Effects of lead pollution in SY River on children's intelligence

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Abstract To investigate the influence of lead pollution in SY River on children's intelligence and provide a scientific data for governance of the SY River and protection of the residents, especially children. The polluted area and control area were selected randomly from less than 5 km and more than 20 km away from the SY river basin, respectively. Concentrations of lead in the river water, drinking water, soil, grain and vegetables were measured by atomic absorption spectrophotometer (flame technique). There were 154 children, aged from 8 to 13, were recruited from two areas. Combined Raven's Test (CRT) was used to measure the intelligence of the children. The concentration of lead in SY River was exceeding the standards of surface water quality. Compared to the control area, the concentrations of lead were significantly higher in the polluted area among drinking water, soil and vegetables ($P<0.05$). Blood lead levels were significantly higher in children who were living in polluted area than those living in control area ($P<0.05$). Similarly, children who were living in polluted area had significantly lower IQ than those living in control area ($P<0.05$). After controlling for confounders, an inverse association was observed between blood lead concentration and IQ scores ($\beta=-0.293$, $P<0.05$). These data suggested that the lead pollution in SY River were still serious and had entered the body by soil, drinking water and vegetables. Finally, our study suggested that environmental lead exposure had affected the children's intelligence to a certain extent.

[Tang CY, Li AQ, Huang H, et al. **Effects of lead pollution in SY River on children's intelligence.** *Life Sci J* 2012;9(3):458-464] (ISSN:1097-8135). http://www.lifesciencesite.com. 65

Key words: Water pollution, Lead, Children, Intelligence

1. Introduction

Lead is a common industrial toxin and environmental pollutant and can enter the human body by mouth, skin and respiratory tract, et al. What's more it can affect the nervous system significantly, especially on the central nervous system. With the rapid development of industrial and urbanization process, more and more developing countries have paid attention to the adverse effects of lead pollution on people's health, especially on children's nervous system (Matte TD, 2003). Children aged from 8 to 13 were in the second peak of growth and development, and more vulnerable to lead poisoning because of incomplete brain development and poor detoxification function. Most research showed that 40% to 50% of lead that children intake were from food, while adults only 5% to 10% (Markowitz M, 2000). A Clinical study have shown that there was a significantly negatively relationship between blood lead and IQ. When the concentration of blood lead was 100μg/L to 200μg/L, the average of IQ would decrease 1 to 3 points, while the average of IQ would drop 5 to 10 points when the blood lead was greater than 300μg/L (Lidsky T I and Schneider J S. 2003). However, more and more studies began to focus on the relationship between low levels of lead exposure and children's IQ. Bellinger DC (2008) found that no level of lead exposure appears to be "safe" and even the blood lead levels which were lower than 10μg/dL in children are associated with neurodevelopment deficits. A series of literatures also showed that even if children's blood lead levels below 10μg/dL, they can appear significant neurological dysfunction (Pamela J. Surkan, et al. 2007, and Marek Jakubowski, 2011) . Tellez-Rojo(2006) and Jusko(2008) reported that children's IQ which were inversely associated with blood lead levels, decrease or deteriorate greater with increasing blood lead levels of <100μg/dL than that of ≧100μg/dL.

Huai River is the third largest river in China which runs through Henan, Anhui, Shandong and Jiangsu provinces. It has a total length of 1,000 km which covers an area of 270,000 km^2, and about 150 million people live here. Since the 1980s, the water pollution in Huai river was getting worth and worth, and the accidents which caused by water pollution occurred frequently(Li X, 2009). After 90 years, the problems of water pollution in Huai River were concerned by the different levels of environmental protection departments and the total pollutants in Huai River were decreased. However, there was a serious rebound of pollution in recent years(Wang G.Y, 2008). SY River is located in the hinterland of Henan province which is the largest tributary of the Huai River. Various types of wastewaters from 31 cities were poured into the river without any sewage disposal. Some researches showed that SY River had lost its self-purification capacity because of receiving so many municipal and agro-industrial wastewaters(Wang W.J, 2009, and Gao H.L, et al. 2010).

The effect of Huai River pollution on health of local people is a major issue of social concern. There were many reports about the effects of Huai River pollution on the health of local people(Zhang H.C. 1989, and Zuo Z.J., et al. 2009). However, research about the impact of lead exposure in SY River on children's intelligence has not been reported. Therefore, children's intelligence and the concentration of blood lead were measured to explore their relationship on basis of the environmental level of lead in SY river water, drinking water, soil, grain and vegetables.

