Psychiatric evaluation of a group of workers in the aluminium industry

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Objective

The aim of the study was to assess cognitive functions, depression, anxiety, and personality changes in workers in the aluminium industry.

Participants and methods

A cross-sectional analytical study was carried out on 50 workers employed in 'General Metal Company', which manufactures aluminium. Fifty individuals with no history of occupational exposure to aluminium were randomly selected from relatives of patients attending the outpatient clinic of industrial medicine in Kasr Al Aini hospital to form a control group. Both groups were matched for age and sex. All of the examined individuals were subjected to clinical, laboratory and environmental examinations that included aluminium and copper dust measurement, noise measurement and heat measurement. The workers were diagnosed according to the ICD-10 research diagnostic criteria. Both groups were subjected to different neuropsychological tests that included the Mini Mental State Examination (MMSE), the Hamilton Depression Rating Scale (HDRS), the Hamilton Anxiety Rating Scale (HARS), the Eysenck Personality Questionnaire (EPQ) and the Wechsler Memory Scale (WMS).

Results

The results showed that serum and urinary aluminium levels were higher in the exposed group when compared with the control group (nonexposed group), with highly statistically significant differences. However, there was no statistically significant difference between the groups with respect to serum copper. There were statistically significant differences between them in all subtests of the WMS (information, orientation, logical memory, digit span and associate learning) except with respect to mental control. Most cases were within the normal range of values according to MMSE, but there was a statistically significant difference. There was a statistically significant difference between the exposed and control individuals as regards all subscales of the EPQ (psychotism, neurotism, extroversion, lying and criminality). Seven per cent of workers had severe depression, 11% had moderate depression and 25% had mild depression in the exposed group, whereas 20% had mild depression in the control group. There was a statistically significant difference between the exposed and control group with respect to depression. Six per cent of workers in the exposed group had severe anxiety, whereas 30 and 34% had mild and moderate anxiety levels, respectively. There was a highly statistically significant difference between the exposed and control groups with respect to anxiety. There was statistically significant negative correlations between serum and urinary aluminium level and the information, logical memory and digit span subtests of the WMS. Serum copper shows no significant correlations with all subtests of Wechsler Memory Scale (WMS). The increase in serum and urinary aluminium levels led to a decrease in the scores of MMSE (a negative correlation, which was statistically significant). In contrast, serum copper showed no statistically significant correlation with the scores on MMSE. There was no statistically significant correlation between metal levels in the exposed group (serum aluminium, urinary aluminium and serum copper) and any of the parameters of the Eysnek personality test, apart from criminality, which seemed to have a statistically significant positive correlation with serum aluminium level. There was a statistically significant positive correlation between serum aluminium and HDRS, whereas there was no statistically significant correlation between urinary aluminium and serum copper with HARS. There was a statistically significant positive correlation between serum aluminium and the HARS. With respect to urinary aluminium and serum copper, there was no statistically significant correlation with the HARS.

Conclusion

The study showed that exposed workers in the aluminium industry are suffering from cognitive decline, memory affection, depression, anxiety and personality changes. Proper monitoring and improved hazard control are strongly recommended.

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Introduction

Aluminium (Al) is the most abundant metal found in the earth's crust (8%) where it is always found in combination with other elements and it is the third most abundant element after oxygen and silicon. Its atomic number is 13 and its atomic weight is 26.98 (Kaye, 1998).

Aluminium is a soft, durable, light weight and malleable metal with high heat conductivity. Hence, it is used widely throughout industry and in larger quantities than any other nonferrous metal and is also widely used in making cooking utensils and containers (Elinder and Sjogren, 1986).

Although it was considered to be harmless, considerable toxic effects of aluminium have been found recently (Pierre *et al.*, 1995).

It was found that occupational exposure to aluminium may affect the central nervous system and result in a wide variety of neuropsychiatric effects ranging from subtle behavioural disturbances to overt psychosis (Candura *et al.*, 2000).

Aluminium foundry workers were found to have changes in psychomotor and intellectual abilities, which could be a consequence of the long-lasting toxic effect of aluminium (Hosovski *et al.*, 1990).

It was found that miners who were exposed to aluminium powder as a prophylactic agent against silicotic lung disease performed poorly compared with unexposed workers on cognitive state examinations (Rifat *et al.*, 1990).

