all miners used their personal protective equipment, e.g. half masks or Racal helmets with Hg° absorbing filters, which in miners exposed to higher air Hg° concentrations was not sufficient to prevent in-

creased mercury absorption (Kobal, 1975b; Kobal & Dizdarevič, 1997). The miners were examined in the period after exposure. The interval between the last exposure and the present evaluation (time since last exposure) varied from 8 to 336 months.

The control workers were taken from "mercury-free" works. They performed jobs in the forests as choppers and transport workers. The final selection of the study population was based on medical examinations and some biological analyses performed at the time of the survey. The following criteria were applied:

- mercury miners and control workers were neither currently nor previously exposed to lead, cadmium, or solvents,
- mercury miners should have been intermittently exposed to mercury vapor for at least 3 years or 12 exposures cycles,
- the medical history and medical examinations of the control and mercury miners should not reveal neurological or neuropsychiatrical affections (alcoholism, head traumatism, meningitis, epilepsy, episodes of severe depression), hepatic and renal diseases of known causes or medical treatment which could influence the results of psychological tests (eg, b-blocker, anti-depressive agents, etc.) or those of renal parameters (eg, certain analgesics and antibiotics),
- the research included persons with average cognitive abilities (data taken from the documents of regular medical checks) capable of cooperating in psychological treatment.
- The study was conducted with the approval of the State Ethical Commission and in accordance with the ethical standards laid down by the Declaration of Helsinki. All participants gave informed consent before being included in the study.

Medical and psychological examination

The medical examination included the determination of general clinical status of examinees' medical history and lifestyle habits (smoking, alcohol consumption). The self-reported mean alcohol consumption was converted to units of pure alcohol in ml per day. A dental amalgam score was calculated using the methodology proposed by Aposhian et al. (1992). The examination included venous blood and urine sampling for determination of: (1) blood total (BT-Hg) and methyl mercury (Me-Hg), urine mercury (U-Hg); (2) selected hematological data (erythrocytes, erythrocyte sedimentation rate, hematocrit, hemoglobin in blood, leucocytes, MCH, MCHC, MCV, reticulocytes, thrombocytes, differential leukocyte count); (3) selected blood and urinary data of kidney urinary tract disorders (creatinine and urea in blood, urine test strip analyses, urine albumin and creatinine) and (4) serum gamma glutamiltransferase (GGT), aminotransferases (ALT, AST), bilirubin, blood glucose and c-reative protein. The examinations were performed by a physician – occupational medicine specialist with long-term experience in the health surveillance of workers exposed to Hg°, in line with the standard clinical methodology. They were carried out at the Medical department of individual plants. The overall examination time took approximately 120 min. per subject, including the time required for instructions on how to perform the tests.

All participants completed a Slovene translation (Lojk, 1981) of the Eysenck Personality Questionnaire (EPQ; Eysenck and Eysenck, 1975) and the Emotional States Questionnaire (ESQ; Lamovec, 1989). The collected data proved the EPQ questions to be appropriate for the Slovene population, as they were for the British and Danish (Eysenck and Eysenck, 1975; Mortensen et al., 1996) populations. The personality structure appears to be similar in spite of the differences in nationality (Lojk, 1981). The self-administrated Emotional State scales include 54 emotional descriptors, which are rated on a 4-point scale from ‘none at all’ to ‘extreme’. The items comprise six emotional states: depression, contentment, aggression, indifference (tendency to emotional rigidity) and self-concept (positive and negative). The ESQ has a very similar theoretical view, as presented in the study of Sjöberg and Svenson (1976) and based on the study results of the Slovene population (Lamovec, 1988). The factor analysis of primary emotions showed that the depression indicated in our questionnaire is in conformity with the clinical description of this condition, which, apart from depression, also includes elements of anxiety (Lamovec 1989). The metric characteristics of ESQ presented in Table 1 suggest that the questionnaire is appropriate for further analysis. Measures of internal reliability, such as the Cronbach alpha coefficient (Vogt, 1993) and the Guttman split-half coefficient, show the consistency or stability of a measure of the test from one use to another. Both are relatively high (ranging from 0.65 to 0.89). Since reliability is associated with accuracy of the test, ESQ may be ranked among those psychometric tests with higher reliability.

Table 1. Reliability coefficients of ESQ.

