

Lead Hair Level Impact on Mongolian Children with Attention Deficit Hyperactivity Disorder

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How to cite this paper: Amgalan, B., Tovvudorj, A., Enkhjargal, A., Nasantsengel, L. and Erdenetuya, G. (2020) Lead Hair Level Impact on Mongolian Children with Attention Deficit Hyperactivity Disorder. *Occupational Diseases and Environmental Medicine*, 8, 188-202.
<https://doi.org/10.4236/odem.2020.84015>

Received: September 24, 2020

Accepted: November 13, 2020

Published: November 16, 2020

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Abstract

Background: High-prevalence disorders among children are attention-deficit/hyperactivity disorder (ADHD) and lead exposure. The purpose of this study was to find out the relationship between ADHD symptoms and hair lead levels and neurocognitive function among Mongolian children. **Methods:** This was the case study to investigate the relationship between hair lead and ADHD in Mongolian school kids. We conducted a pair-matching case-control study with 30 ADHD cases and 30 non ADHD controls for 7 - 12 years of age school children, based on the same age, and sex. Recruitment process was conducted from June 2018 to December 2019. The case and control study children were systematically selected by structured diagnostic interviews, including caregiver interviews based on the Diagnostic and Statistical Manual of Mental Disorders, 4th ed (DSM-IV). **Results:** The average level of hair lead of the ADHD group was 1.45 ± 2.93 ppm and the control group's lead level was 0.7 ± 1.59 ppm. We found ADHD-Combined (ADHD-C) patients showed the highest lead levels ($p < 0.05$). Hair lead levels were positively linked with the severity of ADHD symptoms, negatively linked with the Full-Scale Emotional Intelligence Quotient, but positively correlated with inattention and hyperactivity/impulsivity symptoms ($p < 0.05$). A statistically significant difference was discovered regarding the lead levels between the study and the control groups with significantly increased risks among boys and children whose mother had preeclampsia during the pregnancy period. Spearman's correlation coefficient showed a notable negative connection between children's hair lead levels with ADHD-Hyperactive (ADHD-H), and EQ (Emotional Quotient) level of children (-0.329 and -0.242 , for original and log₁₀ transformed, $p < 0.001$). The lead was linked with vulnerability to ADHD and symptom severity among those school-age children. **Conclu-**

sions: The child hair lead exposure is one of the risk factors of the development of ADHD and decreasing FSIQ (Full Scale Intelligent Quotient) and EQ level of children and linked with susceptibility to ADHD and symptom severity in school-age children.

Keywords

Hair Lead, Children's ADHD, Risk Factor, EQ, FSIQ

1. Introduction

Attention-deficit hyperactivity disorder (ADHD) occurs during the childhood development period which shows signs of reduced attention and hyperactivity/impulsivity. ADHD patients can be divided into three subtypes according to symptoms: inattentive, hyperactive/impulsive, and combined type patients [1]. In a meta-analysis of 179 worldwide studies, the prevalence of ADHD was 31% in Europe, 25% in Asia, 26% in America, and 19% in other continents. This study was conducted 74% school-based, whereas 10% was population-based [2].

Since they measure many features associated with cognitive functions, Wechsler intelligence scales for children (WISC) are among the most frequently used intelligence scales in clinical practice, and in research studies. Wechsler Abbreviated Scale of Intelligence®-Second Edition (WASI-II) is an abbreviated cognitive ability test for evaluating the intelligence of individuals aged 6 to 90 years. The WASI-II was developed to provide a quick and accurate estimation of intellectual functioning for screening and reevaluation purposes. It meets the demands for a short and reliable measure of intelligence in clinical, psychoeducational, and research settings [3].

A commonly reported Wechsler profile among school-aged children with ADHD includes lower scores on different indexes. Several published studies have used WISC to evaluate cognitive factors associated with ADHD; in addition, several studies have also used Intelligence Quotient (IQ) or index scores, profile analyses, or subtest assessments 3 - 5. Some studies reported that children diagnosed with ADHD had lower Performance IQ (PIQ) scores (evaluate specific attention tasks) than Verbal IQ (VIQ) scores, as estimated by the Wechsler Intelligence Scale for Children-Revised [4] [5]. Emotional intelligence has to do with the evaluation and expression of emotions experienced by oneself and others, as well as the ability to understand and control such emotions. Bar-On and Parker are two leading researchers in the field of emotional intelligence among children who have sought to develop a concise theory for construct as well as develop valid and reliable measures to test their theory [6].