In Italian foundry workers, there is evidence of neurotoxic effects with mild cognitive impairment due to exposure to aluminium dust. These effects could be the prelude to Alzheimer's disease or Alzheimer's disease-like neurological deterioration (Adams, 2003).

In the aluminium industry, aluminium is alloyed with a variety of other materials including copper, which makes it more malleable, strong and easily extruded. Copper (Cu) is a chemical element and its atomic number is 29. It is a ductile metal with excellent electrical conductivity, finding extensive use as an electrical conductor, heat conductor, as a building material and as a component of various alloys (Callister, 2002).

Copper is deeply involved with all aspects of the central nervous system, and it is highly associated with most psychological, emotional and often neurological conditions. These include memory loss, especially in young people, depression, anxiety, bipolar disorder, schizophrenia, panic attacks, migraines, insomnia, nervousness and irritability (Wilson, 2003).

It has been suggested that aluminium and copper may be involved in the pathogenesis of Alzheimer's disease through their interaction in the promotion of oxidative events (Becaria *et al.*, 2003).

In the aluminium industry, there is a possibility of heat disorders especially during periods of hot weather; there is also a risk of exposure to high noise levels generated in the aluminium foundry (Bertram, 1998).

It was found that occupational exposure to physical agents such as noise and temperature may be related to mood disorders and suicide (Jong, 2008).

The aim of this study was to assess the cognitive functions, depression, anxiety and personality changes in workers in the aluminium industry.

Participants and methods

A cross-sectional analytical study was carried out on two groups, an exposed worker group and a healthy control group. A random sample of workers employed in 'General Metal Company' in Helwan for manufacturing aluminium frames, long bars and evaporator panels for refrigerators through melting and refining of primary aluminium ingots and aluminium scraps was selected. An exposed worker group of 50 individuals was included in the study with ages ranging from 30 to 50 years; they had been employed for more than 10 years. All of the examined individuals were men. Fifty individuals constituting a control group were selected randomly from relatives of patients attending the outpatient clinic of industrial medicine in Kasr Al Aini hospital with no history of occupational exposure to aluminium. Both groups were matched for age and sex. To be included in the study, individuals had to have good hearing ability, no physical disability and had to be literate; those with a hearing defect, physical disability and who were illiterate were excluded. Participants were diagnosed according to the ICD-10 diagnostic criteria.

A written informed consent was obtained from all participants.

Both groups were subjected to the following:

(1) A detailed psychiatric history taking based on a Kasr Al Aini psychiatric sheet; the questionnaire was answered through a semistructured psychiatric interview.
(2) Full medical history taking, which included personal history, occupational history, medical history, past history and family history.
(3) Clinical examination with special emphasis on neurological examination.

(4) Laboratory investigations that included assessment of serum aluminium, serum copper and urinary aluminium levels.

Blood sample collection and preparation

From each participant, 7 ml of venous blood was taken through a venipuncture using a dry plastic syringe under complete aseptic conditions. A volume of 5 ml of blood was taken into a clean dry tube with no anticoagulant and centrifuged to separate serum for determination of aluminium; the remaining 2 ml of blood was prepared by the same method for determination of copper.

Urine sample collection and preparation

From each participant, 20 ml of urine was collected into a clean dry container under complete aseptic conditions for determination of urinary aluminium. All samples to be analysed were transported to the laboratory on the same day within 2 h.

Determination of aluminium and copper levels in the blood and urine samples

Serum and urinary aluminium levels were measured by means of a graphite furnace atomic absorption spectrophotometer with a Zeeman background (Thermo Elemental M-6 Type, General Metal Company, Cairo, Egypt). Serum copper level was measured using a flame furnace atomic absorption spectrophotometer with a Zeeman background (Thermo Elemental M-6 Type).

The workplace was thoroughly inspected as part of environmental assessment.