		Guttman split-half
Depression	0.85	0.83
Contentment	0.86	0.87
Aggression	0.68	0.65
Indifference	0.67	0.67
Positive self-concept	0.71	0.65
Negative self-concept	0.71	0.73
Total	0.89	0.84

Assessment of exposure

Environmental and biological data on the group of miners studied were collected from 1959 onwards from workload records, daily reports on Hg° measurements in the workplace, personal medical records and biological monitoring data (Kobal & Dizdarevič, 1997). Since 1959, the miners were biologically monitored by means of urine mercury (U-Hg) analyses. On the basis of 5452 U-Hg measurements of miners' urine spot samples performed before during and after cessation of exposure intervals, some biological occupational Hg° exposure indices were calculated.

On the basis of exposure records, the following parameters of the duration and level of exposure were calculated for each miner following environmental indices of Hg° occupational exposure: (1) years of work in the mercury mine (years of exposure), (2) cycles of exposure (intervals of work at exposure to Hg°), (3) average time-weighted (ATW) air Hg° concentration expressed in mgHg0/m^3 air (Kobal, Dizdarevič, 1997). Due to the use of personal protective equipment, the external exposure indices were used as a rough estimate of exposure to Hg°.

The U-Hg concentrations determined during occupational biological monitoring of each exposed miner were used to calculate the following biological indices of occupational exposure: (1) geometrical mean of cycles U-Hg level, calculated from all urine samples determined before and during the cycles of exposure (including samples from the period of half-time elimination of Hg in urine) expressed in mgHg/L, (2) the geometrical mean of cycles peak U-Hg level, calculated from all cycles peak U-Hg levels expressed in mgHg/L, (3) cumulative U-Hg level (the sum of all cycles U-Hg levels) expressed in mgHg/L, (4) U-Hg level at the last exposure expressed in µgHg/L. The present background exposure to Hg° was evaluated by determining the total mercury in blood (BT-Hg) and urine (U-Hg). The potential methyl mercury exposure (from fish intake) was evaluated by determining methyl mercury in blood (B-MeHg).

Analysis of Hg° in air at the workplace

Hg° in the air within the mine was generally determined by UV photometry using two portable instruments (Beckmann Mercury Vapor Meter (K-23) and a Mercury Vapor Indicator (MVI Shawcity, with a range of 0-2 mg/m3, sensitivity 1 mg/m3 and repeatability ± 5 %).

Biological analyses

B-THg and U-Hg were determined by cold vapor atomic absorption spectrophotometry (CVAAS). The limit of detection of B-THg was 0.05 mgHg/ml of blood. The actual U-Hg concentration was analysed in an 8-hour urine sample, collected in a metal-free polypropylene tube during the night (22:00–6:00 h). The detection limit of mercury in a 0.5 ml urine sample was 0.05 mg (Horvat et al., 1996; Horvat et al., 1991). Urinary mercury was expressed in μg/g creatinine. Before 1970, U-Hg was analyzed using the dithizone method, and after that by means of the above-mentioned CVAAS technique expressed in mg/L. Monomethyl mercury in whole blood (B-MeHg) was determined by acid leaching/solvent extraction/aqueous phase ethylation/isothermal GC/CV AFS detection (Liang et al., 1994; Horvat et al. 2000). The limit of detection was 0.01 ng/ml of blood. Urine albumin levels were assessed by immunonephelometry (Behring, BNII), as described in previous publications (Kobal et al., 2000). Creatinine in urine was measured on a Roche/Hitachi 917 automated biochemical analyser (Roche, Mannheim, Germany). Overall CVs were <2.5 %, sensitivity 8.8 mmol/L. The other basic routine biochemical and hematological parameters were determined by applying the usual clinical biochemical methods (data not presented).

Data analyses

Group differences of all observed parameters were evaluated by the application of an analysis of variance using one-way ANOVA software. The relationship between exposure and other variables was evaluated by means of Pearson's correlation coefficient, which reflects the degree of linear relation between two sets of data. For all computations we used the SPSS for windows (Standard version, sep. 2001). To find possible explanations of associations between the target variables (personality traits) and biological indicators of occupational Hg° exposure in combination with covariables, we used machine learning methods such as model trees (Quinlan 1992), a program for inducing regression trees.

