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IMPAIRMENT OF PSYCHOLOGICAL FUNCTIONS IN CHILDREN ENVIRONMENTALLY EXPOSED TO LEAD

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Abstract. The major objective of the study was to determine whether environmental exposure to lead exerts a negative impact upon psychological functions in children. The examined group consisted of school age children (6–15 years old, x = 9.5, SD = 1.4) living close to copper works. Out of 4548 children with measured blood lead concentrations, two groups were selected one with the highest exposure levels (12.0–27.2 μg/dl) and the other drawn from the remaining children, with low blood lead levels. The mean exposure level for the whole examined group equalled 10.18 μ/dl PbB (SD – 4.73 μg/dl).
To assess effects of the exposure, the following variables were measured in the examined children: intelligence, hand-eye coordination, perception, memory, reaction time and accuracy, and behaviour disorders. The moderator variables of sociodemographic character, i.e. parents' education, income, etc., were also controlled. A significant impact of lead upon psychological functions and behaviour was revealed for two variables only: intelligence and attention concentration. An increase in the exposure level by 10 μg/dl PbB was associated with deterioration of general IQ by 5.3 points and growth of the number of mistakes in the Simple Reaction Time test by 3.3. It was also revealed that the short-term memory deteriorates with growing level of exposure, the strength of this relationship was close to the level of statistical significance ($p < 0.07$).

INTRODUCTION

Inorganic lead belongs to the group of neurotoxic substances most commonly found in the environment. Although the environmental exposure does not reach the level resulting in acute poisoning, long-term exposure of a human body to low lead concentrations may also lead to dangerous effects on human health and functioning.

In the exposed population, children are most sensitive to negative effects of lead for the following reasons:

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– immature organs are more endangered with impairment during their rapid development, and that is why the brain of a child is most sensitive to lead during the first two years of life;

– metabolic processes are faster in children, which increases the dose of lead computed for the body weight;

– it is suggested that the blood-brain barrier is less developed in small children, which makes their nervous systems more sensitive to impairment (1).

In order to assess negative effects of environmental lead on the nervous system, psychological methods are employed. Broad use of these methods dates from the 70s. As the accurate mechanism of lead effects on the central nervous system and its specific functions is not known, a wide range of methods have been used in psychological research. Due to experience gained, their number has been now limited to those that show sufficient sensitivity and reveal differences in performance depending on the level of lead exposure of the subjects examined.

The following psychological modalities and behaviour traits are most often measured in psychological research: intelligence, psychomotor performance (hand--eye coordination, motor precision), reaction time to auditory and visual-motor tasks the performance of which serves to assess varied aspects of memory and attention, the level of school performance (reading, counting), and behaviour disorders (impulsivity, hyperactivity, mood changes).

Groups of school age children have been most commonly subjected to examinations aimed at determining the relationship between the level of exposure to lead and psychological effects. The researches focus on children with higher blood lead levels found in the course of clinical examinations, children inhabiting regions close to sources of lead emission, and children from the general population. These groups usually differ as far as the mean body lead levels were considered. On account of that, the effects of lead exposure were assessed at different levels, from very low, close to zero, to the level of circa 60–70 μg/dl PbB. No definite results have as yet been obtained, nevertheless, consideration of the most common results renders it possible to draw some conclusions regarding psychological effects of chronic exposure to low lead concentrations.

Intelligence. The relationship between exposure and the level of intelligence is most frequently revealed: if the exposure values increase, children's intelligence deteriorates (2). The most frequent difference in IQ between the groups with high and low exposure account for 7 points. The research results have not provided a clear basis for determining the threshold value of exposure, above which deficits in children's intelligence could be expected.

School performance. School performance is assessed by means of tests measuring capacities of reading and counting (3). Children with higher lead level obtain, in comparison to the less exposed children, lower results in tests involving rather reading than counting. Moreover, a higher percentage of children from the groups exposed to lead, in comparison to those nonexposed, is described by teachers as hyperactive, impulsive, and quick-tempered individuals.

Other psychological variables. Psychomotor tests aimed at measuring hand-eye coordination appear insensitive to changes in the exposure level, that is the same results are obtained by children with different blood lead concentrations (4). The greatest number of coherent results is obtained using the Bender test, which measures the level of the development of visual-motor integration processes. Other tests measuring the same function were insensitive to the increase in the body lead level.

OBJECTIVES OF THE STUDY

The objective of the study was to find answers to the three following questions:

— Which of the psychological functions deteriorate if they are influenced by environmental exposure to lead? The answer to this question will allow to identify functions that are most sensitive to adverse environmental effects.

— What is the role of lead exposure in explaining variability of psychological variables in comparison to social-demographic variables? The point is to assess the level of relative significance of lead exposure responsible for the deterioration of psychic functions in children.

