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Prevalence and association of blood lead levels with low IQ in children aged 2-9 years in West Bangka, Indonesia: a cross-sectional study

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Abstract— Intelligence is defined as a general mental ability for reasoning, problem solving, and learning. To assess the intelligence quotient (IQ) of a child, many factors play a role such as genetics, family, social, cultural and environmental. Blood lead levels (BLLs) in 5 micrograms per deciliter (µg/dL) or more are associated with decreased intelligence, behavioral disorders and learning problems.This study aimed to determine the prevalence of low IQ and its associated factors.A cross-sectional study design was conducted in West Bangka. Data on 190 children aged 2-9 years and their mothers were collected. The subjects were divided into two categories on the results of intelligence assessment (IQ test) by Startford-Binet intelligence scale. Descriptive and binary logistic regression analyses were applied to determine the prevalence and associated factors with low IQ. The total prevalence of BLL ≥ 5µg/dL and low IQ in children were57.9% and 62.3%, respectively. However, after adjustment for head circumference for age, height for age, maternal and paternal education level, BLL was not associated with low IQ in children. Children with microcephalywere more likely to be low IQ (adjusted OR : 4.304 95% CI : 1.602 – 11.563, p = 0.004) than children with normocephaly. Children whose mothers had low education level were at a higher risk for low IQ (adjusted OR : 3.785, 95% CI : 1.976 – 7.248, p = 0.000) compared to children whose mothers had high level education.

Keywords— Associated factors, Prevalence, BLLs, Low IQ

1. Introduction

Intelligence is defined as a general mental ability for reasoning, problem solving, and learning.[1] An IQ is a total score derived from a set of standardized tests or subtests designed to assess a person's mental abilities through the use of numerical scores. The score reflects a child's performance on an intelligence test relative to that of children of the same age.[2] It shows the quality of cognitive function based on several domains of an individual's mental state[3]

The factors that influence the intelligence of children are numerous.[4]Intelligence tends to aggregate strongly in families. Both genetic and environmental factors contribute to familial similarities in intelligence.[5] Genetic influences on intelligence are strongly correlated with genetic influences on head circumference in infancy and height. These genetic correlations explain common biological pathways for intelligence.[6] Furthermore, genetic factors have a significant impact on children's congenital conditions. Gene changes cause developmental malformations in the form of congenital microcephaly.[7]It is a neurodevelopmental disorder characterized by a marked reductionin brain size, andhas an impact on mild to severe cognitive deficits.[8]

The environmental impact on children's cognitive development has been documented in several studies. Lead is widely found in the environment and is very influential on child development.[9] Lead in the blood of children is strongly associated with exposure to lead in the environment.[10]The adverse effects of lead on children can occur in the prenatal to postnatal period, which can be related to the nervous system and non-nervous system. The potential danger of lead to the neurodevelopment of children occurs from the fetus to the postnatal period.[11]About 1 in 3 children or about 800 million children worldwide have BLLs in the range of 5 micrograms per deciliter (µg/dL) or more, which according to the World Health Organization is associated with decreased intelligence, behavioral disorders and learning problems.[12]

Socioeconomic status, parental education, especially maternal education, are important familial factors that can explain the relationship of environmental factors to child neurodevelopment.[13]–[15] Socioeconomic factors are positively correlated with intelligence in early life, and increase as children get older[16] In younger children (up to nine years old), the effect of socioeconomic status was stronger, on most cognitive functions.[17]

Differences in intelligence in early life affect individual development, and subsequently on socioeconomic, psychological, and health outcomes in adulthood[18], [19]Furthermore, cognitive performance in middle childhood strongly influences adult outcomes, which may outweigh the effects of cognitive development before 5 years of age.[20]These differences vary more in infancy and childhood than in early adolescence to late adulthood according to the stability of genetic and environmental influences.[21]However, growing up in adisadvantaged community may contribute to a decline in IQ score in the early school years, more than individual and familial factors.[22]

There is also variation across studies regarding the underlying factors associated with low IQ children. Besides, to the best of our knowledge, no study has been done to identify factors associated with low IQ in the study area. This study aimed to determine the prevalence of low IQ in children aged 2 – 9 years and its associated factors.Therefore, this study investigated the important factors associated with low IQ in Muntok, West Bangka district. We hypothesized that low IQ would be associated with biological (sex, height for age adn head circumferrence for age) and environmental factors (BLLs, parental education and environmental tobacco smoke).