The *M5' Program for Inducing Regression trees* is a representation for piece-wise constant or piece-wise linear functions. Like classical regression equations, these predict the value of a dependent variable (called class) from the values of a set of independent variables (called attributes). Data represented in the form of a table can be used to learn or automatically construct a regression tree. In the table, each row (example) has the form (x1, x2, ..., x*N*, y), where x are values of *N* attributes (e.g., subjects' age, daily consumption of alcohol, etc.) and y is the value of the class (e.g., the EPQ psychoticism score). Unlike classical regression approaches, which find a single equation for a given set of data, regression trees partition the space of examples into axis-parallel rectangles and fit a model to each of these partitions. A regression tree has a test in each inner node which tests the value of a certain attribute, and in each leaf a model for predicting the class: the model can be a linear equation or merely a constant. Trees that can have linear equations in leaves are also called model trees.

Given a new example for which the value of the class should be predicted, the tree is interpreted from the root. In each inner node, the prescribed test is performed and according to its result, the corresponding left or right sub-tree is selected. When the selected node is a leaf, the value of the class for the new example is predicted according to the model in the leaf. Tree construction proceeds recursively, starting with the entire set of training examples (entire table). At each step, the most discriminating attribute is selected as the root of the (sub)tree and the current training set is split into subsets according to the values of the selected attribute. For discrete attributes, a branch of the tree is typically created for each possible value of the attribute. For continuous attributes, a threshold is selected and two branches are created based on that threshold.

Technically speaking, the most discriminating discrete attribute or continuous attribute test is the one that reduces to the greatest degree the variance of values of the class variable. For continuous attributes, the values of the attribute appearing in the training set are considered thresholds. For the subsets of training examples in each branch, the tree construction algorithm is called recursively. Tree construction stops when the variance of class values of all examples in a node is small enough (or if some other stopping criterion is satisfied). Such nodes are called leaves and are labeled with a model (constant or linear equation) for predicting class value. An important mechanism used to prevent trees from over-fitting data is tree pruning. Pruning can be employed during tree construction (pre-pruning) or after the tree has been constructed (post-pruning). Typically, a minimum number of examples in branches can be prescribed for pre-pruning and the confidence level in error estimates in leaves for post-pruning.

There are a number of systems for inducing regression trees from examples, such as XART (Breiman et al., 1984) and M5 (Quinlan, 1993). M5 is one of the most well-known programs for regression tree induction. We used the M5' system (Wang and Witten, 1997), a re-implementation of M5 within the software package WEKA (Witten and Frank, 1999). The parameters of M5' were set to their default values, except where described differently in this text.

A model tree was induced on the following features: groups (ex-miners - underground work; controls - work in the open), subgroups (active mines, retried miners), age, residence (municipality of Idrija - other location; town centre - hillside) dental amalgam score, cigarettes per day, alcohol consumption (ml/day), albumin in urine g/mol creatinine (potential marker of Hg exposure effect), years of work in mercury mine (years of exposure), work cycles of Hg exposure (number), the geometrical mean of cycles U-Hg level mg/L, the geometrical mean of cycles peak U-Hg level, cumulative U-Hg level mg/L, U-Hg level at the last exposure mg/L, time since last exposure in days (exposure free interval), and the selected personality traits score. Those miners with an exposure free interval below 12 months were excluded from the evaluations. To stress the significance of the last exposure in these evaluations, we ignored the U-Hg value of the last exposure under 10 g/L in five miners.

Results

Characteristics of miners and controls

The majority of miners included in the study were inhabitants of the municipality of Idrija (94 %), residing in the very town center of Idrija, which means that about 58 % of miners lived in the town environment, and the remaining 42 % in settlements and villages surrounding the town. Approximately 20 % of workers from the control group lived in the municipality of Idrija, whereas the remainder lived in neighboring municipalities. The share of workers living in the town environment was practically the same (55 %) in both groups. In addition, all workers of the control group were miners of male gender. The share of workers with vocational qualifications was greater in the control group (60 %) than among miners (53 %), whereas the share of workers with secondary education was lower in the control group (1.8 %) than among miners (13 %). The personal income of miners was 15 to 20 % higher than that of workers in the control group. The group of miners included as many as 80 % married persons, and 74 % of their families had two or more children. The number of married persons in the control group was slightly lower (72 %), whereas the share of families with two or more children was slightly higher (80 %).