— Is there any threshold value of exposure above which psychic functions deteriorate significantly? Determination of such a threshold value would play a crucial role in defining safe levels of exposure.

MATERIALS AND METHODS

The methodological scheme of the study was based on the recommendation of the WHO/CEC collaborative study on neurobehavioural toxicity of environmental lead exposure.

Subjects

The first stage of the subject selection included the measurement of venous blood level in 4548 children within and initial screening survey performed under the Local Health Programme; 200 children with the highest lead exposure were eligible for the study. The cut off point was the exposure of 12 μg/dl. The second group of 200 children with blood lead level lower than 12 μg/dl was randomly selected from remaining children in order to obtain a wide spectrum of exposure in this region. The selected children and their parents were invited to psychological centres, where the children were tested and parents (mainly mothers) interviewed by experienced psychologists.

Lead levels in venous blood were measured using atomic absorbtion spectometry. The laboratory where all the measurements were done participates successfully in the United Kingdom National External Quality Assessment Scheme.

The following characteristics were assessed in testing: intelligence level, memory, reaction time and correctness, perception, attention concentration, hand-eye coordination, and behaviour traits: psychomotor hyperactivity, aggressiveness, sociability, emotional disorders, impulsivity. Moreover, some social-demographic characteristics of a family were observed; these included parents' education level, their professions, economical standard, housing conditions, the course of pregnancy and delivery, diseases and injuries suffered by the child, activity and typical games of the child. Due to the fact that the social-demographic variables may themselves determine the intelligence level of children or their exposure level, they are capable of modifying the strength of relationship between the level of exposure and the development of the psychic functions measured in the study. The complete list of the variables and methods used for their assessment, is presented in Table 1.

Table 1. List of dependent and moderator variables used in the research

Dependent variables (psychological)		Moderator variables (sociodemographic)	
Variable	Method	Variable	Method
Intelligence	WISC-R	Economic situation of the family	
Memory	the Sentence Memory Test of the Basic School Aptitudes Scale	Housing situation of the family	
Perceptual maturity	the Bender-Kopitz Test	Family state. Parents' education level	
Hand-eye coordination	the Joining Points Test, part A; from the Halstead-Reitan battery	The course of pregnancy and delivery	Questionnaire interview
Reaction time	tests: Simple Reaction Time and Choice Reaction Time	Diseases in early childhood	
Behaviour disorders	The Questionnaire of Child's Behaviour in Kindergarten and School by Scheafer and Aaronson		

Statistical analysis

All the examinations were provided by 6 experienced psychologists who had additionally participated in a special training to standardize the procedure of testing (instructions, tests sequence etc.) Psychologists were blinded with suspect to Pb-exposure.

In order to assess the relationship between the exposure level (independent variable) and the psychological variables (dependent variables), the analysis of multiple regression (Forward) was performed so as to exclude the influence of moderator variables. For each psychological variable, an appropriate set of moderator variables was defined. To choose potential confounders we used 2-factorial analysis of variance. A given set contained the moderator variables that were found to correlate with the given psychological variable or lead level.

RESULTS

The analysis was made for the examination results of 380 children. Twenty subjects were excluded because they did not meet the criteria for participation in the study (the same as in the WHO protocol on monitoring lead neurotoxicity in children, Dusseldorf, 1984). All the children came from ecologically endangered areas. The maximum distance from a child's living site to an exposure source (copper works or waste sediment trap) was not longer than 25 kilometres. The exposure level in the examined group ranged from 1.2 μg/dl of lead in blood to 27.2 μg/dl. The mean value of exposure equalled 10.18 μg/dl, and the standard deviation was 4.7. Only in 5% of the subjects the exposure level was higher than 20 μg/dl. The children under study aged from 6 to 15 years but those above 13 made only 1.3% of the whole sample.

The analysis of the results revealed that only two psychological variables correlated with the lead exposure at a statistically significant level. These are: 1) attention concentration measured with the number of correct answers in the Simple Reaction Time test, and 2) the intelligence level measured using the Wechsler test (WISC-R). Short-term memory was the third variable associated with the exposure level, but the correlation coefficient was only close to statistical significance ($p < 0.07$). The remaining psychological variables were not associated with the exposure level. Characteristics of the distributions of the above variables are presented in Table 2.

Table 2. Distribution characteristics of variables associated with the lead exposure level at a statistically significant level ($n = 380$)

Variable	$\bar{x}$	Standard deviation	min	max
WISCR-R:				
– verbal scale	96.3	14.8	51	137
– performance scale	100.0	13.5	64	131
– complete scale	98.2	14.1	58	138
Simple Reaction Time:				
– reaction time in msec	462.4	158.7	245	1348
– number of correct reactions	55.7	10.4	0	60
Sentence Memory				
– number of memorized sentences	6.9	1.3	1	10

The set of potential moderator variables comprises tens of factors, but 2-factor analysis of variance performed in the study showed that only eight of them were significantly correlated with the lead level or with one of psychological variables. These variables (presented in Table 3) were included in the regression equations used to define dependencies between the exposure level and the psychological variables enumerated above.