Aluminium and copper dust measurement:
Equipment:

(1) *Sampler*: a cellulose ester membrane filter, 0.8 μm pore size, 37 mm diameter, in a cassette filter holder.
(2) *Personal sampling pump*: 1–3 l/min, with a flexible connecting tube.
(3) *Atomic absorption spectrophotometer*: a nitrous oxide–acetylene burner head and aluminium hollow cathode lamp for the aluminium and atomic absorption spectrophotometer with an air–acetylene burner head and a copper hollow cathode lamp and two-stage regulators for air and acetylene.
(4) *Regulators*: two-stage for nitrous oxide and acetylene for aluminium.
(5) *Beakers*: Phillips (125 ml) or Griffin (50 ml) with watchglass covers.
(6) *Volumetric flasks*: 10 and 100 ml for aluminium and 25 ml for copper.
(7) *Micropipettes*: 5–500 μl.
(8) *Hotplate*: surface temperature 100–140°C for aluminium and 140–400°C for copper [NIOSH Manual of Analytical Methods (NMAM), 1994b].
(9) *Total sample size*: 10–400 l. Do not exceed 2 mg total dust loading on the filter for aluminium and 50–1500 l for copper (NMAM, 1994a).

Calculations:

(1) Using the measured absorbances, the corresponding concentrations (C_s; μg/ml) of aluminium in the sample and the average media blank (C_b) from the calibration graph were calculated.
(2) Using the solution volumes (V_s; ml) of the sample and media blanks (V_b) the concentration (C; mg/m^3) of aluminium in the volume of air sampled (V; l) was calculated (NMAM, 1994a):

$$C = \frac{(C_s V_s - C_b V_b)}{V}\ \text{mg/m}^3,$$

Noise measurement

Noise measurements were recorded using Digital Sound Level Meter Model 732, which gave direct measurements in decibels ranging from 30 to 130 dB with capability to measure three measurement ranges: low, medium and high. It includes frequency weighting A and C and fast and slow time weighting [National Institute for Occupational Safety and Health (NIOSH), 1998].

Heat measurement

The Wet Bulb Globe Temperature Index (WBGT) is the simplest and most suitable technique to take into account and measure environmental factors. WBGT values are calculated by the following equations:

Outdoors with solar load:

$$\text{WBGT} = 0.7\ \text{NWB} + 0.2\text{GT} + 0.1\text{DB},$$

Indoors or outdoors with no solar load:

$$\text{WBGT} = 0.7\ \text{NWB} + 0.3\text{GT},$$

Where, NWB = natural wet bulb temperature, DB = dry bulb temperature, GT = globe temperature.

Neuropsychological tests

Mini Mental State Examination

It is used for screening cognitive functions. This test is not suitable for making a diagnosis but can be used to indicate the presence of cognitive impairment. The Mini Mental State Examination (MMSE) is far more sensitive in detecting cognitive impairment compared with informal questioning or overall impression of a patient's orientation (Crum *et al.*, 1993). It is a brief test that takes only about 10 min. It provides measurements of orientation, registration (immediate memory), short-term memory (but not long-term memory) and language functioning. The MMSE test includes simple questions like orientation to time and place of the test, repeating lists of words, arithmetics such as the serial sevens, language use and comprehension and basic motor skills. For example, one question asks to copy a drawing of two pentagons (Folstein *et al.*, 1975).

Hamilton Depression Rating Scale

This test is used to measure the severity of depressive symptoms in individuals, often in those who have already been diagnosed as having a depressive disorder. It is sometimes known as the Hamilton Depression Rating Scale (HDRS) (Barry, 1998). Depending on the version used, there are either 17 or 21 items for which an interviewer provides ratings. The 17-item version of the HRDS is more commonly used than the 21-item version, which contains four additional items measuring symptoms related to depression, such as paranoia and obsession rather than the severity of depressive symptoms themselves (Williams, 1988). For the 17-item version, scores can range from 0 to 54. One formulation suggests that scores between 0 and 6 indicate a normal person with no depression, scores between 7 and 17 indicate mild depression, scores between 18 and 24 indicate moderate depression and scores over 24 indicate severe depression (Maruish, 1999).

Hamilton Anxiety Rating Scale

It is a 14-item test measuring the severity of anxiety symptoms. It is sometimes also called the Hamilton Anxiety Rating Scale (HARS) (Barry, 1998). It is one of the first rating scales to be developed to measure the severity of anxiety symptoms and is still widely used in both clinical and research settings. The scale consists of 14 items, each defined by a series of symptoms, and measures both psychic anxiety (mental agitation and psychological distress) and somatic anxiety (physical complaints related to anxiety) (Borkovec and Costello, 1993). Examples of items for which interviewers must give ratings include overall depression, guilt, suicide, insomnia, problems related to work, psychomotor retardation, agitation, anxiety, gastrointestinal and other physical symptoms, loss of libido, hypochondriasis, loss of insight and loss of weight (Williams, 1988). Each item is scored on a scale of 0 (not present) to 4 (severe), with a total score range of 0–56, where score less than 17 indicates mild severity, 18–24 indicates mild-to-moderate severity and 25–30 indicates moderate-to-severe severity (Borkovec and Costello, 1993).