2. Material and methods

2.1 Location and objects selection

This study was conducted in S county which is the last county that SY River runs through in Henan Province. The polluted area and control area were selected randomly from less than 5 km and more than 20 km away from the SY river basin, respectively. There were no differences between the two villages about the social and natural factors like economic situation, educational standard and geological environments et al. None of these two sites was exposed to other potential neurotoxins that are recognized as contaminates influencing IQ value. School children aged 8 to 13 years old who were grade 3 to 5 were selected by cluster sampling. 73 of them were recruited from the polluted area and 90 were from the control area. For the current study, we finally excluded 9 children who didn't complete the questionnaire because of their parents were not at home, resulting in 154 subjects eligible for our study. 69 of them were from the polluted area (30 males and 39 females) and 85 were from the control area (43 males and 42 females). In addition, an informed written consent of participation in the study was signed by the parents of the children. The local Ethics Committee of the human subjects' research, Zhengzhou University, approved this study.

2.2 Questionnaire and quality control

A questionnaire was designed for children's intelligence which was very susceptible to many factors. Father's occupation, mother's education, children's daily intake of protein (especially milk and eggs), family income and other potential confounding factors were included in the questionnaire. Investigators were trained in advance and parents of children were visited by face to face interview survey.

2.3 Blood samples

The subjects were requested to fast for at least 10 hours before they came for the study. The fasting blood samples, totaling 5 ml were drawn into vacuum tubes. Immediately upon collection, samples were stored on ice. At the end of each daily collection, samples were centrifuged to separate serum and stored at -80℃ until analysis. Blood lead was analyzed with Polarograph (Metrohm Ltd., Switzerland). Each sample was measured three times and added standard two times. The mean recovery rate was 98.6%.

2.4 Environment samples

River water samples were collected from three sampling sections which were set up at S county. The upstream section (US) was set up at the place where the SY River just enters the city, the midstream section (MS) was set up at the Huaidian sluice gate and the downstream section (DS) was set up at the place where the SY River runs out of the town. Samples were collected from each section by quartering in the dry season (December to February) and wet season (July to September). Drinking water, soil, grain, and vegetables samples were collected from five positions (east, south, west, north and central) of two villages, respectively. Three samples were collected from each position. The collection and preservation of samples were accordance with the standards of China (GB/T 5750.2-2006). Leads in all samples were assayed by atomic absorption spectrophotometer (flame technique). Each sample was measured three times.

2.5 Assessment of intelligence

Children were administered to take the Combined Raven's Test-The Rural in China (CRT-RC3) to evaluate their intellectual ability. CRT is a recognized intelligence test which is more effective because there is no limit to cultural, ethnic, language and other factors, and the results are simple and intuitive as well. In 1985, the CRT was revised in China and achieved a high degree of reliability and validity(Yin J, 2007). The seven categories of this test scores are as follows: $\leqq$69 retarded (low); 70-79 borderline (below average); 80-89 dull normal (low average); 90-109 normal (average); 110-119 high normal (high average); 120-129 superior (good); $\geqq$130 very superior (excellent).

2.6 Statistical analysis

The database were established using Epidata 3.0 software (Epidata 3.0 for windows, Epidata Association Odense, Denmark) and the data were doubled enter into the database by different people. All the data were analyzed using SPSS 12.0 software (SPSS Inc., Chicago, United States). Kolmogorov-Smirnov test and Levene test were used to inspect the normality and homogeneity of variance of all data. The blood lead was a log-normal distribution and the concentrations of lead in drinking water, soil, grain, vegetables and blood and the IQ of children in two areas were compared using Independent-Sample *t*-test. Mean concentrations of lead in river water, mean blood lead levels and mean IQ in different groups were compared using ANOVA. The chi-squared test was used for comparison between qualitative variables of the groups studied. Spearman's rank correlation coefficient *r* was used to determine the relationship between blood lead and IQ scores. In addition, we performed a multiple linear regression model to analyze the association of blood lead with IQ scores which controlled for potential confounding factors. Significance level was α= 0.05.

3. Results

3.1 The concentrations of lead in SY River

The river water samples were gathered and detected both in dry season and wet season. The mean concentrations of lead were presented in Table 1. When comparing the mean concentrations of lead in river water, no statistically significant differences were observed in the three sections (P>0.05). Compared with the standards of surface water quality (GB 3838-2005), the contents of lead in river water were exceeding class Ⅳ both in wet and dry seasons.

