Relating personality traits and mercury exposure in miners with machine learning methods

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Abstract
We use machine learning/data mining methods to analyse scientific data in the area of environmental epidemiology, i.e., the study of the influence of environmental factors on human health. In particular, the aim of this study was an evaluation of the impact of long-term past occupational exposure to elemental mercury vapour (Hg°) on the mental health, i.e., personality traits of ex-mercury miners. The study groups included 53 ex-mercury miners and 53 age matched controls. The collected data included indices of previous occupational exposure to Hg°, medical history and lifestyle habits and some biological indices of actual non-occupational exposure.

The variables of interest were personality traits as defined by the Eysenck Personality Questionnaire (EPQ) and Emotional States Questionnaire (ESQ) in the period after exposure. For example, these variables include scores for traits such as depression and negative self-concept. Statistical analyses were performed to determine if there are significant differences between the values of the scores for ex-miners and controls.

For the psychological traits for which significant differences were found between ex-miners and non-miners, we performed regression analysis. The target variables were the personality trait scores, while the independent/explanatory variables were the indices of previous occupational exposure to Hg°, medical history and lifestyle habits and some biological indices of actual non-occupational exposure. Regression/model trees were used to perform the analyses and revealed many interesting findings, e.g., that alcohol consumption and mercury exposure increase the depression score.

1 Introduction
The central nervous system is the critical organ for Hg° vapor exposure [71]. Post mortem studies [37, 7, 17] 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 [66, 18, 57, 9, 65, 29, 31, 71, 72, 73, 13]. In his work entitled “De Hydragyro Idriensi Tentamina Physico-Chymico-Medica” [63], 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 [1, 2, 15, 48, 40]. To our knowledge, only the study of Letz et al. [40] 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 [5] 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° [26, 30, 31], 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.

2 Subjects and methods
2.1 Subjects
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 pre-
Mercury miners were intermittently exposed to Hg\textsuperscript{2+} 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: 31-63). 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\textsuperscript{2+} in intervals - cycles at air concentrations varying from 0.05 to over 1.00 mg/m\textsuperscript{3}, depending on specific workplaces. When exposure to Hg\textsuperscript{2+} exceeded the occupational exposure limit of 0.1 mg/m\textsuperscript{3}, all miners used their personal protective equipment, e.g., half masks or Racal helmets with Hg\textsuperscript{2+} absorbing filters, which in miners exposed to higher air Hg\textsuperscript{2+} concentrations was not sufficient to prevent increased mercury absorption [29, 32]. 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 neuropsychiatric affections (alcoholism, head traumaism, meningitis, epilepsy, episodes of severe depression), hepatic and renal diseases of known causes or medical treatment which could influence the results of psychological tests (e.g., \(-\)blocker, anti-depressive agents, etc.) or those of renal parameters (e.g., 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.

### 2.2 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 Apostion et al. [3]. 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-reactive protein.

All participants completed a Slovene translation [42] of the Eysenck Personality Questionnaire (EPQ; [16]) and the Emotional States Questionnaire (ESQ; [38]). The collected data proved the EPQ questions to be appropriate for the Slovene population, as they were for the British and Danish [16, 50] populations. The personality structure appears to be similar in spite of the differences in nationality [42]. 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 [64] and based on the study results of the Slovene population [38]. 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 [38].

### 2.3 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\textsuperscript{2+} measurements in the workplace, personal medical records and biological monitoring data [32]. 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\textsuperscript{2+} 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\textsuperscript{2+} occupational exposure: (1) years of work in the mercury mine (years
of exposure), (2) cycles of exposure (intervals of work at exposure to Hg\textsuperscript{o}). (3) average time-weighted (ATW) air Hg\textsuperscript{o} concentration expressed in mgHg\textsuperscript{o}/m\textsuperscript{3} air [32]. Due to the use of personal protective equipment, the external exposure indices were used as a rough estimate of exposure to Hg\textsuperscript{o}.

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 (gHg/L, (2) the geometrical mean of cycles peak U-Hg level, calculated from all cycles peak U-Hg levels expressed in (gHg/L, (3) cumulative U-Hg level (the sum of all cycles U-Hg levels) expressed in (gHg/L, (4) U-Hg level at the last exposure expressed in (gHg/L). The present background exposure to Hg\textsuperscript{o} was evaluated by determining the total mercury in blood (B-MeHg) and urine (U-Hg). The potential methyl mercury exposure (from fish intake) was evaluated by determining methyl mercury in blood (B-MeHg).

### 2.4 Analysis of Hg\textsuperscript{o} in air at the workplace
Hg\textsuperscript{o} 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/m\textsuperscript{3}, sensitivity 1 mg/m\textsuperscript{3} and repeatability \(\pm 5\%\)).