Table 2 presents some other characteristics of both groups. The observed groups did not differ in mean age, body mass index (BMI), dental amalgam score, fish intake, cigarette and alcohol consumption, B-THg and B-MeHg concentrations.

Table 2. Characteristics of observed groups.

	Miners (n = 53)		Controls (n = 53)		
	Mean	*SD*	*Mean*	*SD*	*p*
Age	47.32	9.90	44.64	8.54	0.072
BMI (kg/m^2)	27.80	4.10	27.40	4.10	0.536
Dental amalgam score	12.80	12.40	12.50	10.90	0.912
Fish meals per week	0.52	0.96	0.59	0.88	0.649
Cigarettes/d[1]	21.60	7.30	20.50	9.50	0.693
Alcohol ml/d[2]	35.20	40.20	22.40	18.60	0.099
B-THg (g/L)	2.50	1.50	2.50	1.20	0.158
B-MeHg (g/L)	1.09	0.92	1.21	1.00	0.237
U-Hg (g/g createnine)	2.10	1.40	1.40	1.10	0.003

[1] % of smokers: miners 59 %, controls 41 %

[2] % of alcohol consumers over 20 ml/day: miners 28 %, controls 19 % ($p>0.05$) (Gerchow J, Schrappe O. Alkoholismus. Köln: Deutscher Arzte-Verlag, 1989.p.48)

The mean consumption of alcohol tended to be higher in miners (35 versus 22 ml/day). The number of alcohol consumers with over 20 ml/day was higher in miners (28 % versus 19 %), but no significant differences between the two groups were detected (p>0.05). At these levels of alcohol consumption, the induction of the microsomal ethanol-oxidizing system – MEOS and the increased activity of certain liver enzymes may be expected (Marks et al., 1996) but no differences in mean serum GGT, ALT and AST activity (p>0.05) between the two groups were detected (data not presented). The dental mercury amalgam score in controls correlated with T-BHg (r=0.30, p=0.04); no such correlation was found in the group of miners. Only the U-Hg concentration (µg/g creatinine) from 8-hour urine samples was significantly higher (p = 0.003) in the miners' group than in the control group.

Occupational Hg° exposure status

Mercury miners were observed in the period after long-term intermittent exposure to Hg°, which lasted 7 to 31 years. Prior to the present observations, the miners had no longer been exposed to Hg° for on average 5.9 years (range: 8 to 336 months). The total number of exposure intervals - cycles of exposure - varied from 13 to 119. On average, the miners' cycles of Hg° exposure lasted 19 days (range: 3-34 days). The biological indices of occupational exposure presented in Table 3. were high in spite of the use of personal protective equipment. The geometrical mean of cycles of U-Hg levels varied from 20 to 120 mg/L. The U-Hg level at the last exposure also showed a broad individual range (8-135 mg/L). No correlation was found between the present U-Hg level and previous occupational biological exposure indices evaluated by means of Pearson's correlation coefficient.

Table 3. External and biological indices of previous occupational Hg° exposure in miners (N=53).

	Geometrical Mean	*SD*	*Range*
Years of exposure	14.6	5.5	7 – 31
Cycles of exposure	41	21	13 –119
ATW air Hg° concentration mg/m^3	0.29	0.08	0.14 – 0.45
Cycles U-Hg level (g/L)	53.1	20.5	20 –120
Cycles peak U-Hg level (g/L)	77.2	23.0	40 –134
Cumulative U-Hg level (g/L)	6584	4444	1286 - 21390
Last exposure U-Hg level (g/L)	26	29	8 – 135

For abbreviations, see the Subjects and Method section.

Psychological evaluation

Table 4 presents the Eysenck Personality Questionnaire. A comparison of the group of miners and the control group revealed a lower mean score of extraversion in the group of miners ($p = 0.017$). The average score on a lie scale was also lower in the group of miners ($p = 0.003$).

Table 5 presents the Emotional State Questionnaire. The average scores for depression and negative self-concept were significantly higher ($p<0.01$) in miners than in controls. The indifference average score also tended to be higher in miners ($p=0.025$) in comparison to the controls. No correlation between scores of EPQ and ESQ variables, or between indices of past exposure or alcohol consumption evaluated by means of Pearson's correlation coefficient were detected, probably due to the non-linear relationship between these variables.