Table 1. The results of lead in river water in wet and dry seasons($\bar{x}$±s，μg/L)

	n	Wet season	Dry season
US	24	52.1±8.9	75.3±11.4
MS	24	70.4±12.8	54.3±5.4
DS	24	64.8±7.8	74.0±13.3
F value		2.587	3.662
P value		0.155	0.091

3.2 The concentrations of lead in environmental samples

The concentrations of lead in soil, grain, vegetables and drinking water were shown in Table 2. Compared with control area, the mean concentrations of lead in soil, vegetables, grain and drinking water of polluted area were significantly higher (P<0.05). The concentrations of lead in the samples of control area were below the standards of relevant quality in China. But in the polluted area, the concentrations of lead in soil, grain, drinking water and vegetables were exceeding the standards. The standard of soil, grain and drinking water quality were GB 15618-2008, GB 2175-2005 and GB 5749-2006, respectively.

Table 2. Concentrations of lead in soil, grain, vegetables, and drinking water in two areas ($\bar{x}$±s)

	Soil(mg/kg) (n=60)	Grain(μg/kg) (n=30)	Vegetables(μg/kg) (n=30)	Drinking water(μg/L) (n=30)
Control area	68.01±52.28	180.75±114.18	582.11±197.58	7.200±1.202
Polluted area	90.00±55.89	325.31±155.19	815.64±380.81	17.200±8.311
t value	-2.300	-3.001	-2.177	2.663
P value	0.023	0.005	0.037	0.029

3.3 The basic situation and blood lead levels of children in two areas

Children's age and sex in two areas were demonstrated in Table 3, and the mean concentrations of blood lead of children in two areas were shown in Table 4. Mean age of the children in two areas had no significant difference (P>0.05) and similar results were found in children's sex (P>0.05). Children who were living in polluted area had significantly lower IQ than those living in control area (P<0.05). Similarly, blood lead levels were significantly higher in children who were living in polluted area than those living in control area (P<0.05).

Table 3. Children's age and sex in two areas

	Age (yr，$\bar{x}$±s)	Male	Female
Control area（n=85）	10.51±1.24	48	37
Polluted area（n=69）	10.89±1.18	30	39
$t(\chi^2)$ value	1.967	2.572	
P value	0.051	0.109	

Table 4. Mean IQ and blood lead levels of children in two areas

	IQ (scores)	Log(Blood lead)(μg/L)
Control area (n=85）	111.00±12.65	1.67±0.188
Polluted area (n=69)	106.75±11.81	1.77±0.17
t value	-2.126	3.227
P value	0.035	0.002

3.4 Age and IQ scores of children with different blood lead levels

According to the blood lead levels of children, four groups were divided as follows: <30, 30-50μg/L, 50-75μg/L and >75μg/L. The ages and IQ scores of children with different blood lead levels were shown in Table 5. Statistically significant differences of age were observed between the four groups. Moreover, children with high blood lead level had significantly older than those with low blood lead level ($P<0.05$). Compared the mean IQ scores of the four groups, the differences between each of them were statistically significant ($P<0.001$). Meanwhile, IQ scores were significantly reduced in children with blood lead levels increased ($P<0.05$).

Table 5. Age and IQ of children with different blood lead levels ($\bar{x} \pm s$)

	N	Age (yr)	IQ scores
Blood lead levels			
<30(μg/L)	18	10.12±1.39	120.38±11.25
30-50(μg/L)	48	10.22±1.14	112.75±10.04
50-75(μg/L)	56	11.07±0.95	107.67±10.84
>75(μg/L)	32	11.09±1.35	99.51±11.841
F		8.126	16.654
P		<0.001	<0.001

3.6 Blood lead levels of children with different ages

According to the ages of children, six groups were divided. The tendency chart of blood lead levels changing with age was shown in figure 1. Blood lead levels were increasing with age. Compared the mean blood lead levels of the six groups, the differences between each of them were statistically significant ($F=6.358$, $P<0.001$).