The Eysenck Personality Questionnaire

It is a pencil/paper test in which participants are asked to complete a brief questionnaire of 90 items in a yes or no format; it is used to assess the personality traits of a person (Eysenck and Eysenck, 1975). It consists of four scales: E (extroversion–introversion), N (emotional stability–neuroticism), P (psychoticism) and L (lying and social desirability of responses, indirectly showing a tendency towards conformity).

The Wechsler memory scale

It is a neuropsychological test used to assess verbal and nonverbal memory abilities in adults especially when either cognitive impairment or dementia is suspected. Developed by David Wechsler, this test assesses learning, memory and working memory (Wechsler, 1945).

The scale includes the following subtests: information, orientation, mental control, logical memory, digits forwards, digits reversed, visual reproduction and associate learning.

Statistical analysis

Data were coded and entered using statistical package SPSS version 16 (IBM, Chicago, Illinois, USA).

Data were summarized using mean, SD and range for quantitative data and number and percentage for qualitative data.

Comparison between the two groups was made using the χ^2-test for qualitative variables, the independent sample *t*-test and analysis of variance.

Two-way analysis of variance was used to test the combined effect of smoking and exposure on metal levels.

Correlations were made to test for linear relation between variables.

P-values less than 0.05 were considered statistically significant.

Results

The threshold limit for aluminium dust is 10 mg/m^3 according to NIOSH and American Conference of Governmental Industrial Hygienists (ACGIH) and 15 mg/m^3 according to Occupational Safety and Health Administration (OSHA). The threshold limit for copper is 1 mg/m^3 according to OSHA. Permissible exposure limits for noise exposure are 90 dB according to OSHA and Egyptian law and 85 dB according to NIOSH. In terms of the heat generated during a moderate workload, the WBGT should range from 28.7 to 30.5°C according to Egyptian law and should be 29°C according to ACGIH.

Table 1 shows that 62% in the exposed group had affective disorders, whereas 56% had neurotic, stress-related and somatoform disorders.

Twelve per cent of the exposed group had mental and behavioural disorders due to the use of psychoactive substances.

Table 2 shows that the levels of serum and urinary aluminium were higher in the exposed group when compared with the control group with highly statistically significant differences, whereas with respect to serum copper there was no statistically significant difference between the groups.

Table 1 Psychiatric diagnosis according to ICD-10 research criteria

	N (%)	
Variables	Exposed (*n*=50)	Control (*n*=50)
Affective disorders		
Positive	31 (62%)	0 (00%)
Negative	9 (38%)	50 (100%)
Neurotic, stress-related and somatoform disorders		
Positive	28 (56%)	5 (10%)
Negative	12 (44%)	45 (40%)
Mental and behavioural disorders due to psychoactive substance use		
Positive	6 (12%)	0 (00%)
Negative	44 (88%)	0 (00%)
Others	–	–

Table 2 Comparison between exposed and control groups as regards metal levels

	Mean ± SD			
	Exposed (*n*=50)	Control (*n*=50)	*t*-test	*P*-value
Serum aluminium (μg/l)	32.67 ± 5.20	1.53 ± 0.48	42.136	0.000*
Urine aluminium (μg/l)	47.79 ± 5.35	11.36 ± 1.78	45.675	0.000*
Serum copper (mg/l)	0.97 ± 0.23	0.97 ± 0.19	0.216	0.830

*Statistically significant.

Table 3 shows that there were statistically significant differences between exposed and control participants in all subtests of the Wechsler Memory Scale (WMS) (information, orientation, logical memory, digit span and associate learning), except for mental control, for which there was no statistically significant difference.

Table 4 shows that most of the exposed workers had normal scores, but there was a statistically significant difference between exposed and control groups regarding MMSE.