2. Methods

2.1 Sampling Method

A non-probability sampling design, purposive sampling was used to recruit the study participants. It uses the judgment of the researcher in selecting samples or it selects samples with a specific purpose. The final study sample is selected from eligible potential respondents in the target population. The study sites were two sub-districts in the West Bangka, Muntok and SimpangTeritip in July 2020. The research sample is mothers who complete all research procedures with their children. The child inclusion criterion is aged between 2 - 9 years (24 – 119 months). Children exclusion criteria were the mother did not complete the research procedure, the child suffering from illness, chronic medical conditions or medication use, or could not follow and complete the research procedure.

The Samples that met the criteria were 228 mothers and 228 children. Individual, maternal, environmental data were collected from all participants. However, IQ data was available from 190 children, resulting in a final sample size of 190. The subjects were divided into two categories on the results of intelligence assessment (IQ test) by Startford-Binet intelligence scale Comparisons were made between those with average intelligence or above (IQ greater than 89) and low intelligence (IQ less than or equal to 89).

Blood lead was measured by ICP-MS. Venous blood was drawn from the cubital vein into an evacuated, heparinised 3 ml venoject tube. Linear growthwas measured as a child's stature from 24 mo onwards. Measured standing height of all participants were converted to sex- and age-specific Z-scores based on WHO growth reference. It refers to a chronic nutritional disorder. Head circumference was measured using a non-stretchable measuring tape. The tape is wrapped around the widest possible circumference of the head, from the broadest part of the forehead above the eyebrow, above the ears to the most prominent part of the back of the head. Take the measurement two times and select the largest measurement to the nearest 0.1 cm.Demographic characteristics including sex, maternal and paternal education and environmental tobacco smoke exposure were measured using a questionnaire that was asked to the mother.

2.2 Data Analysis

IQ scores were divided into two groups, normal IQ (90 or higher) and low IQ (89 or less). The study data were analyzed using the Statistical Package for Social Science (SPSS) software.version 22. The descriptivedata were expressed as frequency and mean ± standard deviation (SD). The Chi-square test

was conducted to determine the differences between the proportions of low IQ in the six variables. Determinants of low IQ were examined using binary logistic regression. The magnitude of confounding is the percent difference between the crude and adjusted measures of association. We use a 10% OR difference for identifying the presence of confounding.

The dependent variable was low IQ and the independent determinants were :

- child's sex
- BLL was categorized into <5 and ≥5µg/dL.
- head circumference for agewas categorized into normocephaly (equal or less than 2 standard deviations below the mean) and microchephaly (greater than 2 standard deviations below the mean).
- height for agewas calculated using the WHO Anthro and AnthroPlus. Children with HAZ < -2 were classified as stunted.
- mother's and father's education were categorized into high education level (completed senior secondary school or higher education) and low level of education (completed junior secondary school or less).
- environmental tobacco smokewas identified as "no" (for living without exposure to environmental tobacco smoke) and "yes" (for living with exposure). In the binary logistic regression model, the differences were considered to be statistically significant when the p-value obtained was <0.05.

2.3 Ethical approval and consent procedure

This study was approved by the Research and Community Engagement Ethical Committee of Faculty of Public Health Universitas Indonesia. Informed written consent was taken from the parents of the children. All consent givers were briefed and assured about non-disclosure of the information and use of the analyzed data findings for scientific purposes.

3. Result

A total of 190 children participated in this study. The distribution of the general characteristics of the sample is shown in Table 1.