Table 4. Average scores on the Eysenck Personality Questionnaire (EPQ) of observed groups.

	Miners (n = 53)		Controls (n = 53)		
EPQ	*Mean*	*SD*	*Mean*	*SD*	*p*
Psychoticism	3.80	2.37	3.74	2.06	0.905
Extroversion	12.09	3.81	13.93	3.15	0.017
Neuroticism	8.14	4.27	7.55	4.21	0.522
Lie	12.45	4.22	15.05	3.54	0.003

For abbreviations, see the Subjects and Method section.

Table 5. Average scores on the Emotional State Questionnaire (ESQ) of observed groups.

	Miners (n = 53)		Controls (n = 53)		
ESQ	*Mean*	*SD*	*Mean*	*SD*	*p*
depression	20.33	5.07	17.73	3.61	0.009
contentment	30.52	4.97	31.05	6.06	0.667
aggressions	17.17	4.20	15.95	2.71	0.122
indifference	9.74	2.73	8.51	2.11	0.025
positive self-concept	15.52	3.16	16.51	2.91	0.143
negative self-concept	8.98	2.51	7.68	1.71	0.008

For abbreviations see Subjects and Method section.

The M5 pruned models built for extroversion, lie, depression, indifference and negative self-concept score are presented in Tables 6, 7, 8, 9 and 10, respectively. The model describing extroversion score presented in Table 6. consists of a single linear equation LM1 (a model tree with a single leaf node) comprising the following features: groups, age, years of work in the mercury mine, cumulative U-Hg level, U-Hg level at last exposure, and alcohol consumption per day. Evidently, the "extroversion score" is associated with the sub-groups of retired miners and control groups. Years of work in the mercury mine and alcohol consumption increased the extroversion score. Age, cumulative U-Hg level and U-Hg level at last exposure tended to decrease the extraversion score.

The model describing lie score presented in Table 7 consists of a single linear equation comprising age and place of residence. We can see that the lie score increases with age and decreases in miners living in the center of Idrija (55 % of miners), but it is not related to the occupational exposure indices.

Table 6. Linear regression model constructed by M5', describing the extroversion score and its correlation coefficient.

Linear Regression Model

extroversion_score =

2.9701	× group = retired miners, controls +
-0.1642	× age_in_years +
0.1891	× years_ of_ work_in_mercury_mine +
-0.0002	× cumulative_uhg_level_ g_L +
-0.0198	× uhg_at_last_exposure_ g_L +
0.15	× alcohol_consumption_ml_per_day +
17.7282	

$r = 0.43$

The model tree predicting the depression score presented in Table 8 contains four leaves, of which three contain constant predictions and one linear model. It is evident from the LM1 model, which was based on a larger number of subjects (39 controls and 9 miners), that low alcohol consumption (<26.6 ml/day) at a lower level of occupational exposure (mean cycle U-Hg <38.7 μg/L) did not increase the depression score. Models LM2 and LM3 relate to an increased depression score in 28 miners at a higher level of exposure (male cycles U-Hg >38.7 μg/L). A higher consumption of alcohol (per se) (>26.6 ml/day) tends to increase the depression score in 14 miners and 10 controls.

Table 7. Linear regression model constructed by M5', describing the lie score and its correlation coefficient.