Initially, the Bar-On Emotional Quotient Inventory (EQ-i) (Bar-On, 1997) was developed to measure emotional intelligence in adults, and more recently, the companion Youth Version was constructed to assess children and adolescents (Bar-On & Parker, 2000). Both instruments are self-report in format and

are relatively easy to administer, giving test users a quick and simple method of measuring Bar-On's conception of emotional intelligence [7]. However, children with ADHD also rated themselves slightly lower on average in some areas when it came to putting this EQ knowledge into practice.

Environmental exposures to lead, predominantly from contaminated water or lead paint chips, account for the majority of exposures to children. It is estimated approximately that 3% of neurodevelopmental disorders and disabilities are caused by exposure to neurotoxins, inducing neuronal damage; intellectual disabilities, ADHD, learning disability, and an autism spectrum disorder. Lead exposure is a major concern for the developing nervous system. *In utero* and early life exposures to lead have been associated with lower IQ, antisocial and delinquent behaviors, and attention-deficit hyperactivity disorder [8]. Lead is one of the most dangerous environmental pollutants. The WHO (World Health Organization) has identified lead as one of ten chemicals of major public health concern that require action by the Member States in order to protect the health of workers, children, and women of reproductive age [9]. Lead (Pb) is one of the most important models for biomonitoring of exposure, with the blood lead concentration as a predominant choice in practice and epidemiology [10].

Mongolia is a landlocked country in northern Central Asia located between China and Russia; it has a vast grassland steppe, desert, and mountain covering an area of 1,565,000 square kilometers. Mongolia has a surface area of nearly 1.6 million square kilometers with the Gobi desert in the south and mountainous regions in the northern and western parts [11]. Ger districts usually lack access to utilities such as water, electricity, heating, and waste collection and the majority of inhabitants live in gers or in spontaneously built wooden houses with bad insulation [12]. In recent years due to urbanization, coal burning, and increasing numbers of vehicles in Mongolia environmental pollution is getting worse and biomonitoring issues are emerging. Thus, we had conducted a recent study aimed to define hair level of Lead and ADHD-correlation among children aged 7 - 12 years old in Ulaanbaatar, Mongolia.

2. Materials and Methods

Sixty Mongolian children of 7 to 12-year-old, who 30 diagnosed ADHD and 30 healthy controls, residing in Ulaanbaatar city, were chosen in a case-control study. The control group consisted of 30 children with a case group by age, gender, and school year. Almost a half of population of Mongolian population is living in the capital city of Mongolia. Thus the participants' recruitment process was conducted from June, 2018 to December 2019 in capital Ulaanbaatar city of Mongolia. ADHD diagnoses were analyzed according to DSM-IV diagnostic criteria by the psychiatrist for kids at the National Center of Mental Health (NCMH). In total 84 children were diagnosed with ADHD. Upon getting approval from caregivers were agreed to participate in the survey only 30 children's parents. Thus, we also invited same number of children from non-ADHD group.

We conducted 93 children's caregivers and agreed 60 of them, and we selected 30 children to the non-ADHD group.

Patients with organic diseases and other serious psychiatric disorders, including organic mental disorders, schizophrenia, and other mental disorders; neurodegenerative disorders, traumatic brain injury, or cerebral vascular disease; serious heart, liver, kidney dysfunction, and other major disease history or a history of drug dependency were excluded from the study.

Hair samples of all participants were randomly selected and processed for a panel of mineral analysis by inductively coupled plasma mass spectrometry (ICP-MS). After extensive washing of removing external contamination, hair samples were analyzed by Doctors Data Clinical lab. Hair levels lead was reported in parts per million (ppm) or $\mu\text{g/g}$. Hair samples were collected by the instruction of the U.S. Doctor's Data Laboratory (<https://www.doctorsdata.com/>).

The history of hair dyeing was reviewed to exclude possible exogenous bio elements that may be incorporated into hair samples. Scalp hair samples were randomly gathered from approximately ten sites around both sides of posterior parietal eminences and external occipital protuberance. The hair was cut closest to the scalp by stainless steel scissors. Only proximal parts of hair, approximately 2.5 cm in length, were collected, while the distal parts were thrown away. This ensured that only the recent and uniform period of bio element deposition in each participant's sample was collected. Samples were then packed at room temperature and submitted for laboratory analysis.