Table 5 shows that there was a statistically significant difference between exposed and control subjects with respect to all subscales of the Eysenck Personality Questionnaire (EPQ) (psychotism, neurotism, extroversion, lying and criminality).

Table 6 shows that 7% had severe depression, 11% had moderate depression and 25% had mild depression in the exposed group, whereas 20% had mild depression in the control group. There was a statistically significant difference between exposed and control participants with respect to depression.

Table 7 shows that 6% in the exposed group had severe anxiety, whereas 30 and 34% had mild and moderate anxiety, respectively. There was a highly statistically significant difference between the exposed and control participants with respect to anxiety.

Table 8 shows that the levels of serum and urinary aluminium were higher among the exposed group when compared with the control group (nonexposed group) with highly statistically significant differences. However, there was no statistically significant difference between the groups regarding serum copper. There were statistically significant differences between the groups in all subtests of the WMS (information, orientation, logical memory, digit span and associate learning) except mental control. Most cases were within the range of normal values according to MMSE but there was a statistically significant difference. There was a statistically significant difference between exposed and control subjects with respect to all subscales of the EPQ (psychotism, neurotism, extroversion, lying and criminality). Seven per cent had severe depression, 11% had moderate depression and 25% had mild depression in the exposed group, whereas 20% had mild depression in the control group. There was a statistically significant difference between the exposed and control groups with respect to depression. Six per cent in the exposed group had severe anxiety, whereas 30 and 34% had mild and moderate anxiety, respectively. There was a highly statistically significant difference between the exposed and control groups with respect to anxiety.

Discussion

Although environmental measures of aluminium and copper dust were within the acceptable levels, neuropsychiatric disorders were detected in workers exposed to aluminium; this can be explained by the synergistic effects of both metals. Occupational noise may lead to multiple nonauditory effects such as annoyance, irritability, psychosocial defects, psychiatric disorders, sleep deprivation and effects on performance (De Hollander *et al.*, 2004).

There is reliable evidence, largely from laboratory studies, that noise exposure impairs performance and speech perception. Noise interference with speech comprehension results in a large number of personal disabilities, handicaps and behavioural changes (Stansfeld *et al.*, 2000).

Irritability and performance decrement have also been associated with noisy work environments. Irritability increases when noise is unpredictable and uncontrollable (Dunn and Rabinowitz, 2004).

The results also show measurement of heat using the WBGT and these measurements ranged between 21.3 and 31.5, the highest level being 31.5, at which the melting process occurred, which is characterized by high temperature and high humidity, in addition to lack of ventilation within the factory.

This level in our factory, which involves a moderate workload in which work–rest regimen is 50–70%, is higher than the recommended WBGT levels, which ranges from 28.7 to 30.5°C according to the Egyptian law and 29°C according to ACGIH (2008).

Hot temperatures can cause a variety of psychiatric disturbances such as increased aggressive motives and behaviours and may trigger irritability and episodic psychological distress; hot temperatures increase aggression by directly increasing feelings of hostility and indirectly increasing aggressive thoughts (Anderson, 2002).

Evidence has shown that environmental changes can affect mental health and elevated temperatures may exacerbate psychiatric conditions (Woodruff *et al.*, 2006).

Table 3 Wechsler Memory Scale among exposed and control groups

	Exposed (*n*=50)		Control (*n*=50)			
	Number of impaired (%)	Mean ± SD	Number of impaired (%)	Mean ± SD	*t*-test	*P*-value
Information	15 (30%)	4.58 ± 0.7	0 (0%)	5	− 4.228	0.000*
Orientation	48 (96%)	4.04 ± 0.2	0 (0%)	5	− 34.293	0.000*
Mental control	13 (26%)	5.38 ± 1.48	14 (28%)	5.72 ± 0.45	− 1.550	0.127
Logical memory	49 (98%)	5.63 ± 3.03	14 (28%)	12.59 ± 1.48	56.500	0.000*
Digit span	50 (100%)	7.44 ± 2.36	43 (86%)	11.40 ± 1.16	− 10.656	0.000*
Associate learning	35 (70%)	9.22 ± 3.51	0 (0%)	14.96 ± 1.97	206	0.000*

*Statistically significant.