### 2.5 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 ngHg/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 ng [23, 24]. Urinary mercury was measured in \(\mu Hg/g\) creatinine. Before 1970, U-Hg was analyzed using the dithizone method, and after that by means of the above-mentioned CVAAS technique expressed in (g/L). Monomethyl mercury in whole blood (B-MeHg) was determined by acid leaching/solvent extraction/aqueous phase ethylation/isothermal GC/CV AFS detection [41]. 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 [34]. Creatinine in urine was measured on a Roche/Hitachi 917 automated biochemical analyser (Roche, Mannheim, Germany). Overall CVs were \(<2.5\%\), sensitivity 8.8 (mol/L). The other basic routine biochemical and hematological parameters were determined by applying the usual clinical biochemical methods (data not presented).

### 2.6 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\textsuperscript{o} exposure in combination with covariables, we used machine learning methods such as regression and model trees [6, 60].

Regression trees are 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 \((x_1, x_2, ..., x_N, y)\), 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 psychotism 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 subtree 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 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
Pruning and the confidence level in error estimates in leaves 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 CART [6] and M5 [60]. M5 is one of the most well-known programs for regression tree induction. We used the M5′ system [70], a re-implementation of M5 within the software package WEKA [74]. 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, retired 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 of U-Hg level (g/L), the geometrical mean of cycles peak U-Hg level, cumulative U-Hg level (g/L), U-Hg level at the last exposure (g/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 focus on miners with higher exposure we also ignored five miners with U-Hg value of the last exposure under 10 (g/L).

3 Results

3.1 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 1 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. 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 [47] 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.

3.2 Occupational Hg\textsuperscript{\circ} exposure status Mercury miners were observed in the period after long-term intermittent exposure to Hg\textsuperscript{\circ}, which lasted 7 to 31 years. Prior to the present observations, the miners had no longer been exposed to Hg\textsuperscript{\circ} 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\textsuperscript{\circ} exposure lasted 19 days (range: 3-34 days). The biological indices of occupational exposure presented in Table 2 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
Table 2: External and biological indices of previous occupational Hg exposure in miners (N=53).

<table>
<thead>
<tr>
<th></th>
<th>Geometrical Mean</th>
<th>SD</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Years of exposure</td>
<td>14.6</td>
<td>5.5</td>
<td>7 – 31</td>
</tr>
<tr>
<td>Cycles of exposure</td>
<td>41.2</td>
<td>21</td>
<td>13 – 119</td>
</tr>
<tr>
<td>ATW air Hg conc. (mg/m³)</td>
<td>0.29</td>
<td>0.08</td>
<td>0.14–0.45</td>
</tr>
<tr>
<td>Cycles U-Hg level (g/L)</td>
<td>53.1</td>
<td>20.5</td>
<td>20 – 120</td>
</tr>
<tr>
<td>Cycles peak U-Hg level (g/L)</td>
<td>77.2</td>
<td>23.0</td>
<td>40 – 134</td>
</tr>
<tr>
<td>Cumulative U-Hg level (g/L)</td>
<td>6584</td>
<td>4444</td>
<td>1286–21390</td>
</tr>
<tr>
<td>Last exposure U-Hg level (g/L)</td>
<td>26</td>
<td>29</td>
<td>8–135</td>
</tr>
</tbody>
</table>

Table 3: Average scores on the Eysenck Personality Questionnaire (EPQ) of observed groups.

<table>
<thead>
<tr>
<th>EPQ</th>
<th>Miners Mean</th>
<th>SD</th>
<th>Controls Mean</th>
<th>SD</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Psychoticism</td>
<td>3.80</td>
<td>2.37</td>
<td>3.74</td>
<td>2.06</td>
<td>0.905</td>
</tr>
<tr>
<td>Extroversion</td>
<td>12.09</td>
<td>3.81</td>
<td>13.93</td>
<td>3.15</td>
<td>0.017</td>
</tr>
<tr>
<td>Neuroticism</td>
<td>8.14</td>
<td>4.27</td>
<td>7.55</td>
<td>4.21</td>
<td>0.522</td>
</tr>
<tr>
<td>Lie</td>
<td>12.45</td>
<td>4.22</td>
<td>15.05</td>
<td>3.54</td>
<td>0.003</td>
</tr>
</tbody>
</table>

Table 4: Average scores on the Emotional State Questionnaire (ESQ) of observed groups.

<table>
<thead>
<tr>
<th>ESQ</th>
<th>Miners Mean</th>
<th>SD</th>
<th>Controls Mean</th>
<th>SD</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Depression</td>
<td>20.33</td>
<td>5.07</td>
<td>17.73</td>
<td>3.61</td>
<td>0.009</td>
</tr>
<tr>
<td>Contentment</td>
<td>30.52</td>
<td>4.97</td>
<td>31.05</td>
<td>6.06</td>
<td>0.667</td>
</tr>
<tr>
<td>Aggressions</td>
<td>17.17</td>
<td>4.20</td>
<td>15.95</td>
<td>2.71</td>
<td>0.122</td>
</tr>
<tr>
<td>Indifference</td>
<td>9.74</td>
<td>2.73</td>
<td>8.51</td>
<td>2.11</td>
<td>0.025</td>
</tr>
<tr>
<td>Pos. self-concept</td>
<td>15.52</td>
<td>3.16</td>
<td>16.51</td>
<td>2.91</td>
<td>0.143</td>
</tr>
<tr>
<td>Neg. self-concept</td>
<td>8.98</td>
<td>2.51</td>
<td>7.68</td>
<td>1.71</td>
<td>0.008</td>
</tr>
</tbody>
</table>

3.3 Psychological evaluation

Table 3 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 4 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 difference in the 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.

