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Investigation of Creative Cognition among Miners at Sarcheshmeh Copper Complex

Movahedeh Mohammadi [1], Tabandeh Sadeghi [2], Soghra Akbari Chermahini [3], Narjes Soltani [4], Majid Saadloo [5], Dariush Zeiaee Pour [5], Majid Alizadeh [5], Ayat Kaeedi [4] and Ali Shamsizadeh [5, *]

[1]Non-Communicable Diseases Research Center, Rafsanjan University of Medical Sciences, Rafsanjan, Iran
[2]Department of Pediatric Nursing, Non-Communicable Diseases Research Center, School of Nursing and Midwifery, Rafsanjan University of Medical Sciences, Rafsanjan, Iran
[3]Department of Psychology, Faculty of Human Science, Arak University, Arak, Iran
[4]Physiology-Pharmacology Research Center, Research Institute of Basic Medical Sciences, Rafsanjan University of Medical Sciences, Rafsanjan, Iran
[5]Occupational Safety and Health Research Center, NICICO, WSO and Rafsanjan University of Medical Sciences, Rafsanjan, Iran

[*]*Corresponding author*: Occupational Safety and Health Research Center, NICICO, WSO and Rafsanjan University of Medical Sciences, Rafsanjan, Iran. Tel: +98-3431315079, Email: alishamsy@gmail.com

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Abstract

Background: Miners are frequently exposed to toxic metals in the environment. Excessive intake of heavy metals, such as arsenic, lead, and copper, is neurotoxic and promotes neurodegenerative diseases, such as Alzheimer's and Parkinson's diseases.
Objectives: This study aimed to investigate the creativity among personnel of the Sarcheshmeh Copper Complex, the second-largest copper deposit worldwide.
Methods: The research population included personnel working at the Sarcheshmeh Copper Complex in Rafsanjan, southeast Iran. The convenience sampling method was used to identify 204 participants based on inclusion and exclusion criteria. Convergent and divergent thinking were assessed using the remote associates test (RAT) and the alternative uses test (AUT), respectively.
Results: The total mean scores of RAT and AUT were 3.05 ± 2.05 and 10.91 ± 6.63, respectively. The mean scores of both AUT and RAT in miners with more than 10 years of work experience were lower than others. Moreover, AUT scores were lower in miners who used opium and also in those who were less educated (with no college or university education).
Conclusions: The results of this study demonstrated that cognitive abilities might be more affected in copper miners. However, more future studies using two groups of miners and non-miners are needed to conduct a more accurate interpretation.

Keywords: Alternative Uses Test, Copper Miners, Creative Cognition, Remote Associates Test

1. Background

Human exposure to toxic heavy metals is a global challenge. In miners, the situation intensifies as the concentrations of heavy metals are generally high in mining facilities. Exposure to heavy metals, such as lead, cadmium, copper, and arsenic, has long-lasting effects on the brain structure and function, promoting neurodegeneration, astrocyte homeostasis, and neurodegenerative diseases, such as Parkinson's disease, Alzheimer's disease, and dementia (1). From a functional viewpoint, it was reported that both long-term and short-term memory might be damaged in women with more than 2.4 mg/L of copper in their serum (2). Moreover, Mini-Mental State Examination scores have been reported to be inversely correlated with serum copper concentrations (3). Cadmium, a heavy metal with a very long half-life (approximately 23 years) in men (4), may also affect cognitive abilities. It has been reported that higher cumulative cadmium exposure may decrease performance in tasks requiring attention and perception (5). A recent study reported that the mean blood concentrations of cadmium in children with learning disorders were significantly higher than in controls (6). Some studies have reported an inverse relation between nitrogen dioxide and sulfur dioxide pollution and cognitive abilities (7, 8).

Creativity, as one of the main human cognitive abilities that has been less investigated, is defined as a set of mental processes that support the generation of novel and useful ideas. However, few studies have been conducted on the possible effects of heavy metals on creative cognition.