Table 4 Mini Mental State Examination among exposed and control groups

	Exposed (*n*=50)		Control (*n*=50)			
	N (%)	Mean ± SD	*N* (%)	Mean ± SD	*t*-test	*P*-value
Normal	26 (52%)	24.24 ± 3.19	47 (94%)	26.46 ± 1.58	− 4.408	0.000*
Mild	16 (32%)		3 (6%)			
Moderate	8 (16%)		0 (0%)			

*Statistically significant.

Table 5 Eysenck Personality Questionnaire among exposed and control groups

	Exposed (*n*=50)		Control (*n*=50)			
	N (%)	Mean ± SD	*N* (%)	Mean ± SD	*t*-test	*P*-value
Psychotism	23 (46%)	4.64 ± 1.88	5 (10%)	3.16 ± 1.06	*Z*-test 4.182	0.000*
Neurotism	37 (74%)	13.82 ± 3.61	0 (0%)	8.18 ± 1.53	10.161	0.000*
Extroversion	23 (46%)	12.04 ± 3.36	0 (0%)	7 ± 2.36	8.670	0.000*
Lying	45 (90%)	13.02 ± 3.75	3 (6%)	5.38 ± 1.74	13.073	0.000*
Criminality	20 (40%)	12.04 ± 3.43	0 (0%)	5.80 ± 2.35	*Z*-test 7.473	0.000*

*Statistically significant.

Table 6 Results of Hamilton Depression Rating Scale among exposed and control groups

	Exposed (*n*=50)		Control (*n*=50)			
	N (%)	Mean ± SD	*N* (%)	Mean ± SD	*Z*-test	*P*-value
Normal	7 (14%)	15.98 ± 9.94	40 (80%)	5.14 ± 1.59	251.500	0.000*
Mild	25 (50%)		10 (20%)			
Moderate	11 (22%)		0 (0%)			
Severe	7 (14%)		0 (0%)			

*Statistically significant.

Table 7 Hamilton Anxiety Rating Scale among exposed and control groups

	Exposed (*n*=50)		Control (*n*=50)			
	N (%)	Mean ± SD	*N* (%)	Mean ± SD	*Z*-test	*P*-value
Normal	15 (30%)	16.52 ± 8.42	50 (100%)	5.70 ± 2.45	177.5	0.000*
Mild	17 (34%)		0 (0%)			
Moderate	15 (30%)		0 (0%)			
Severe	3 (6%)		0 (0%)			

*Statistically significant.

Table 8 Correlation between Wechsler Memory Scale, Mini Mental State Examination, Eysenck Personality Questionnaire, Hamilton Depression Rating Scale and Hamilton Anxiety Rating Scale and levels of metals among exposed groups

	S aluminium		U aluminium		S copper	
	R	*P*-value	*R*	*P*-value	*R*	*P*-value
Wechsler Memory Scale						
Information	−0.414	0.003*	−0.333	0.018*	0.087	0.549
Orientation	0.063	0.666	0.178	0.217	−0.104	0.474
Mental control	−0.368	0.009	−0.228	0.111	−0.064	0.658
Logical memory	−0.58	0.000*	−0.522	0.000*	0.004	0.978
Digit span	−0.453	0.001*	−0.396	0.004*	0.002	0.988
Associate learning	−0.224	0.118	−0.185	0.199	0.129	0.371
Mini Mental State Examination	−0.558	0.000*	−0.346	0.014*	−0.102	0.481
Eysenck Personality Questionnaire						
Psychotism	0.052	0.722	0.116	0.421	0.103	0.477
Neurotism	0.265	0.063	0.163	0.260	−0.174	0.226
Extroversion	0.210	0.144	0.169	0.240	−0.028	0.848
Lying	−0.038	0.794	0.015	0.916	−0.114	0.429
Criminality	0.359	0.010*	0.228	0.112	−0.099	0.496
Hamilton Depression Rating Scale	0. 342	0.015*	0.208	0.147	−0.043	0.769
Hamilton Anxiety Rating Scale	0.318	0.024*	0.260	0.068	−0.123	0.393

*Statistically significant.

A highly statistically significant difference was found between the exposed and control group as regards serum aluminium, with higher values in the exposed group (32.67 ± 5.20 μg/l) compared with the control group (1.53 ± 0.48 μg/l); a highly statistically significant difference was also found between the exposed group and the control group with regard to urinary aluminium, with higher values in the exposed group (47.79 ± 5.35 μg/l) than in the control group (11.36 ± 1.78 μg/l).