The Wechsler Abbreviated Scale of Intelligence (WASI) is a short assessment battery of intelligence for aged 6 - 89. The scale comprises four subtests: Vocabulary, Similarities, Block Design, and Matrix Reasoning. These four subtests yield a verbal intelligence quotient (VIQ), a performance intelligence quotient (PIQ), and a full-scale intelligence quotient (FSIQ). We examined VIQ and PIQ independently in our analyses, given that one PIQ subtest is timed and may be influenced by motor speed, which we hypothesized may be lower in children with ADHD. The subtests are scaled to a *T*-score metric. The WASI-II provides four composite scores: the Verbal Comprehension Index (VCI), the Perceptual Reasoning Index (PRI), the Full-Scale IQ-2 Subtest (FSIQ-2), and the Full-Scale IQ-4 Subtest (FSIQ-4) [13]. For assessment of emotional Intelligence EQ-i: YV - Emotional Quotient Inventory: Youth Version [6] (Bar-On & Parker, 2000; it ad. Sannio Fancello, & Cianchetti, 2012) was used [14]. Thus, according to the Bar-On model, general intelligence is composed of both cognitive intelligence, measured by IQ, and emotional intelligence measured by EQ. The Bar-On Model of EQ consists of five major dimensions such as intrapersonal, interpersonal, adaptability, stress management, and general mood.

3. Statistical Analysis

The most common characteristics of ADHD reported by parents and school teachers were analyzed from their questionnaires to determine specific clinical

features. Clinical features that were frequently repeated in both questionnaires from parents and teachers were analyzed to reveal specific characteristics of children in Mongolia. The chi-square test was conducted to determine significant differences in the dissemination of the chance to calculate the risk factors after communicating their rate as rates among children with and without the diagnosis of ADHD.

Data Analysis Statistical analyses were conducted using SPSS version 22.0 using the appropriate parametric and nonparametric analysis. Sample characteristics (e.g., age, gender) and their potential effect on the primary hypotheses of interest were assessed with descriptive and correlational analyses. Correlations between hair levels of lead and number of inattention, hyperactivity, and total symptoms were determined by Spearman's correlation. We conducted linear regression analyses to predict the lead level of risk factors for ADHD. The principal component factor analysis was done for defining the main risk factors. Cognitive function and clinical symptoms of selected patients were evaluated, respectively.

4. Ethical Statements

The study proposal was approved by the Research Ethics Committee at the Mongolian National University of Medical Sciences (Reg. No. 2018/D-10). All participants were informed about the study and gave written informed consent from the caregivers before the study. Children with ADHD and their parents were free to continue with their allocation in the ADHD group or control group during the study period or withdraw from the study at any time.

5. Results

The general characteristics of the child participants are summarized in **Table 1** & **Table 2**.

Table 1. General socio-economic characteristics of child participants.

Indicators	ADHD (n = 30)	Control (n = 30)	χ^2	P value
Gender				
Boys	24 (80.0%)	24 (80.0%)	-	
Girls	6 (20.0%)	6 (20.0%)		
Living condition				
Ger	8 (26.7%)	12 (40.0%)	1.2	0.273
Apartment	22 (73.3%)	18 (60.0%)		
Live with whom				
With both parents	16 (53.3%)	23 (76.7%)	3.929	0.140
With grand parents	6 (20.0%)	4 (13.3%)		
With mother or father	8 (26.7%)	3 (10.0%)		
Type of breastfeeding				
Yes	25 (83.3%)	29 (96.7%)	1.667	0.197

Continued

No	5 (16.7%)	1 (3.3%)		
Birth weight				
1500 - 2499 gram	1 (3.4%)	3 (10.0%)		
2500 - 4499 gram	27 (93.1%)	24 (80.0%)	2.932	0.402
4500 over gram	1 (3.4%)	2 (6.7%)		
Unknown	0 (0.0%)	1 (3.3%)		
Alcohol usage during the pregnancy period				
Seldom	3 (10.0%)	0 (0.0%)		
Always	1 (3.3%)	1 (3.3%)	4.23	0.115
Never	26 (86.7%)	29 (96.7%)		
Exposed during pregnancy to the secondhand smoke				
Seldom	19 (63.3%)	7 (23.3%)		
Always	2 (6.7%)	3 (10.0%)	10.57	0.014
Never	8 (26.7%)	19 (63.3%)		
Unknown	1 (3.3%)	1 (3.3%)		
Pregnant preeclampsia				
Yes	15 (53.6%)	6 (22.2%)	5.723	0.017
No	13 (46.4%)	21 (77.8%)		
Pregnancy complications				
Yes	9 (32.1%)	1 (3.7%)	5.684	0.017
No	19 (67.9%)	26 (96.3%)		

Table 2. General characteristics of continuous variables of respondents, by both groups.