Table 1 General characteristics of the children (N = 190)

Variable	Frequency	Percent (%)
Child's sex		
boy	70	36.8
girl	120	63.2
Head circumference for age		
normocephaly	155	81.6
microcephaly	35	18.4
Height for age		
normal	146	76.8
stunting	44	23.2
Maternal Education		
high level education	93	48.9
low level education	97	51.1
Paternal Education		
Completed senior secondary school or higher education	84	44.2
Completed junior secondary school or less	106	55.8
Environmental Tobacco Smoke		
no	78	41.1

yes	112	58.9

Of all the subjects whose data was analysed, the majority of participants being girls (63.2%), stunting 23.2%, more than half children had mother with low education level (51.1%), father with low education level (55.8%), and with environmental tobacco smoke (58.9%).Around one in every five children (18.4%) identified with a head circumference abnormality (microcephaly).

Table 2 presents the BLLs and IQ data of children taken during the survey.The highest proportion of children were BLL 5 - 9 µg/dL (46.8%) and low IQ (63.2%), and the mean of child's BLL and IQ were 5.52 ± 2.62 µg/dL 89 ± 14.

Tabel 2 BLLs and IQ scores of Children

Variable	Frequency	Percent (%)	Mean (± SD)
BLLs			
< 5 µg/dL	80	42.1	5.52 (± 2.62)
≥ 5µg/dL	110	57.9	
Child IQ Score			
normal	83	36.8	89 (± 14)
Low	107	63.2	

Based on results in Table 3, the proportions of characteristics were grouped by IQ categories. Proportion of low IQ in BLL ≥ 5 µg/dL was 61.8%, girls was 57.5%, microcephaly was 82.9%, stunting was 70.5%, child whose mother had low education level was 72.2%, child whose father had low education level was 68.9%, and environmental tobacco smoke was 58.9%. Furthermore, the results indicated a significantly higher proportion of low IQ children being microcephaly (p=0.001), stunting (p = 0.047), had mothers with low education level (p = 0.000) and had fathers with a low education level (p = 0.000).However, the proportion of children being with BLL ≥ 5 µg/dL (p = 0.100), girls (p = 0.780) and with environmental tobacco smoke (p = 0.471) was not significantly different between the normal and low IQ groups.

Table 3 Characteristics of children by IQ categories

Variable	IQ categories		P value	Crude OR*	OR (95% CI)
	Normal IQ	Low IQ			
BLLs					
< 5 µg/dL (ref.)	41 (51.2)	39 (48.8)	0.100	1.702	0.950 – 3.050
≥ 5 µg/dL	42 (38.2)	51 (61.8)			
Child's sex					
Boy (ref.)	32 (45.7)	38 (54.3)	0.780	1.139	0.629 – 2.062
girl	51 (42.5)	69 (57.5)			
Head circumference for age					
Normocephaly (ref.)	77 (49.71)	78 (50.3)	0.001	4.771	1.876 – 12.138
microcephaly	6 (17.1)	29 (82.9)			
Height for age					
normal (ref.)	70 (47.9)	76 (52.1)	0.047	2.196	1.064 – 4.532
stunting	13 (29.5)	31 (70.5)			
Maternal Education					
high level education (ref.)	56 (60.2)	37 (39.8)	0.000	3.924	2.136 – 7.207
low level education	27 (27.8)	70 (72.2)			
Paternal Education					
high level education (ref.)	50 (59.5)	34 (40.5)	0.000	3.253	1.787 – 5.922
low level education	33 (31.1)	73 (68.9)			

Environmental Tobacco Smoke					
No (ref.)	37 (47.4)	41 (52.6)	0.471	1.295	0.723 – 2.318
yes	46 (41.1)	66 (58.9)			

ref.: reference category; OR—odds ratio; CI—confidence interval; *—binary logistic regression analysis considering the effect of one explanatory/predictor variable.

In a bivariable logistic regression, head circumference for age, height for age, maternal education, and paternal education were found to be significantly associated with low IQ. In a multivariable logistic regression, head circumference for age and maternal education were significantly associated with low IQ. Children with microcephalywere more likely to be low IQ (adjusted OR : 4.304 95% CI : 1.602 – 11.563, p = 0.004) than children with normocephaly. Children whose mothers had low education level were at a higher risk for low IQ (adjusted OR : 3.785, 95% CI : 1.976 – 7.248, p = 0.000) compared tochildren whose mothershadhigh level education.In contrast, BLLs, height for age and paternal educationwere not significantly associated with low IQ. However, it was concluded that there was confounding. The percent OR difference of BLL (between crude and adjusted height for age) was greater than 10%. Results in Table 4 showed the BLLs and associated factors of low IQ children.