The results of the analysis of multiple regression, which show the relationship between the scores on the Simple Reaction Time Test and the blood lead concentrations, with the moderator variables taken into account, are presented in Table 4. In the analysis, two indicators of the test performance were used, namely the mean reaction time and the number of correct reactions. No correlation was found between the mean reaction time and the exposure, on the other hand, the number of correct reactions, which is an indicator of the attention concentration quality, turned

Table 3. List of moderator variables and their categories, included in the regression equation

Variables	Categories of variable
Sex	girl/boy
Number of children in the family	Continuous variable: 1 to 9
Mother's occupational status	1. employed 2. staying at home
Mother's education	1. low educated 2. high educated (university level)
Income per a family member	continuous variable
Smoking during pregnancy	Yes/No
Delivery disturbances	Yes/No
Birth weight	continuous variable: 2500 to 4900 g

Table 4. Parameters of the multiple regression equation between number of correct reactions in Simple Reaction Time Test, and lead exposure level and moderator variables (n = 380)

Independent and moderator variables	B	β	p
1. Lead exposed children	−0.33	−0.15	0.002
2. Delivery disturbances	−4.62	−0.13	0.008
3. Age	3.68	0.17	0.000
4. Income	3.90	0.15	0.007
5. Number of children	−1.36	−0.06	ns
6. Mother's education	−2.32	−0.11	0.041

out to be associated with the blood lead concentration at a statistically significant level. The B and beta-standardized coefficients and the statistical significance levels for all the variables included in the regression equation, are presented in the same table. All the variables except one are significantly related to the number of correct reactions. The strength values for the relationships, shown by the beta--coefficients are similar.

Intelligence was another psychological variable that correlated with the blood lead level. The Wechsler Intelligence Scale For Children – Revised gives us three main indicators: global IQ, verbal intelligence quotient and nonverbal intelligence quotient.

Table 5. Parameters of the multiple regression equation between scores on the WISC-R (verbal scale) and lead exposure level and moderator variables (n = 380)

Independent and moderator variables	B	β	p
1. Lead exposure	−0.575	−0.18	0.000
2. Family income	4.130	0.14	0.008
3. Occupational status of mother	−2.053	−0.07	ns
4. Number of children	−1.634	−0.06	ns
5. Mother's education	8.829	0.29	0.000

The results of the analysis of multiple regression for the indicators mentioned above are presented in Tables 5, 6, and 7. It appears that mother's education exerts the dominant influence upon child's scores on the intelligence test. The higher

Table 6. Parameters of the multiple regression equation between scores on the WISC-R (performance scale) and lead exposure level and moderator variables (n = 380)

Independent and moderator variables	B	β	p
1. Lead exposure	0.344	−0.12	0.013
2. Number of children	−1.938	−0.07	ns
3. Smoking	−1.216	−0.04	ns
4. Occupational status of mother	−1.253	−0.05	ns
5. Mother's education	8.116	0.30	0.000

Table 7. Parameters of the multiple regression equation between scores on the WISC-R (global scale) and lead exposure level and moderator variables (n = 380)

Independent and moderator variables	B	β	p
1. Lead exposure	−0.530	−0.18	0.000
2. Number of children	−1.895	−0.07	ns
3. Smoking	−0.504	−0.02	ns
4. Sex	−0.543	−0.02	ns
5. Occupational status of mother	−1.564	−0.05	ns
6. Mother's education	9.292	0.32	0.000
7. Income	3.674	0.13	0.014

mother's education (primary, secondary, university) the higher child's scores. They increase by 8.8 points on the verbal scale by 8.1 points on the performance scale, and by 9.3 points on the global scale. Another factor found to influence significantly the scores on the Wechsler test is the blood lead level. The increase by 10 μg/dl in the lead level results in lowering IQ by 5.8 points on the verbal scale, by 3.4 points on the performance scale, and by 5.3 points on the global scale.

The relationship between the levels of exposure, mother's education and the intelligence level, is presented in Fig. 1. The same tendency may be observed in both groups of mothers, i.e. with higher and lower education; the higher level of exposure, the lower IQ indicator. The most rapid deterioration of IQ was observed at the exposure levels between 5−10 μg/dl and 11−15 μg/dl PbB.