The high serum and urinary aluminium levels among the workers of the exposed group may be explained by occupational exposure of workers to aluminium dust and fumes and their inhalation and absorption from work environment. In addition, lack of ventilation in the factory increases the dose of metal dust and fumes inhaled.

The high levels of serum aluminium reflect long-term exposure of workers to metal, whereas the high levels of urinary aluminium indicate recent exposure. From this we can assume that workers were exposed to aluminium for a long period of time and that they continue to be exposed.

Similar results were obtained by Polizzi *et al.* (2002), who studied the neurotoxic effects of aluminium among foundry workers. They found significantly higher serum aluminium levels in workers compared with the control group and recommended considering a 10 μg/l cutoff level for serum aluminium.

There was no statistically significant difference between exposed and control individuals with respect to serum copper. The copper level measured was found to be within acceptable levels (0.6–1.3 mg/l). This can be explained by the presence and addition of copper in small concentrations during aluminium production as a hardener in order to make aluminium more malleable and strong. In addition, copper dust is poorly absorbed on inhalation.

The result shows that there were statistically significant differences between the exposed and control groups in all subtests of the WMS (information, orientation, logical memory, digit span and associate learning), except for mental control. WMS is one of the neuropsychological tests that assess short-term memory, learning and attention.

These results were consistent with those in the study by Hanninen *et al.* (1994), who studied 17 male welders with a mean age of 37 years exposed to aluminium fumes during welding for about 4 years. They measured aluminium levels in serum and urine, and central nervous system functions were examined using neuropsychological tests. From the result of the study they suggested that there are disturbing effects of aluminium on short-term memory, learning and attention.

The results were also in agreement with those of Hosovski *et al.* (1990), who studied 87 aluminium foundry workers exposed to aluminium dust and fumes for at least 6 years compared with 60 matched controls. They found that the exposed workers had lower scores in tests of memory. It is to be noted that poor memory and deficient attention are the earliest and the most consistent symptoms of Alzheimer's disease (Baddeley *et al.*, 1991). Giorgianni *et al.* (2003) evaluated the relation between aluminium exposure and cognitive functions using a battery of neuropsychological tests. One of them was the WMS, using which they found a reduction in memory, concentration and a slight reduction in attention.

Serum copper shows no significant correlations with any parameters of the WMS, although in these results we cannot exclude the possible role of copper in the pathogenesis of Alzheimer's disease either alone or in combination with aluminium.

Copper ions have a role in promoting the aggregation and/or stabilization of the amyloid fibrils and can also catalyse the generation of the most damaging radicals, such as hydroxyl radicals (Kowalik-Jankowska *et al.*, 2002). However, in combination with aluminium, there is a synergistic interaction between these two metals, which increases the oxidative events that result in enhanced production of reactive oxygen species (Becaria *et al.*, 2003). Both metals are also responsible for initiating or propagating an inflammatory response within the ageing brain (Campbell, 2006).

The results of the study show that there was a statistically significant difference between the exposed and control groups with respect to the results of MMSE that was used to detect cognitive impairment. Among the exposed workers 26 (52%) were normal, 16 (32%) had mild cognitive impairment and eight (16%) had moderate cognitive impairment; none of the cases had severe cognitive impairment.

These results were consistent with those of Adams (2003), who studied foundry workers who had been exposed to aluminium dust; he used the MMSE to assess cognitive function of workers. He found that aluminium foundry workers had mild cognitive impairment and that there was a significant difference between the exposed group and the control group. The most common type of cognitive impairment is mild cognitive impairment, which can be considered as a precursor to Alzheimer's disease. This may represent an important step towards diagnosing the illness in its earliest stage (Ringman *et al.*, 2009).

These results were also consistent with those of Rifat *et al.* (1990), who studied aluminium miners exposed to aluminium powder; they found that the exposed miners performed poorly compared with the unexposed controls on cognitive state examination.

These results were in contrast to those of Lang and Letzel (1995), who studied the mental performance of a group of workers exposed to aluminium over many years in the aluminium powder industry and compared them with the nonexposed control group. They found no signs of cognitive decline despite high concentration of aluminium in plasma and urine. Also, these results were in contrast to those of Deschamps *et al.* (2009), who studied exposed workers in an aluminium salvage plant and found that chronic exposure to aluminium does not induce measurable cognitive decline.