Creativity consists of 2 information-processing stages in the brain: Idea generation and idea evaluation. In idea generation (also called divergent thinking), a bottom-up process associated with diffuse attention would happen in the brain networks, while idea evaluation (also called convergent thinking) and an up-bottom process associated with focused attention and cognitive control would happen in brain networks (9). Creativity influences various aspects of human life, such as individual cognition, culture, and work engagement (10). Work engagement is a positive state that involves vigor, dedication, and absorption (11) and can be understood as job performance. Engaged personnel are cognitively and effectively associated with their work, so they perform their tasks more quickly and efficiently.

Copper miners are exposed to higher concentrations of copper, cadmium, molybdenum, nitrogen dioxide, and sulfur dioxide pollutants (12). Sarcheshmeh Copper Complex, located 50 km south of Rafsanjan, Iran, is the second largest copper deposit worldwide. It was reported that large amounts of sulfur dioxide, nitrogen dioxide, and ozone gases are produced in this mine, and the concentrations of copper, zinc, cadmium, molybdenum, and gold in the mine environment are high (13).

2. Objectives

This study aimed to investigate the creative cognition among personnel of the Sarcheshmeh Copper Complex.

3. Methods

3.1. Participants

This research is a cross-sectional study. The research population included personnel working at the Sarcheshmeh Copper Complex in Rafsanjan, southeast Iran. The sample size was calculated by formula $n = \frac{\left(z_{1-\frac{\alpha}{2}}\right)^2 \times \left(\sigma^2\right)}{d^2}$, with a confidence interval of 95%, an effect size of (d = 0.09) for remote associates test (RAT), as well as σ = 0.6, based on the previous research (14). One hundred and seventy people (n = 170) were determined as the sample size for this study. Given the possibility that some participants may not respond and participants' drop out, 204 people were selected.

The inclusion criteria of the study included (1) aged 18 - 65 years, (2) ability to read and write, (3) at least three years of work experience at Sarcheshmeh Copper Complex, and (4) willingness to participate in the research and signing the informed consent. Diagnosed neuropsychiatric disorders (seizures, attention deficit disorder, cognitive deficit disorders, paralysis, uncontrolled anger, migraine headaches, addiction, and eating disorders) and the use of drugs affecting memory during the past six months were exclusion criteria. The convenience sampling method was used to identify 204 participants based on inclusion and exclusion criteria.

3.2. Creativity Assessment Method

Remote associates test: The evaluation of convergent thinking by RAT in the Persian sample takes 5 minutes. The validity and reliability of this test for the Persian sample have been confirmed by Akbari Chermahini et al. (15). This task consists of 20 questions, with each question containing three unrelated words. Participants must find a common associate for each question to create a new combination. For example, three words, including garden, delicious, and red, can combine with the word “apple” and create three meaningful concepts. The number of correct answers is counted.

3.3. Evaluating Divergent Thinking (Alternative Uses Test)

Alternative uses test (AUT) was used to assess divergent thinking (it reflects the ability to find alternative solutions to open-ended problems, break the schemes, and try to be as creative as possible). In this task, participants were asked to write down common and unusual uses for ‘shoes’ or ‘bricks’ in 3 minutes (16). The score in this test consists of four sections:

Originality: In comparing the answers, a given unusual response by only 5% of all participants receives 1 point, and a given unusual response by only 1% receives 2 points.

Fluency: The total number of answers is counted and scored. Then, each answer is compared with the total number of answers and is scored.

Flexibility: The number of used categories is measured; then, each answer is compared with the total number of answers in that category.

Elaboration: The details of each answer are evaluated and scored. For example, "building bricks" gets 0, but "bricks to build a house wall and prevent it from being destroyed by the wind" gets 2 (1 point for building the wall and 1 point to describe the destruction by the wind).

3.4. Ethical Considerations

This study was approved by the Ethics Committee of Rafsanjan University of Medical Sciences (IR.RUMS.REC.1401.141). The study objectives were explained to the participants, with the participants' names and information kept confidential. In addition, the principles of confidentiality were met in publishing information, and the participants were assured to be free to leave the study at any time they desired.