Indicators	Groups	Mean	95% Confidence Interval	Median	95% Confidence Interval	P-value
Age	ADHD	9.14 ± 0.99	[8.76:9.46]	9.00 ± 4.00	[9.00:10.00]	0.343
	Control	9.34 ± 0.97	[8.97:9.69]	9.00 ± 4.00	[9.00:10.00]	
BMI	ADHD	16.69 ± 3.09	[15.60:17.93]	15.80 ± 14.10	[14.90:18.10]	0.882
	Control	16.86 ± 3.44	[15.69:18.33]	15.90 ± 14.40	[14.80:18.00]	
Weight	ADHD	31.03 ± 9.21	[28.15:35.14]	29.00 ± 48.00	[26.50:32.00]	0.382
	Control	32.31 ± 8.94	[29.38:36.24]	30.00 ± 41.00	[27.51:32.00]	
Height	ADHD	135.45 ± 8.37	[132.74:138.70]	133.00 ± 39.00	[131.00:138.00]	0.065
	Control	137.78 ± 6.33	[135.35:140.19]	137.00 ± 25.50	[133.75:140.00]	
Mother's age	ADHD	36.00 ± 4.83	[34.45:37.71]	35.00 ± 18.00	[33.00:38.00]	0.958
	Control	36.24 ± 5.13	[34.33:38.20]	36.00 ± 21.00	[33.00:40.00]	
Number of family members	ADHD	4.48 ± 0.69	[4.22:4.72]	5.00 ± 2.00	[4.00:5.00]	0.677
	Control	4.52 ± 0.87	[4.17:4.81]	5.00 ± 3.00	[5.00:5.00]	
EQ score	ADHD	52.28 ± 6.17	[50.00:54.45]	52.00 ± 28.00	[48.00:56.00]	<0.001
	Control	59.24 ± 5.68	[57.22:61.39]	58.00 ± 19.00	[56.00:62.00]	
FSIQ	ADHD	85.66 ± 16.81	[79.80:92.27]	80.00 ± 61.00	[75.00:93.97]	<0.001
	Control	110.17 ± 20.40	[102.52:118.24]	117.00 ± 76.00	[99.00:123.00]	
Pb level	ADHD	1.39 ± 0.76	[1.12:1.67]	1.50 ± 2.93	[1.06:1.70]	0.003
	Control	0.81 ± 0.48	[0.64:1.00]	0.70 ± 1.59	[0.49:0.86]	

In both groups, gender, living condition, birth weight of children participants was the same. 26.7% of the ADHD group, 40.0% of the control group children lived in ger area. 53.3% of ADHD and 76.7% of the control group children lived with both parents.

The characteristics of respondents of both groups on birth weight, breast-feeding, and alcohol usage during the pregnant period were significantly the same. However, mother's exposure during the pregnancy period, pregnant preeclampsia, any pregnancy complications were significantly high among children with ADHD (**Table 1**).

According to the ADHD types, 20.0% of the ADHD group of children diagnosed as an ADHD-I, 21.7% of them diagnosed as an ADHD-H and 8.3% of them had an ADHD-C. The median age of both groups of children was 9.00 ± 4.00 .

There were not observed a significant difference between children of both groups on their BMI (ADHD = 15.80 ± 14.10 , control = 15.90 ± 14.40), weight (ADHD = 29.00 ± 48.00 , control = 30.00 ± 41.00), height (ADHD = 133.00 ± 39.00 , control = 137.00 ± 25.50), mother's age (ADHD = 35.00 ± 18.00 , control = 36.00 ± 21.00), and numbers of a family member (ADHD = 5.00 ± 2.00 , control = 5.00 ± 3.00).

The median of EQ score and FSIQ score of children of the ADHD group (EQ = 52.00 ± 28.00 , FSIQ = 80.00 ± 61.00) were significantly lower than the control group (EQ = 58.00 ± 19.00 , FSIQ = 117.00 ± 76.00). Despite the fact, the hair lead level of children of the ADHD group was 2.14 times higher than the control group (**Table 2**).

The detailed hair level of lead was shown in **Table 3**. The hair lead level was significantly high among ADHD group's boys ($p = 0.025$), 9 ($p = 0.043$) and 10 years old children ($p = 0.034$), normal weighted child ($p = 0.02$), a child who lives in an apartment ($p = 0.03$), a child who had a mother of higher education ($p = 0.01$), a child living with dual-parents (0.028), and child whose mother had preeclampsia during a pregnant period ($p = 0.033$) had significantly higher hair lead level by 1.6 - 2.9 times than the control group.