Table 4 BLLs and Other Associated Factors of Low IQ Children

Variable	P value	Adjusted OR	95% CI
$BLLs_1$	0.912	1.040	0.520 – 2.079
Head circumference for age_1	0.004	4.304	1.602 – 11.563
Height for age_1	0.365	1.480	0.633 – 3.457
Maternal $Education_1$	0.000	3.785	1.976 – 7.248

BLL_1 is blood lead level ≥ 5 µg/dL; head $circumference_1$ is microcephaly; $heigh_1$ is stunting; maternal $education_1$ is low level

4. Discussion

IQ tests are most widely used to measure children's intelligence for neuropsychological assessment. IQ scores reflect a child's performance on intelligence tests relative to children of the same age.[2]Based on our findings, the prevalence of low IQ among children in Muntokis higher than the finding of previous studies (63.2 ; 30.3%, respectively).[23]In addition, the mean IQ of children in this study is slightly higher than the two previous studies with samples of Indonesian elementary school student in 2010 and in Bali, Indonesia in 2012 (89 ; 87 and 84, respectively).[24], [25] However, our result is lower when compared to the results of a study on Jakarta elementary school, Indonesia in the 2017 data (84; 106, respectively).[26]

The neurotoxic effects of lead are long term. This fact makes it difficult to prove the association of low lead exposure with children's IQ in observational study design. Also in our results, the association of blood lead levels with children's IQ was not found. A previous study, with a sample of children aged 3-4 years, found no association between blood lead levels and IQ scores, either in verbal IQ, performance IQ or full-scale IQ.[27]In addition, chronic lead exposure in children from families with higher socioeconomic status showed a slight increase in lead levels at about 2 years of age. Significant declines in intellectual performance were reported after the child was 10 years old.[28]Thus, a longitudinal study is needed to prove the long-term consequences of exposure to lead on children.

The presence of controlled potential confounders, such as head circumference for age, height for age, education level of mother and father, also played a major role in the relationship between BLL and children's IQ. The findings in China might be in line with our findings. An association of blood lead levels with children's IQ was found at higher blood lead levels (> 10 µg/dL), but this association became insignificant after controlling for potential confounder variables (sex, mother's education, father's education, father's smoking, etc.) in multivariate analysis.[29]

Compared to previous studies in Indonesia, the mean blood lead level of children in this study was lower than the mean blood lead level of children in the area around a used lead acid batteries smelter in Tegal Regency, Central Java (39.3 µg/dL)[30] and the Telawaan traditional gold mining area, North Minahasa Regency (25.8 µg/dL).[31] However, by category of children with high blood lead levels, the proportion was higher than the findings of other studies. In this study, the proportion of children with blood lead levels 5 g/dL was greater than that of children living in a used lead acid batteries recycling facility in Jakarta (57.9% versus 47.3%, respectively).[32]

Head circumference correlates with cognitive function.[33]–[35]Thus, the current finding of an association between head circumference and children's IQ is not surprising. Several studies have documented a association between head circumference and child's IQ.[36]–[40]Our findings are reasonable because head circumference has also been shown to be positively correlated with brain volume.[33], [39], [41], [42]

Developmental disorders of head circumference (microcephaly) may be caused by malformations associated with gene changes. Congenital microcephaly can be caused by single gene abnormalities, chromosomal abnormalities, microdeletions, microduplications or mitochondrial mutations.[7] Recent data suggest that mutations in chromosome alignment-maintaining phosphoprotein 1 (CHAMP1) are found in patients with intellectual impairment, motor developmental delay, and microcephaly.[43]Therefore, the growth of the head circumference of the child should not be neglected.However, there are findings from previous studies that are not completely in line with our findings. Past findings showed that head circumference at birth up to one year was a significant predictor of IQ up to four years. However, at age 8 years, head circumference at birth is no longer a statistically significant predictor of a child's IQ.[33]