3.5. Data Analysis

The total mean scores for RAT and AUT were 3.05 ± 2.05 and 10.91 ± 6.63, respectively. The normality of the data was examined using the Kolmogorov-Smirnov test, and non-parametric tests were used due to the non-normal distribution of the data ($P < 0.05$). Kruskal-Wallis tests were applied to compare participants' performance between RAT and AUT in age, educational level, and work experience subgroups. Bonferroni-adjusted P-values were applied for all pairwise comparisons. The data were analyzed using SPSS statistics v.18.0. The significance level was determined to be less than 0.05.

4. Results

4.1. Demographic Data

Table 1 summarizes participants' demographic characteristics. The mean age of the participants was 38.77 ± 6.29, and their age range was 26 to 58 years. Based on their age range, the participants were divided into three subgroups, including 26 - 36 years (subgroup 1), 37 - 47 years (subgroup 2), and 48 - 58 years (subgroup 3).

In terms of education, participants were divided into 4 subgroups: Subgroup 1 had at least 12 years of education, subgroups 2 and 3 had at least 14 and 16 years of education, respectively, and subgroup 4 had more than 18 years of education. The highest percentage of participants belonged to subgroup 1 (39.7%).

The participants were also divided into three subgroups based on years of work experience. In subgroup 1, the participants had less than 10 years of work experience, and in subgroups 2 and 3, they had 10 - 20 and more than 20 years of work experience, respectively. The majority of participants had 10 - 20 years of work experience (49.3%).

Table 1. Participants' Demographic Characteristics (N = 204)

Characteristics and Subgroups	No. (%)
Age (y)	
1. 26 - 36	89 (43.6)
2. 37 - 47	93 (45.6)
3. 48 - 58	22 (10.8)
Gender	
1. Male	192 (94.1)
2. Female	12 (5.9)
Job	
1. Miner	139 (68.8)
2. Office staff	63 (31.2)
Work experience (y)	
1. < 10	65 (32.0)
2. 10 - 20	100 (49.3)
3. > 20	38 (18.7)
Educational level	
1. 12	81 (39.7)
2. 14	32 (15.7)
3. 16	68 (33.3)
4. 18 or more	23 (11.3)
Marital status	
1. Married	193 (94.6)
2. Single	11 (5.4)
Opium use	
1. Yes	30 (14.8)
2. No	173 (85.2)
Alcohol use	
1. Yes	58 (28.6)
2. No	145 (71.4)

4.2. Comparison of Remote Associates Test and Alternative Uses Test Scores Based on Age, Educational Level, Work Experience, and Opium Use

4.2.1. Age

Results showed that performance in AUT was significantly affected by age [H (2) = 9.95, P = 0.007 and r = 0.22]. Pairwise comparisons showed that the AUT score decreased in subgroup 2 [(37 - 47 years) (mean rank = 92.40)] compared to subgroup 1 [(26 - 36 years) (mean rank = 117.14) (P = 0.014, r = 0.21)].

Regarding RAT, the results showed no significant effect of age ([H (2) = 2.32, P = 0.31, r = 0.07]) (Table 2).

4.2.2. Educational Level

Regarding the effect of education level on AUT and RAT, the results showed that performance in AUT was significantly affected by participants' education level [H (3) = 24.2, P = 0.0001, and 34% of variance in AUT was explained by education r = 0.34]. Pairwise comparisons showed that the difference in the AUT score was significant between subgroups 1 [(12 years of education) (mean rank = 78.31)] and 3 [(16 years) (mean rank = 119.54) (P = 0.0001, r = 0.35)] and between subgroups 1 and 4 [(18 years) (mean rank = 128.61) (P = 0.002, r = 0.35)].

Remote associates test was also different in different educational levels [H (3) = 10.31, P = 0.016, and 22% variance of RAT was explained by education r = 0.22].

Pairwise comparisons showed that the difference in RAT performance was significant between subgroups 1 (mean rank = 88.65) and 4 (mean rank = 127.67) (P = 0.005, r = 0.28) (Table 2).

4.2.3. Work Experience

The results showed the significant effect of work experience on AUT [H (2) = 7.45, P = 0.024, and 19% of the variance of AUT was explained by work experience r = 0.19]. Pairwise comparisons showed that the difference in AUT performance was significant between subgroups 1 (< 10 years) [(mean rank = 113.15)] and 3 (> 20 years) [(mean rank = 85.76) (P = 0.026, r = 0.22)].