Table 3. The average concentration of lead (Pb) in hair.

Indicators	ADHD	Control		P-value	
	Mean \pm SD	Median \pm IQR	Mean \pm SD		Median \pm IQR
Gender					
Boys	1.345 \pm 0.806	1.390 \pm 2.930	0.803 \pm 0.451	0.700 \pm 1.520	0.025
Girls	1.577 \pm 0.467	1.450 \pm 1.370	0.867 \pm 0.604	0.710 \pm 1.430	0.135
Age					
8 years	1.274 \pm 0.692	1.230 \pm 2.030	0.998 \pm 0.593	0.930 \pm 1.360	0.476
9 years	1.675 \pm 0.882	1.680 \pm 2.720	0.871 \pm 0.521	0.700 \pm 1.520	0.043
10 years	1.233 \pm 0.654	1.435 \pm 2.040	0.707 \pm 0.396	0.625 \pm 1.390	0.034

Continued

BMI					
Underweight	1.257 ± 0.776	1.400 ± 2.290	1.223 ± 0.422	1.360 ± 0.810	0.864
Normal	1.623 ± 0.773	1.585 ± 2.740	0.762 ± 0.462	0.680 ± 1.590	0.02
Overweight	1.159 ± 0.712	0.920 ± 2.140	1.015 ± 0.827	1.015 ± 1.170	0.889
Obese	1.690	1.690 ± 0.000	0.667 ± 0.388	0.550 ± 0.750	0.5
Living conditions					
Apartment	1.534 ± 0.657	1.450 ± 1.950	0.668 ± 0.354	0.520 ± 1.210	0.03
Ger area	1.340 ± 0.788	1.495 ± 2.930	0.914 ± .526	0.745 ± 1.59	0.07
Mother's education level					
Bachelor and high	1.229 ± 0.462	1.365 ± 1.160	0.619 ± 0.407	0.470 ± 1.360	0.01
Not completed secondary	1.645 ± 0.835	1.900 ± 2.210	1.248 ± 0.467	1.350 ± 1.120	0.263
Secondary	1.289 ± 0.940	1.150 ± 2.930	0.868 ± 0.446	0.745 ± 1.390	0.481
Family structure					
Dual-parents	1.316 ± 0.732	1.300 ± 2.400	0.787 ± 0.446	0.700 ± 1.430	0.028
Grandparents	1.420 ± 0.625	1.560 ± 1.830	0.910 ± 0.573	0.910 ± 1.340	0.171
Single mother or father	1.520 ± 0.930	1.550 ± 2.670	0.910 ± 0.739	0.550 ± 1.340	0.376
Pregnant preeclampsia					
Yes	1.452 ± 0.833	1.530 ± 2.930	0.661 ± 0.315	0.710 ± 0.930	0.033
No	1.322 ± 0.664	1.450 ± 2.210	0.870 ± 0.520	0.680 ± 1.520	0.061
Pregnancy complications					
Yes	1.749 ± 0.723	1.620 ± 2.480	0.930	0.930 ± 0.000	0.400
No	1.238 ± 0.723	1.150 ± 2.400	0.835 ± 0.475	0.700 ± 1.520	0.066
Had difficulties with learning at the class					
Yes	1.334 ± 0.804	1.230 ± 2.930	0.839 ± 0.577	0.685 ± 1.590	0.226
No	1.596 ± 0.692	1.740 ± 1.920	0.772 ± 0.431	0.700 ± 1.360	0.023
Unknown	0.450 ± 0.184	0.450 ± 0.260	0.420 ± 0.154	0.420 ± 0.000	0.109
Family pressures					
Yes	1.414 ± 0.933	1.230 ± 2.740	0.755 ± 0.595	0.590 ± 1.360	0.286
No	1.374 ± 0.694	1.620 ± 2.300	0.852 ± 0.428	0.700 ± 1.360	0.004
Unknown	1.395 ± 0.525	1.460 ± 1.260	0.753 ± 0.592	0.430 ± 1.590	0.636
Academic performance					
A	1.285 ± 0.217	1.260 ± 0.480	0.837 ± 0.485	0.705 ± 1.590	0.091
B	1.266 ± 0.835	1.400 ± 2.300	1.061 ± 0.446	1.025 ± 1.130	0.636
C	1.596 ± 0.790	1.595 ± 2.480	0.666 ± 0.473	0.555 ± 1.590	0.004
D	1.650 ± 0.256	1.650 ± 0.001	0.935 ± 0.484	0.925 ± 1.210	0.286

The average level of hair lead (ppm) of the ADHD group was 1.45 ± 2.93 ppm and the control group's lead level was 0.7 ± 1.59 ppm. The highest hair level of

lead was determined in children who had ADHD-C. Besides, when hair lead is high then more likely the children's academic performance is low and they have difficulties at school (Figure 1).