Linear Regression Model

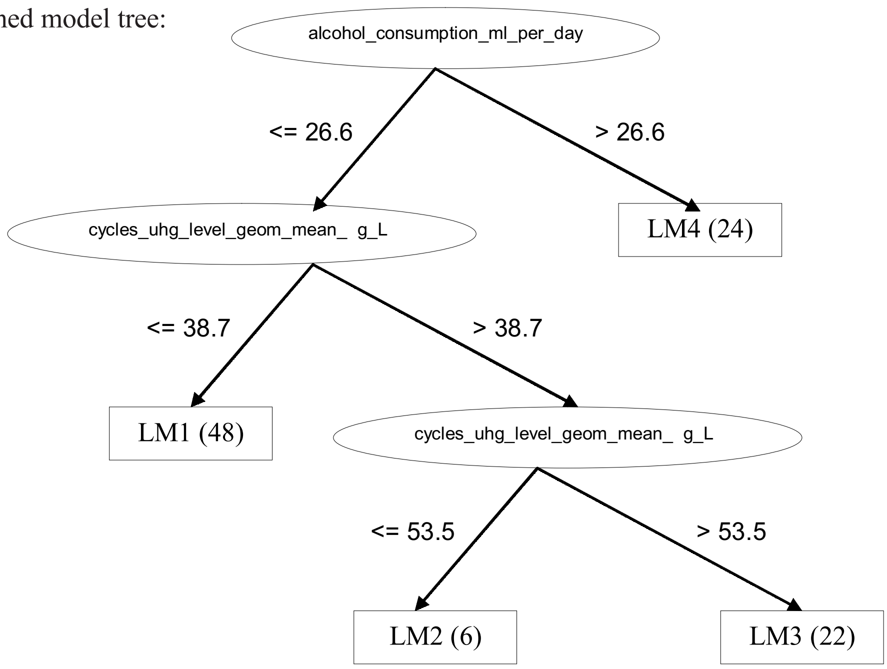
lie_score =

0,1374 × Age_in_years +
2,6639 × residence_in_town_centre +
5,9845

r = 0.452

Table 8. Model tree (with 4 linear models) constructed by M5', describing the depression score and its correlation coefficient. The number of subjects in each leaf is given in parenthesis.

M5 pruned model tree:



LM1: Linear Regression Model
depression_score = 17.9792
LM2: Linear Regression Model
depression_score = 24.8333
LM3: Linear Regression Model
depression_score = 19.3636
LM4: Linear Regression Model

depression_score =

-0.7987 ´ dental_amalgam_score +
0.1671 × cigarettes_per_day +
20.1545

r = 0.537

The indifference score described by the model and presented in Table 9 consists of a single linear equation comprising group, age, the mean of cycles and the mean of cycles peak U-Hg level, U-Hg level at last exposure, and cigarette consumption per day. We can see that the indifference score is typical for the ex-miners' group. All mentioned variables increased the observed score, except the mean of cycles peak U-Hg levels, which does not seem to represent the miners' integral occupational exposure level.

Table 9. Linear regression model constructed by M5', describing the indifference score and its correlation coefficient.

Linear Regression Model

indifference_score =

1.8823	× group = miners, retired miners +
0.0538	× age_in_years +
0.0331	× cycles_uhg_level_geom_mean_ g_L +
-0.0469	× cycles_peak_uhg_level_geom_mean_ g_L +
0.0201	× uhg_at_last_exposure +
0.0607	× cigarettes_per_day +
5.7682	

r = 0.424

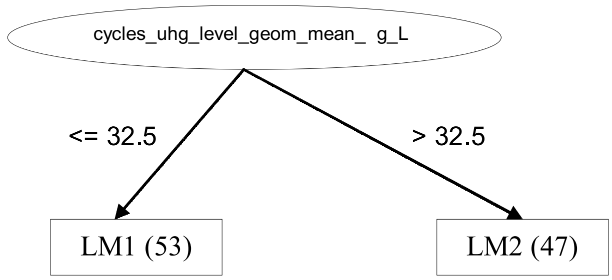
The model tree predicting the negative self-concept score presented in Table 10 contains two leaves with one linear model. Model LM1 represents the controls (N=53) with a relatively lower score. Age and alcohol consumption partly increased their negative self-concept score. LM2, which represents the ex-miners (N=47, only miners with "last exposure" U-Hg >10 μg/L), relates the negative self-concept score to mean cycles of U-Hg level (>32.5 μg/L) and U-Hg level at last exposure. In these cases as well, the mean cycles peak U-Hg level did not increase the observed score.

Discussion

In both groups the present levels of B-THg and B-MeHg were at a level of around 2 μg/L, an average level in the general population that is not associated with particular actual sources of mercury exposure (Nordberg et al., 1992). The present U-Hg concentration was unexpectedly low in observed miners (mean 2.1, range 0.2–7.5 μg/g creatinine), but still significantly higher (p=0.003) than in the controls. In some studies (Schaller et al., 1983; Yamamura, 1990), the U-Hg level in non-occupationally ex-

Table 10. Model tree (with 2 linear models) constructed by M5', describing the negative self-concept score and its correlation coefficient. The number of subjects in each leaf is given in parenthesis.