The results showed the significant effect of work experience on RAT [H (2) = 12.33, P = 0.002, and 12% of the variance in RAT was explained by education (r = 0.12)]. Pairwise comparisons showed that the difference was significant between subgroups 1 [(mean rank = 122.31) and 2 (mean rank = 90.95) (P = 0.002, r = 0.27)] (Table 2).

4.2.4. Opium Use

The results showed that the AUT score decreased in opium users compared to non-users [(Mdn = 7, Mdn = 10, respectively) (U = 1914, P = 0.022)] (Table 3).

5. Discussion

In this study, we investigated creative cognition in copper miners. According to the results, both aspects of creative cognition may affect copper miners. Both AUT and RAT decreased in miners with more than 10 years of work experience.

Mining and industrial production are major sources of human exposure to heavy metals. The World Health Organization (WHO) reported that lead, cadmium, methylmercury, and arsenic were among the most toxic metals that target essential organs, including kidney, liver, and brain, causing nephrotoxicity, hepatotoxicity, and neurotoxicity (17).

There are different mechanisms by which heavy metals interact with the brain. They can interact with neurotransmitters, receptors, calcium, ion pumps, enzymes, and amino acid functional groups (18). The hippocampus is one of the structures most influenced by heavy metals (19). Also, this structure is an important brain region involving cognitive functions (20).

Lead has shown to impair learning and memory through disruption of N-methyl-D-aspartate receptors, protein kinase C function, and calmodulin mRNA expression in the hippocampus (19). Cadmium can inhibit the acetylcholine esterase and sodium/potassium ATPase (Na+/K+ ATPase) pump in neuronal cells (19). Arsenic causes cognitive dysfunction through reduced adrenaline, noradrenaline, dopamine, and serotonin in the brain's corpus striatum, frontal cortex, and hippocampus areas (19). Abbaoui and Gamrani have conducted interesting studies on copper sub-chronic intoxication in rodents and reported that sub-chronic copper-intoxication increased serotonergic outputs in the dorsal raphe nucleus, basolateral amygdala (21) and decreased dopaminergic neurons in the substantia nigra and ventral tegmental area in rats (22). According to human studies, individuals with high copper intake diets may have a faster rate of cognitive decline (23), and both long-term and short-term memory may inversely correlate with serum copper concentrations (2, 3).

The underlying neurobiological mechanisms of creative cognition are sparsely addressed and poorly understood. Boot et al. reported creative cognition as a function of dopaminergic modulation in fronto-striatal brain circuitries (24). Lin and Vartanian reported that the locus ceruleus-norepinephrine neuromodulatory system underlay creative cognition (25), and Liu et al. also reported that creative cognition was modulated by competition between the glutamate and γ-aminobutyric acid (GABA) neurotransmitter systems (26). Comparing the results of these studies with our study leads one to the conclusion that cognitive abilities may affect copper miners to a higher extent. The mechanism for these effects may be due to the neurotoxicity of heavy metals in miners. These metals can particularly modulate brain structures and neurotransmitters involved in creative cognition. However, more future studies are needed to measure the level of heavy metals in miners. In addition, using two groups of miners and non-miners is required for a more accurate interpretation.

In this study, we also found that AUT decreased with increasing age as it was lower in the age range of 37 - 47 than in 26 - 36 years. However, RAT did not change in 26 - 58 years of age. Reports on creative cognition and age are different. Wu et al. reported that adults and adolescents would perform equally well on most creativity measures (27). Massimiliano reported that divergent thinking and creative object production stabilized after 40 years and declined after 70 years (28). The decrease in AUT in adult miners may be due to the accumulation of more heavy metals and other pollutants in their bodies during their years of working in the mine.