Linear regression analysis confirmed that there is a substantial negative relationship with children's hair lead by FSIQ and EQ and a positive relationship between hair lead with 3 types of ADHD when adjusted for the confounders. In general, 5.8% - 15.3% of selected indicators displayed by Table 4 are explained by the hair lead level. The highest regression was defined to the EQ (15.3%) and the lowest was ADHD-I (Table 4).

The factor analysis was conducted to define the main factors for developing ADHD among children. The three main factors are for factor 1 was children's age, BMI, and mother's age. Another main factor by factor 2 was hair Pb level, age of children and mother's age. While the main 3 factors of third option were mother's age, FSIQ, and BMI). In general aspect, the main factors that child gets ADHD are hair lead level, and age of child and mother (Table 5).

Spearman's correlation coefficient displays a significant negative relationship between children's hair lead levels with ADHD-H, and EQ level of children (-0.329 and -0.242 , for original and log10 transformed, $p < 0.001$) (Figure 2).

Table 4. Linear regression analysis model of hair Pb with ADHD (I, H, C), IQ, and EQ.

Dependent variables	Equation of regression	P-value	Adjusted R ²
ADHD-I	$4.776 + 2.151 \times \text{Pb ppm}$	0.036	0.058
ADHD-H	$3.929 + 3.145 \times \text{Pb ppm}$	0.04	0.123
ADHD-C	$0.167 + 0.378 \times \text{Pb ppm}$	0.01	0.147
FSIQ	$108.384 - 10.347 \times \text{Pb ppm}$	0.014	0.084
EQ	$105.278 - 7.743 \times \text{Pb ppm}$	0.01	0.153

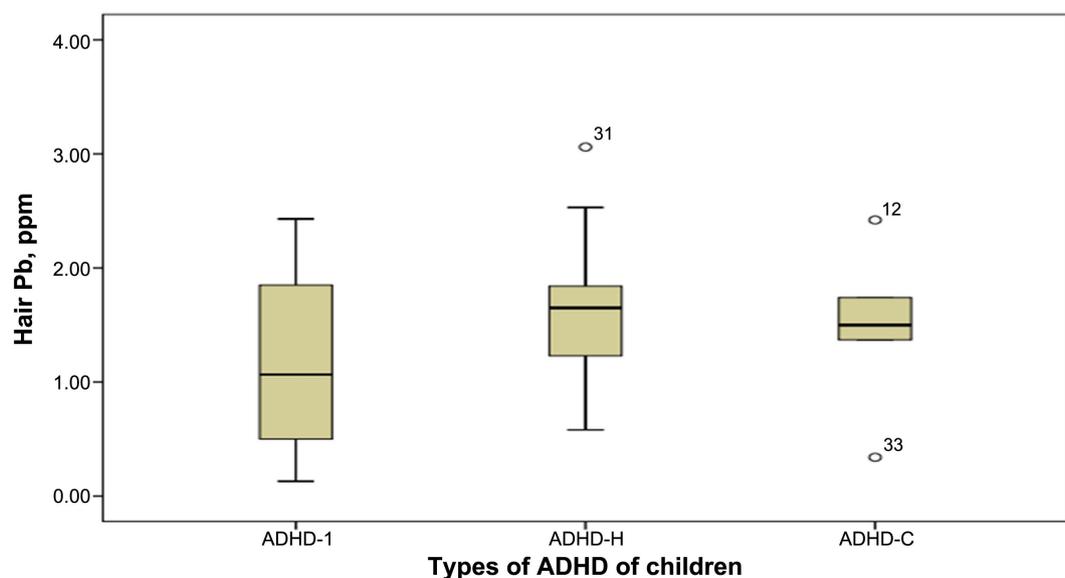


Figure 1. Hair lead (Pb) level by ADHD types of children.

Table 5. Principal component factor analysis of ADHD.