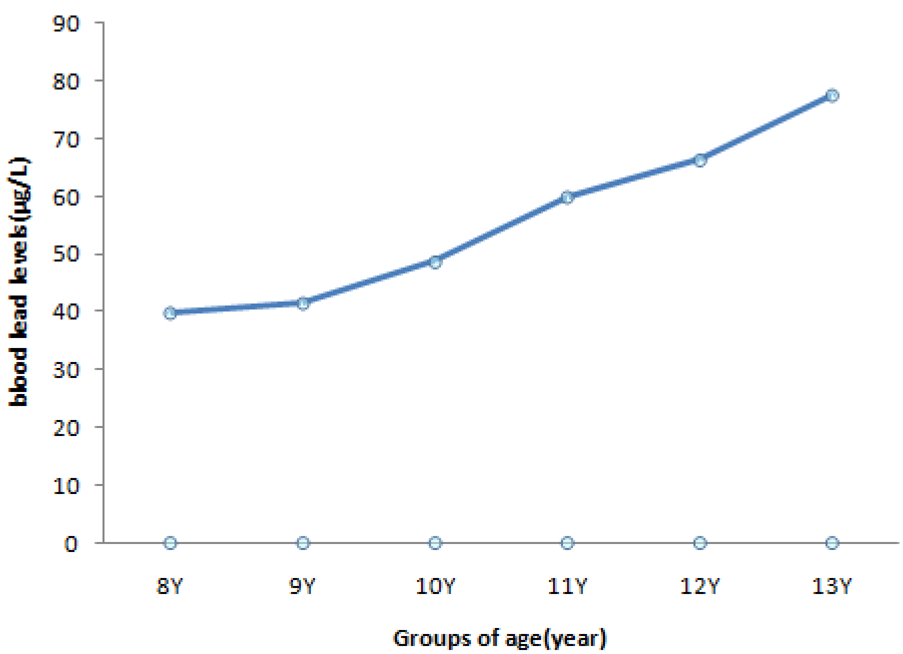

Figure 1. Blood lead levels of children with different ages

3.7 The association between blood lead levels and IQ scores

To test the association between lead in blood and IQ scores, Pearson's correlation analysis and multiple regression models were calculated. Results are shown in Table 6. The coefficient (*r* value) was -0.55, but adjusted for feeding patterns, father's occupation, mother's educational, family income, children's daily intake of protein (especially milk and eggs) and other potential confounding factors, the coefficient (β value) was -0.293 (P<0.001).

Table 6 Multivariable model results for IQ by blood lead, adjusted for confounding variables (n=154)

	Coefficients	*P*
Pearson		
Log(Blood lead)	-0.55	<0.001
Adjusted model		
Log(Blood lead)	-0.293	<0.001
Feeding patterns	0.013	0.852
Mother's educational	0.019	0.786
Fother's educational	0.014	0.846
Family income	0.127	0.062
Father's occupation	0.072	0.295
Mother's occupation	-0.097	0.192
Breakfast	0.071	0.297
Picky eaters	-0.094	0.169
Milk intake	0.055	0.421
Eggs intake	0.080	0.240
Sleeping time	-0.044	0.523

4. Discussions

4.1 The lead pollution in SY River and its diffusion paths

The results of this study showed that the concentrations of lead in SY River were exceeding the standards of surface water quality. The groundwater which was the source of drinking water for the nearby residents had been contaminated by lead in SY river via the spread horizontally, infiltrate vertically, as well as dissolved by rainwater. And the soil were contaminated because of irrigation. The grain and vegetables could gain the lead from the contaminated soil. Eventually, the contents of the lead in drinking water, soil, grain and vegetables in the polluted area were significantly higher than in the control area.

Lead contamination in environmental will give rise to increase of lead content in groundwater and soil, and all the crops in the severely polluted areas will contain lead. Study had shown that various heavy metal pollutants were detected in the groundwater near the SY river at depth of 20-50 m even over 200 m, and their concentrations showed a downward trend with the increasing distance from the river(Xu X.L, 2007). Other research also indicated that the pollutants in groundwater shifted primarily through the role of convection–diffusion(Huang X.X, 2008). In addition to that lead could be filtrated, adsorbed, degraded and so on by the soil. Finally, the pollutants were stayed in the soil. And the farther away from sources of pollution the lower concentration of pollutants in soil. Contaminants in soil entered into crops through bacterial decay and the absorption of plants etc.

4.2 Children's blood lead levels and exposure pathways

This study showed that blood lead levels were significantly higher in children who were living in polluted area than those living in control area. Meanwhile, the mean blood lead levels of older children were significantly higher than younger children. These results indicated that blood lead levels were not only related to the dose of environmental exposure, but also had a certain relationship with the exposure time. The greater dose of environmental exposure and the longer exposure, the higher blood lead levels of children had. Therefore, lead in environment had entered into children's body via drinking water, vegetables, food and soil et al. and the blood lead levels were related to the time of environmental exposure, the longer the children exposure, the higher blood lead levels they had.