The M5 models built for extraversion, lie, depression, indifference and negative self-concept score are presented in Tables 5, 6, 7, 8, and 9, respectively. The model describing extraversion 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 "extraversion 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 extraversion 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 6 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.

The model tree predicting the depression score presented in Table 7 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

Table 5: Linear regression model constructed by M5’, describing the extraversion score and its correlation coefficient.

extraversion_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_micro_g_L + -0.0198 * uhg_at_last_exposure_micro_g_L + 0.15 * alcohol_consumption_ml_per_day + 17.7282

Correlation coefficient = 0.4304

Table 6: Linear regression model constructed by M5’, describing the lie score and its correlation coefficient.

lie_score = 0.1374 * age_in_years + 2.6639 * residence_in_town_centre = not + 5.9845

Correlation coefficient 0.4518
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: 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.

The indifference score described by the model and presented in Table 8 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.

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

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### Table 8: Linear regression model constructed by M5’, describing the indifference score and its correlation coefficient.

indifference_score = 1.8823 * group = miners,retired_miners + 0.0538 * age_in_years + 0.0331 * cyc_uhg_level_geom_mean_mic_g_L + -0.0469 * cyc_peak_uhg_level_geom_mean_mic_g_L + 0.0201 * uhg_at_last_exposure + 0.0607 * cigarettes_per_day + 5.7682

Correlation coefficient = 0.4238

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### Table 9: 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.

LM1: negative_self-concept_score = 0.0465 * age_in_years + 0.0254 * alcohol_consumption_ml_per_day + 5.3991

LM2: negative_self-concept_score = -0.0455 * cycles_peak_uhg_level_geom_mean_micro_g_L + 0.0248 * uhgl_at_last_exposure_micro_g_L + 12.3991

Correlation coefficient = 0.4978

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### 4 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 [54]. The present U-Hg concentration was unexpectedly low in observed miners (mean 2.1, range 0.2-7.5 µg/L), but still significantly higher (p=0.003) than in the controls. In some studies [61, 75], the U-Hg level in non-occupationally exposed subjects was generally below 5 µg/L, while in other studies [49] 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 [58, 10, 4, 33], although it seems that the long-term elimination kinetics of mercury in the brain and kidneys is not well elucidated [67, 37, 55, 17].

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 [20, 45, 31]. Unoxidised Hg° can be oxidized and become trapped in the brain. Taking into account the above-mentioned facts and results of quoted post-mortem studies in ex-mercury miners [37, 7, 17], 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 unspecified symptoms were most frequently observed at U-Hg levels ranging between 30-100 µg/L [18, 8, 56, 57], 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 [65, 13]. 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 [14], depression, less extraversion and more emotional liability were detected [19].

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 extraversion. 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 [16, 42], 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 [62, 39]. 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 partly compared to the personality changes in workers during low-level Hg° occupational exposure [65, 13], and non-occupational exposure [19]. Only a few investigations using the measurements of neuropsychological effects to study workers previously exposed to Hg° are available to our knowledge [28, 48, 40]. Mood scales (tenison, depression, anger, fatigue and confusion) were applied only in the study of Letz et al. [40], but no residual mood changes with depression have been observed.

Some studies have reported a decreased nocturnal melatonin concentration in the blood of a depressed patient [52]. In our miners, however, we detected precisely the opposite, i.e., an increased concentration of melatonin in morning blood samples; these results have been presented elsewhere [35]. 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 melatonin [12]. Theoretically, consideration should also be given to the potential impacts of mercury on the metabolism of neurotransmitters [51] and the impacts of increased accumulation of mercury in the pineal gland itself [37, 17], which might also influence the synthesis of melatonin and, indirectly, the balance of serotonin [27]. The disturbance of this balance, serotonin – melatonin, can, in the opinion of certain researchers [22], influence the occurrence of depression and low self-concept
In evaluating the potential synergy neurotoxic impacts of alcohol and mercury, which, in the opinion of certain authors [47, 21, 43, 59, 51], 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 production of free radicals and antioxidative capacity, not to the lowest observed adverse effect level [68, 73].

The present study is part of the research project entitled "The impact of long-term past exposure to elemental mercury on antioxidative capacity and lipid peroxidation in mercury miners". This project study was financially supported by the Slovene Ministry of Education, Science and Sport and the Idrija Mercury Mine, Slovenia. Our sincere acknowledgements to the participants of this study. We would like to thank the staff of the Jožef Stefan Institute, Ljubljana, the Clinical Institute of Clinical Chemistry and Biochemistry, University Medical Centre, Ljubljana, Slovenia, for their kind support, and the Idrija Mercury Mine, Slovenia, for its assistance in sampling, analyses and the collection of environmental and biological data on miners’ past exposure.

We are grateful to the medical staff of the Department of Occupational Medicine, Idrija, for enabling the completion of this study.

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