M5 pruned model tree:



LM1: Linear Regression Model

negative_self-concept_score =

$0.0465 \times$ age_in_years +
$0.0254 \times$ alcohol_consuption_ml_per_day +
5.3991

LM2: Linear Regression Model

negative_self-concept_score =

$-0.0455 \times$ cycles_peak_uhg_level_geom_mean_µg_L +
$0.0248 \times$ uhgl_at_last_exposure_µg_L +
12.3991

$r = 0.498$

posed subjects was generally below 5 µg/L, while in other studies (Minoia et al., 1990) the mean U-Hg level was 3.5 µg/L. It is obvious that the present U-Hg poorly reflects the accumulation and retention of Hg° from miners' previous exposure. This is in accordance with the elimination kinetics of mercury in urine shortly after exposure observed in some studies (Piotrowski et al., 1975; Cherian et al., 1978; Barregard, 1992; Kobal et al. 1999), although it seems that the long-term elimination kinetics of mercury in the brain and kidneys is not well elucidated (Takahata et al. 1970; Kosta et al. 1975; Nylander et al. 1991; Falnoga et al. 2000).

In any case, the presented biological indicators of occupational exposure are the only reliable evidence (there currently being no other!) that the miners from our study were actually exposed to Hg° in the past. Those biological indicators of occupational exposure also provide a quite reliable definition of the degree of exposure or the received internal doses of Hg° during previous exposure. It is known that the oxidation process of Hg° in blood is dose dependent (Halbach, Clarkson 1978, Magos et al. 1989, Kobal 1991). Unoxidised Hg° can be oxidized and become trapped in the brain (Clarkson 1989). Taking into account the above-mentioned facts and results of quoted post-mortem studies in ex-mercury miners (Kosta et al. 1975, Byrne et al. 1995, Falnoga et al. 2000), we can presume that the accumulation and retention of mercury in the miners' central nervous systems and kidneys during occupational exposure was very high.

Alternations of emotional state, mood and some unspecific symptoms were most frequently observed at U-Hg levels ranging between 30-100 µg/L (Gerstner and Huff, 1977; Camerino et al., 1981; Piikivi et al., 1984: Piikivi and Hänninen, 1989), while in some studies they were also observed at lower levels of occupational exposure at U-Hg mean levels ranging from 30 to 40 µg/L (Soleo et al., 1990; Echeveria et al., 1995). In the study of Soleo et al., 1990 and Echeverria et al., 1995, the personalities of exposed workers was found to be considerably changed at lower levels of occupational exposure, whereas certain mood measures were associated with Hg exposure. In patients not occupationally exposed to Hg° who attributed their illness to mercury from amalgam fillings, a subtle pre-clinical effect on mood (Echeveria et al., 1998), depression, less extroversion and more emotional liability were detected (Grandjean et al., 1997).

In our present study, the lower EPQ score of extraversion found in mercury miners suggests that miners are less outgoing, less sociable and more introverted than the control group. However, it is evident from the regression model that extraversion seems to be properly associated with retired miners and controls, decreasing with age cumulative U-Hg level and U-Hg at last exposure. Years of work and alcohol consumption slightly increase extroversion. The latter is apparently connected with the acute, short-term effects of alcohol. The influence of age to extraversion in males had also been reported in other studies (Eysenck and Eysenck, 1975; Lojk, 1979), but less is known about late impacts of occupational exposure. The lower score on the lie scale (EPQ) of mercury miners is not associated to Hg° exposure, but suggests that the answers obtained from miners could be considered more valid in comparison to the controls. This could also mean that sincerity is one of the most important personality characteristics enabling miners to preserve their collaborative and team working spirit.

The results obtained from the ESQ showed some significant differences between miners and the control group. Mercury miners tend to be more depressive, more rigid in expressing their emotions, and are likely to have a more negative self-concept than the members of the control group. From the regression tree we can see that permanent increased alcohol consumption per se (> 26 ml/day) increases depression in both miners and controls, which is also known from other studies (Schuckit, 1986; Leibenluft et al., 1993). Lower permanent alcohol consumption (< 26 ml/day) associated with long-term higher occupational Hg° exposure (cycles U-Hg level > 38 μg/L) seems to increase the miners' depression score. The relative indifference (emotional rigidity) expressed by the indifference score is a common characteristic of all miners. This is also slightly increased by the level of internal Hg° doses received during previous occupational exposure (geometrical mean U-Hg level, U-Hg of last exposure). The Indifference established in miners in the period after exposure is in genuine contradiction to the known emotional lability that is typical for the state of increased absorption and chronic occupational intoxication with Hg°. From the regression tree we can see that the internal doses received during occupational exposure, expressed by the geometrical mean U-Hg level (> 32 mg/L) and U-Hg at last exposure, appear to be the factor most strongly associated with miners' negative self-concept.