Lead in the environment can enter the human body through the respiratory tract, digestive tract, skin and other ways. Song Huaqin (1993) found that 90% to 98.5% of lead that daily intake of children in Beijing were from gastrointestinal tract, while respiratory tract only 1.5% to 10.0%. Children are more susceptible than adults by environmental lead pollution. When the lead reached the digestive tract, children could absorb 30% to 75%, nevertheless adults only 11%(Farley D, 1998). Another way that children intussuscepted lead is hand to mouth. According to related reports, the blood lead levels will increase 2.3μg/L when the natural logarithm of lead in dust of children's living environment augments one unit(Schillins R.J, 1988). Lead can pass through the placental barrier and enter into children's body. Some literatures showed that the levels of lead exposure to mothers during pregnancy could affect children's intelligence and physical development seriously(Takashi Yorifuji, et al, 2011, Susan Claire Edwards, et al, 2010, and Wieslaw Jedrychowski, et al, 2008). They all declared that children can be affected by environmental pollutants before birth. Reinhard Kaiser et al.(2001) had shown that children's blood lead levels increased with age, which was consistent with the results of this study, may be related to exposure time and accumulation in body.

4.3 Influence of lead exposure on children's intelligence

The results showed that children who were living in polluted area had significantly lower IQ than those living in control area. Meanwhile, IQ scores were significantly reduced in children with blood lead levels increased. We found that exposure to lead in blood was associated with reduced IQ scores before and after adjusting for confounders. These results indicated that the intelligence of children who were living in contaminated area were affected by lead to some extent. And there was a significant negative correlation between the level of lead exposure and children's intelligence.

There were many reports about the relationship between lead exposure and children's intelligence in worldwide. Hu Qiansheng had researched the relevance of children's intelligence and contents of lead in deciduous teeth in the context of different environments of lead contamination. The results showed that children's teeth lead levels were significantly different in different contamination background, and there was a significant negative correlation between teeth lead levels and children's IQ (β=-0.382, P=0.006) (Hu and Dong, 1997). Another study also displayed that the relationship between children's blood lead levels and intelligence was a significant negative correlation(r=-0.789, P<0.001)(Guan Y.Q, et al. 2005). Yuan Liu (2010) had reported that children's mental retardation were significantly associated with lead content in the environment where their mother living. Another research also showed that children with mental retardation were related to the soil lead levels(Suzanne McDermott, et al. 2011). A series of studies in abroad had shown that even the blood lead level <100μg/L which is a criterion in public health advisories of the U.S. Environmental Protection Agency and the Center for Disease Control could give rise to neurological disorders(Lisa M. Chiodo, et al. 2004, and Meeyoung O. Min, et al. 2009). Therefore, there was no safe limit value for lead exposure on children's intelligence and our findings were consistent with it.

Considering Children's intelligence is affected by many factors, our study conducted a questionnaire to comprehend the potential confounding factors which could affect children's IQ. Some researches displayed that mother's education, father's occupation, family income, children's daily intake (especially eggs and milk) and sleep time were the potential confounding factors of intelligence. After correction of these factors, the correlation coefficients between blood lead levels and IQ would reduce(Jose A. Menezes-Filho, et al. 2011, and Shen X.M., et al. 1998). This study found that correlation coefficients were -0.55 and -0.293 before and after adjusting for confounders, respectively. It also suggested that it's important to consider of the potential confounding factors when we analysised the impact of lead exposure on children's intelligence. Consequently, it's a gordian technique to choose the potential confounding factors and it can determine the authenticity and reliability of the final results.

5. Conclusions

In summary, the results of this study showed that the lead pollution in SY River was still very serious, and had entered into children's body via drinking water, vegetables and soil et al. Meanwhile, the lead can accumulate in children's body and elevated blood lead levels. Ultimately, children's intelligence was affected seriously. This study also verified the significant negative correlation between the level of lead exposure and children's intelligence. Considering the limitation of this study, it is essential to replicate these findings in different village near the SY River with lager sample sizes as well as more detail information of children's intelligence.

Acknowledgement

We appreciate all the students and their parents for their participation in this study. We thank all the leaders and the masses in the survey area and all the teachers in the primary schools for their support. We thank the cooperation of the Center for Disease Control and Prevention of Shengqiu and the School of Public Health in Zhengzhou University. This work was financially supported by National Major Projects of Water Issues in China(No.2009ZX07210-006-3-3) and Chinese College Students' Innovative and Entrepreneurial Training Program(No.121045961).

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6/20/2012