	Component		
	Model 1	Model 2	Model 3
Age	0.337	0.560	0.356
Mother's age	0.279	0.336	0.777
BMI	0.316	0.543	0.439
Hair Pb level	0.009	0.610	0.047
EQ	0.940	0.099	0.017
FSIQ	0.681	0.520	0.369

Extraction Method: Principal Component Analysis. a. 3 components extracted.

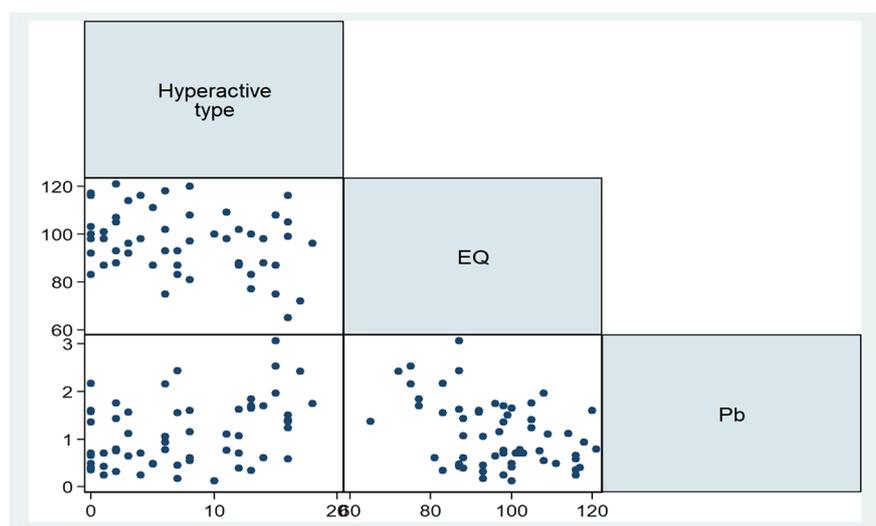


Figure 2. Spearman correlation between hair levels of lead (Pb) with children ADHD-H (hyperactive type) and EQ.

6. Discussions

We examined the consequences of hair lead in ADHD cases and non-ADHD controls with adjustment for many other known risk factors among children 7 - 12 years of age in Mongolia. Mother's exposure during the pregnancy period which was exposed to secondhand smoke, preeclampsia, any pregnancy complications were positive high-risk factors. This is consistent with previous work indicating that low maternal education, low socioeconomic status, prenatal smoking, prenatal illicit drug use, maternal depression, and single parenthood are important adverse factors for ADHD [15] [16] [17].

We discovered that ADHD cases were more likely to have been exposed to lead. In our study, the children with hair lead high level had 2.14 fold higher risks for ADHD. Lead may play important roles in the etiology of ADHD. Recently, Braun *et al.* analyzed data from a U.S. population-based sample and concluded that prenatal tobacco exposure and environmental lead are risk factors for ADHD; they found 4.1-fold increased odds of ADHD with increased blood

lead levels [18].

Awaga *et al.* had conducted a case-control study on lead exposure among Egyptian children. The lead level among ADHD children was significantly higher than control (20.88 ± 7.47 ug/dl versus 16.13 ± 7.91 ug/dl). While, there is no significant difference between lead level and degree of symptoms among ADHD children. There is a notable connection with ADHD in the examined sample of children and exposure to lead especially through water decontamination containing lead [19]. The lead level is significant for reflecting exposure to lead. Based on our survey findings of hair lead is a risk factor of child ADHD.

Choi *et al.* was investigated the blood lead level and parental marital status that might affect the development of attention-deficit/hyperactivity disorder (ADHD) symptoms in school-aged children. The participants in the survey were elementary school children, and they were followed up biennially. The participants' parents or caregivers were given a questionnaire to fill out containing an ADHD rating scale. Among 2967 who were not suspected to have ADHD at baseline survey, 2195 children who took follow-up tests for ADHD were evaluated. The RR was 3.567 (95% CI 1.595 - 7.980) in children with relatively high blood lead levels (42.17 $\mu\text{g}/\text{dL}$) from single-parent families, compared with low blood lead and a two-parent family. The ADHD risk in association with blood lead level was altered by family status [20]. Similar patterns were defined in this study.

A study was conducted on hair samples of children with ADHD and revealed that children's hair lead concentrations ranged from less than one to 11.3 ppm ($\mu\text{g}/\text{g}$) with an observed notably striking relation between ADHD and hair lead levels. Children with a blood lead level ≥ 5 $\mu\text{g}/\text{dl}$ doubled the risk of developing ADHD whereas, in inorganic arsenic, a greater risk is observed only when urinary inorganic arsenic concentration is in the highest quintile [21].