The results obtained from EPQ and ESQ in the present study could be party compared to the personality changes in workers during low-level Hg° occupational exposure (Soleo et al., 1990, Echeverria et al., 1995), and non-occupational exposure (Grandjean et al., 1997). Only a few investigations using the measurements of neuropsychological effects to study workers previously exposed to Hg° are available to our knowledge (Kishi et al., 1994; Mathiesen et al., 1999; Lezt et al., 2000). Mood scales (tension, depression, anger, fatigue and confusion) were applied only in the study of Letz et al. (2000), but no residual mood changes with depression have been observed.

Some studies have reported a decreased nocturnal melatonine concentration in the blood of a depressed patient (Noir et al. 1984; Beck-Friis et al. 1985). In our miners, however, we detected precisely the opposite, i.e. an increased concentration of melatonine in morning blood samples; these results have been presented elsewhere (Kobal et al., 2002). Despite the fact that work in the mine is conducted with relatively good local lighting and not in the dark, we cannot completely exclude the effect of "darkness" on the synthesis of melatonine (Durlach et al., 2001). Theoretically, consideration should also be given to the potential impacts of mercury on the metabolism of neurotransmitters (Mottet et al., 1997)) and the impacts of increased accumulation of mercury in the pineal gland itself (Kosta et al. 1975; Falnoga et al. 2000), which might also influence the synthesis of melatonine and, indirectly, the balance of serotonin (Kasper et al., 1996). The disturbance of this balance, serotonin – melatonin, can, in the opinion of certain researchers (Heeringen, 2001), influence the occurrence of depression and low self-concept (Kobal, 2000; Kobal Grum, 2003). In evaluating the potential synergy neurotoxic impacts of alcohol and mercury, which, in the opinion of certain authors (Marks et al. 1996; Halliwel & Gutteridge, 1989; Lund et al., 1993; Salonen et al. 1994; Mottet et al., 1997), are connected with the increased production of free radicals and a decreased level of antioxidative capacity, we must nevertheless take into account the indirect effects of alcohol resulting from interaction with catalase. It is alcohol that enables the increased transition (passage?) of non-oxidised mercury into the brain (Nilsen-Kudsk, 1973; Magos et al., 1978).

Despite the above-mentioned theoretical outline, our results suggest that emotional rigidity, depression, negative self-concept, and partly also introversion, which characterise the personalities of miners, may be associated with long-term substantial occupational exposure to Hg°. We presume that the mutual interaction of long-term increased exposure to Hg° and long-term "moderate" alcohol consumption has had a decisive influence on the development of depression in the miners observed.

This depressive mood itself could, as a result, increase the risk of suicide among miners of the Idrija Mercury Mine. Other studies (Kobal Grum, 2003) also indicate that a low or negative self-concept could be a significant factor for suicidalness. However, the increased mortality due to suicides among miners of the Idrija Mercury Mine in the last 40 years (standardized mortality rate 123.95 %, confidence interval 88-168; unpublished data) cannot completely confirm the relation between occupational exposure to Hg° and depression as one of the potential causes of suicidal behavior. This is primarily because the results of the epidemiological study on the mortality of miners in four mercury mines (Boffeta et al., 1998) are not consistent, probably due to errors in the classification of the cause of death in some countries, or due to variations in psychosocial or genetic risk factors (Marušič & Farmer, 2001).

Despite the limitations, long-term intermittent substantial exposure to Hg° in interaction with alcohol remains a plausible explanation for depression, disposition to emotional rigidity, and negative self-concept established by the present study in mercury miners in the period after exposure. This study thus further supports efforts to reduce the occupational and non-occupational exposure levels of Hg°, in our case the U-Hg level, to the lowest observed adverse effect level (UNEP, 2002; WHO, 2003) capable of preventing the late effects of Hg° exposure on the potential development of depression, emotional rigidity and negative self-concept, which can significantly decrease resistance towards psychosocial stress factors.

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