These contrasting results can be explained by the inability of the MMSE to detect subtle memory loss, particularly in well-educated patients; therefore, well-educated people may score well despite having cognitive impairment (Tombaugh and McIntyre, 1992).

There were negative correlations between serum, urinary aluminium levels and scores of MMSE that were statistically significant, whereas in case of serum copper there was no significant correlation with scores of the MMSE.

The study results were in agreement with those of Polizzi *et al.* (2002), who studied Italian workers exposed to aluminium and compared them with unexposed controls. The MMSE score was used to assess their cognitive functions. They found a negative relationship between internal aluminium concentration and MMSE score and concluded that aluminium has a role in early neurotoxic effects that can be detected at a preclinical stage by MMSE score and other neuropsychological tests, which could lead to early treatment to prevent or retard the onset of Alzheimer's disease.

The results show that there was a statistically significant difference between the exposed and control group with respect to all aspects of the EPQ used to assess the personality traits of a person and consisting of the following scales: interoversion, neurotism, psychotism, lying and criminality. The results showed that 23 men (46%) had psychotism, 37 (74%) had neurotism, 23 (46%) had extrovertion, 45 (90%) had a tendency to lie and 20 (40%) had traits of criminal behaviour. There were statistically significant positive correlations between serum aluminium levels in the exposed group and criminality as a part of the EPQ. Although there were positive correlations between serum and urinary aluminium levels and psychotism, neurotism (emotional instability) and extroversion, they were not statistically significant.

These results were relatively similar to those of Candura *et al.* (2000), who studied the effect of aluminium as one of the occupational intoxicants on the central nervous system and found that occupational exposure to aluminium results in a wide variety of neuropsychiatric disturbances to overt psychosis.

The results were relatively similar to those of Hosvski *et al.* (1990), who found that foundry workers exposed to high levels of aluminium dust and fumes for at least 6 years had lower scores in the test related to emotional instability when compared with controls.

Neurotisim, alone or in combination with other personality traits, has been shown to be predictive for Alzheimer's disease (Wang *et al.*, 2009).

However, in contrast to the results of the study by Guo *et al.* (1998), who studied neurobehavioural function of exposed aluminium workers and compared them with controls, they found no change in personality traits in exposed workers.

The study shows that in the exposed group 7% had severe depression, 11% had moderate depression and 25% had mild depression, whereas 20% had mild depression in the control group. There was a statistically significant difference between the exposed and control group with respect to depression. There were significant positive corelations between levels of serum aluminium and scores of the HDRS, whereas in urinary aluminium and serum copper there was no statistically significant correlation with the HDRS.

This was consistent with the results of Guo *et al.* (1998), who studied changes in psychological functions in workers exposed to aluminium; they found that scores for depression in workers exposed to aluminium for more than 10 years were significantly higher than those of nonexposed controls.

These results were also in agreement with those of Iregren *et al.*(2001), who examined a group of aluminium welders. They found that the performance of welders exposed to high concentrations of aluminium was affected and caused lower scores in the mood questionnaire.

These results were consistent with those of Guo *et al.* (1998) who studied changes in psychological functions in workers exposed to aluminium. They found that scores for depression in workers exposed to aluminium for more than 10 years were statistically significant compared with nonexposed controls.

The results show that 6% of workers in the exposed group had severe anxiety levels, whereas 30 and 34% had mild and moderate anxiety, respectively. There was a highly statistically significant difference between exposed and control participants with respect to the HARS. Also, there were statistically significant positive correlations between levels of serum aluminium and the HARS, whereas in case of urinary aluminium and serum copper there was no statistically significant correlation with the HARS.

These results were consistent with those of Guo *et al.* (1998), who studied psychological changes among aluminium workers and found that scores of tension and anger were higher among aluminium workers than among controls. The results were also consistent with those of He *et al.* (2003), who found that scores for tension and anxiety were higher among aluminium workers than among controls. Hence, they concluded that aluminium exposure had adverse effects on workers' moods and neurobehavioural functions.

Acknowledgements

Conflicts of interest

There are no conflicts of interest.

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