Short-term memory, measured with the Sentence Memory Test, turned out to be the third psychological variable associated with the level of lead exposure. The strength of relationship between these variables is very small, hardly close to the statistically significant level ($p < 0.07$). The Sentence Memory was much more dependent on the age of subjects and their mothers' education (Table 8).

Table 8. Parameters of the multiple regression equation between the number of memorized sentences, and lead exposure level and moderator variables (n = 380)

Independent and moderator variables	B	β	p
1. Lead exposure	−0.026	−0.09	0.070
2. Occupational status of mother	−0.150	−0.05	ns
3. Birth weight	0.194	0.05	ns
4. Age	0.794	0.29	0.000
5. Mother's education	0.403	0.15	0.007
6. Income	0.133	0.05	ns

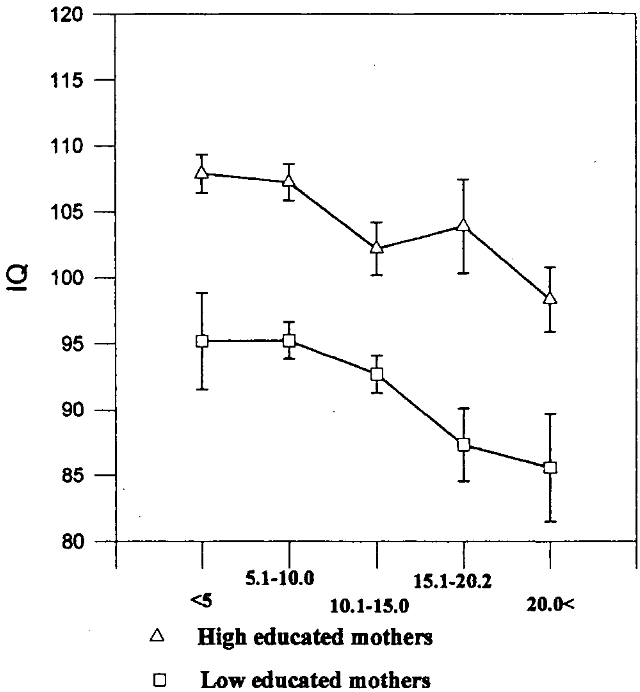

Fig. 1. Relationship between lead exposure and 1Q (WISC-R-full scale) in two groups of mothers.

DISCUSSION AND CONCLUSIONS

The obtained results render it possible to draw some conclusions with regard to the research objectives.

1. Only three psychological functions turned out to be sensitive to the adverse effects of environmental lead. These are: intelligence, attention, and short-term memory. The very important role these functions play in cognitive functioning of a man stresses the significance of negative lead effects and points to the necessity of eliminating lead from the human environment.

2. The variable of lead exposure explains variability of psychological functions to a small extent only. The beta-standardized coefficients, which roughly correspond with the partial correlation coefficients, range from 0.09 to 0.18. Some of the social-demographic variables appeared to be more important determinants of the level of psychological functions. In this group of variables, mother's education was the most important one.

In other studies (4) the relationship between psychological variables and the level of lead exposure were equally weak, which is not strange as one variable cannot be expected to explain a large percentage of variance of psychological functions dependent on many factors.

3. An important objective of all studies of the lead exposure influence on psychological functions lies in determining the lowest dangerous level of exposure. Such a threshold value was defined in the Greek research (5); the authors recognized that the dangerous level of exposure begins with 25 μg/dl PbB. The results of our

study indicate that this limit should be lowered to 15 μg/dl PbB. This conviction is underpinned by the analysis of curves given in Fig. 1 which shows that the highest gradient of curves lies at the passing from the level of 5 – 10 μg/dl to 11 – 15 μg/dl. Our conclusion regarding the safe exposure level is consistent with the recommendations contained in the Preventing Lead Poisoning in Young Children (6).

Finally, similarities between our results and the results obtained by other researchers (1,4), are worth noting as they justify generalization of some dependencies. For instance, lack of relationship between the reaction time and the exposure, whereas a significant relationship between the number of correct reactions and the exposure, was found by Winneke et al. (7). They examined children living near lead emission sources, namely smelters, with the exposure level range from 2 to 30 μg/dl of lead in blood (mean – 10.0 μg/dl). As for the way and the level of exposure, the study group was very much alike our group. According to the results reported by Winneke at al. (8), the exposure to lead exerts destructive effects on the attention process and lowers children's capability of attention. Winneke repeated the research after 3 years and observed a similar relationship between the exposure level and the number of correct reactions, which proves the tendency to be constant.

In the majority of studies (1,9) with observed a relationship between the level of lead exposure and the intelligence quotient, the tendencies found were the same as in our study. The highest correlation was noted between the level of lead exposure and the performance on verbal scale. However, no correlation or much weaker one, was found between the level of lead exposure and the scores on performance scale.

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