Our results also revealed that the AUT score decreased in opium user miners. Parts of the structures of the nervous system are both the basis of addiction and involved in cognitive functions such as learning, memory, attention, and reasoning. Reports demonstrate that

Table 2. Comparison of Remote Associates Test and Alternative Uses Test Scores Based on Demographic Characteristics, Including Age, Work Experience, and Educational Level (the Kruskal-Wallis Test Results)

Characteristics and Subgroups	RAT, Mean Rank	P	AUT, Mean Rank	P
Age (y)		0.31		0.007 **
1. 26 - 36	105.51		117.14	
2. 37 - 47	103.82		92.40	
3. 48 - 58	84.75		85.98	
Work experience (y)		0.002 **		0.03 *
1. < 10	122.31		113.15	
2. 10 - 20	90.95		103.04	
3. > 20	108.39		85.75	
Educational level (years of education)		0.016 *		0.001 **
1. 12	88.65		78.31	
2. 14	101.42		108.75	
3. 16	110.99		119.54	
4. 18 or more	127.67		128.61	
2. Total	99.22		101.2	

Abbreviations: RAT, remote associates test; AUT, alternative uses test.

Table 3. Comparison of Remote Associates Test and Alternative Uses Test Scores Based on Demographic Characteristics, Including Gender, Job Status, Marital Status, Opium Use, and Alcohol Use (the Mann-Whitney Test Results)

Characteristics and Subgroups	RAT, Median	P	AUT, Median	P
Gender		0.88		0.09
1. Male	3		9	
2. Female	3		14	
Job status		0.16		0.42
1. Miners	3		9	
2. Office staff	3		11	
Marital status		0.61		0.92
1. Single	4		6	
2. Married	3		10	
Opium use		0.26		0.02*
1. Yes	3		7	
2. No	3		10	
Alcohol use		0.28		0.76
1. Yes	3		10	
2. No	3		9	

Abbreviations: RAT, remote associates test; AUT, alternative uses test.

long-term use of addictive drugs leads to permanent cognitive decline. The nature of deficits depends on the drug type, the environment, and the user's genetics. For opioids, Lyvers and Yakimoff reported that opioid dependence is associated with disruption of executive cognitive functions mediated by the prefrontal cortex (29). Li et al. (as cited by Ouzir and Errami) measured the level of GABA and glutamate of codeine-addicted patients and noticed a decrease in both GABA levels and cognitive abilities (30). Our results are in agreement with previous findings and demonstrate the deleterious effect of opium addiction on creative cognitions in miners.

5.1. Limitations

In this study, we did not measure heavy metal concentrations in miners. In the last few decades, bio-monitoring has become a useful tool to measure exposure to toxic compounds in occupational settings, and its relevance for public health has become increasingly apparent (31). Nail and scalp hair have become interesting bio-indicators in various disciplines, such as the biological, medical, environmental, and forensic fields (32). On the other hand, it was reported that some confounding factors (age, the type of work activity, and smoking) have modulated the concentrations of trace elements in hair and nails (33). In addition, Gerhardsson et al. measured the concentrations of cadmium, copper, and zinc in tissues (hair, nail, lung, kidney, brain, and liver) of deceased copper smelter workers. They concluded that neither copper nor zinc concentrations in hair and nails seemed to provide a useful measure of the trace element status of the smelter workers (34).

Future studies (considering confounding factors) are needed to make any conclusion about the relation between trace element concentrations in miners and cognitive abilities.

Also, in this study, we did not compare cognitive creation between miners and non-miners. Comparing the creative cognition between the two groups of miners and non-miners would give a more accurate interpretation. So, more future studies should be conducted to answer these two questions: (1) is there any relation between trace elements intoxication and creative cognition? and (2) how is creative cognition in copper miners and non-miners?

5.2. Conclusions

This study demonstrated that creative cognition might be affected in copper miners. Also, opium addiction and age might impair creative cognition in copper miners.

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Footnotes

Authors' Contribution: A. S., T. S, and A. K.: Conceiving and designing the evaluation and drafting the manuscript; M. A., S. A., and D. Z.: Participating in designing the evaluation, performing parts of the statistical analysis and helping draft the manuscript; M. M., N. S., and M. S.: Collecting and interpreting the clinical data and revising the manuscript. All authors read and approved the final manuscript.

Conflict of Interests: There was no conflict of interest.

Data Reproducibility: The dataset presented in the study is available on request from the corresponding author during submission or after publication.

Ethical Approval: This study was approved by the Ethics Committee of Rafsanjan University of Medical Sciences (IR.RUMS.REC.1401.141).

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Informed Consent: Participants signed the informed consent.

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