Previous studies have reported that environmental toxicants, especially lead and mercury, contribute to the risk of ADHD. A meta-analysis was conducted by Goodlad *et al.* discovered that lead exposure was associated not only with inattention and hyperactivity/impulsivity symptoms but also intelligence among children and adolescents, with a small effect size ($r = 0.13 - 0.16$) [22]. Specifically, lower scores were found on self-rated performance when interacting with others, as well as adapting to new environments. Both of these skills are more common areas of difficulty for children with ADHD [23]. Children with ADHD also reported comparable performance abilities on the trait-based total EQ-I score, as well as on the Intrapersonal and Stress Management scales. However, they scored significantly lower on the Interpersonal and Adaptability Scales, as well as on the Positive Impression Scale [24]. In our study, it was also the same, if a child had a higher level of hair lead then FSIQ, and the EQ score of the child was low. Some studies documented varying behavioral effects of lead exposure among children [15] [20]. In this regard, it is noteworthy that concurrent rather than earlier blood lead levels have shown the strongest association with IQ in school-age children [25] [26] [27].

Based on the results of observational studies findings, there is an association between lead and ADHD and that even low levels of lead raise the risk. However, there is still a lack of longitudinal studies about the relationship between lead exposure and the development of ADHD. Given the potential importance for public health, further research including the entire potential risk factors for ADHD in children must be encouraged [28].

Generally, exposure to neurotoxicants earlier in life has a more critical effect on the brain; this is also the case for many other environmental chemicals [29] [30]. Therefore, regarding the reported correlations between concurrent lead exposure and child IQ, an alternative hypothesis may need to be taken into account when inferring the direction of causality. For example, a child who is experiencing symptoms of ADHD is perhaps at a higher chance of undergoing greater amounts of environmental lead exposure [31]. We had defined a direct correlation between hair lead and ADHD among children.

In Mongolia, a few researchers have conducted studies on lead and child health. In 2019, Erdenechimeg *et al.* had defined the mean blood lead level of children in the two cities of Mongolia was found to be $3.8 \pm 2.6 \mu\text{g/dL}$ (range: $< 1.5 - 17.2 \mu\text{g/dL}$) and 27.8% of the children had blood lead levels $\geq 5 \mu\text{g/dL}$. The average blood lead level of children in Erdenet (a mining center) was significantly higher than that for children in Darkhan, and there was a statistically significant difference between the average blood lead level of children who live in ger districts ($4.2 \pm 2.8 \mu\text{g/dL}$) compared to those of children living in city apartments ($3.2 \pm 2.4 \mu\text{g/dL}$). Despite the low values, blood lead levels were significantly associated with several effects on the spectrum of behavioral disorders, specifically with the scores for hyperactivity, conduct disorder, and prosocial behavior [32]. Based on our survey, children who live in ger districts have higher levels of hair lead compared with children who live in apartments.

While Tuul *et al.* have been defined that the hair lead level of children who had allergic rhinitis was higher than the healthy children and the hair lead level of boys was 1.6 times higher than the girls [33]. Regarding our survey, the hair levels of the boy's lead in the ADHD group were significantly higher than the control group. While no significant difference was observed among girls of both groups.

Moreover, the blood test conducted among Ulaanbaatar children to detect the content of lead, which has a strong negative impact on all the organs, in particular the nerves, kidneys, blood generation, and reproductive system and delays growth of children, revealed that the average content of lead is 16 mgr/dl, which is high enough to affect children's health. The main sources of lead in the air of Ulaanbaatar are the smoke of automobiles that use lead-containing petroleum and households burning raw coal for heating [34].

7. Conclusion

In conclusion, our findings revealed that executive function patterns are different in children with ADHD compared to normal children and confirmed that

ADHD subtypes are different in terms of perseveration and response inhibition domains; ADHD-C type showed more deficits in perseveration and response inhibition. The child hair lead exposure is one of the risk factors of the development of ADHD and reducing FSIQ and EQ level of children and is associated with susceptibility to ADHD and symptom severity in school-age children.

Limitations

This study suffers some limitations. First, in this study, we did not compare behavioral differences between children with ADHD and other neurodevelopmental disorders. Another limitation is that the cognitive processes investigated were not supported by the other neuropsychological tests. The third limitation was the special use of retrospective measures such as information of the perinatal period, socio-economic, and childhood behavior.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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