In contrast to findings related to microcephaly, height for age was found not to be associated with children's IQ after being controlled by the variables of head circumference for age, maternal and paternal education. Previously, it has been proven that stunting in early childhood has a significant negative correlation with children's cognitive ability.[44]It is clear that the current findings differ from previous studies. Despite the strong association, the magnitude of stunting-related cognitive deficits varies according to various studies.[45]

Stunting in early childhood was shown to be correlated with cognitive deficits in previous studies, but this correlation can be reduced by stimulation at an early age.[46]Other studies also provide evidence that the negative impact of cognitive development (in the form of deficits in IQ scores) in stunted children can decrease over time. The effect of stunting on cognitive test scores may decrease with age, even in severely stunted children. Schooling, learning experiences and other educational stimulation can also attenuate the effects of stunting on children's cognitive development.[47], [48]However, ourstudy design may not represent the true linear growth of children. The children identified as not stunted in this study may actually have experienced stunting at a previous age.Poor cognitive development outcomes still occurred in the sample who had experienced stunting in the past, even though they were currently recovering. Previous studies have shown that children who recover from stunting at the age of five years still perform significantly worse on cognitive tests than children who do not experience early stunting, and are almost as poorly as children who remain stunted.[49]

Furthermore, we found that maternal education was significantly associated with the child's IQ. This is in line with findings in previous studies.[50], [51]Additionally, maternal education had the strongest influence on a child's cognitive development.[52]Another study documented the association of low educational status in mothers with several other risk factors such as poor nutrition, poor stimulation, and poor family environment. Then, these factors influence intelligence adversely.[53]–[56]

In our study sample there is a strong association in the unadjusted basic models with both maternal and paternal education, but with a stronger influence of maternal education. This is in line with other studies. Some found that maternal but not paternal education had an important effect on children's

cognitive development.[15], [50], [57]Furthermore, maternal rather than paternal education seems to have more influence on children's cognitive development at a young age.[58]

Children spend more time with their mothers so that the quality of the child care environment is strongly related to maternal factors. The level of IQ and education of the mother has a greater influence on the quality of the parenting environment than the level of IQ and education of the father. Furthermore, a mother's intellectual ability has a direct effect on the intellectual development of children because it is a genetically inherited trait.[59]–[61]However, maternal IQ was not controlled for in this study. In this analysis, maternal education was used as an approximate measure or surrogate for the maternal IQ variable as was also applied in previous studies.[57]

Environmental exposure to tobacco smoke has been reported to increase the risk of IQ impairment. However, in our study, environmental tobacco smoke and child's IQ were not associated. Limitations in this study are incomplete data on environmental cigarette smoke exposure, such as the length of smoking habit and the time of exposure to tobacco smoke in children. Data on the time of exposure to cigarette smoke in children is important to assess the level of risk of developmental disorders in children. The risk of developmental delay caused by exposure to prenatal tobacco smoke is much higher than that of postnatal in the first 2 years.[62]

Prenatal exposure to cigarette smoke is negatively associated with neurodevelopmental outcomes in children under five years of age, but postnatal exposure is associated with lower academic achievement and neurocognitive performance in older children (five years and older) and adolescents.[63]The relationship between prenatal cigarette smoke exposure and IQ of children over 5 years is much weaker.[64], [65]Developmental disorders in children who are exposed to tobacco smoke at the age of 6-7 years are in the form of weak language and attention skills.[66]This fact may explain why there was no association between environmental tobacco smoke and the IQ of children in this study.

5. Conclusion

Our findings provide evidence that BLL increases the risk of low IQ children in Muntok, Bangka Island. In addition, our results indicate an increase in the proportion of low IQ along with a decrease in the head circumference of children according to age and maternal education. Therefore, increasing the education of adolescent mothers is important to prevent negative effects on infant neurodevelopment. Although the relationship between height for age and paternal education level are not significantly related, both are potential confounding variables.

6. Recommendation

More research is needed to explore the influence of environmental factors and genetic characteristics on children's IQ. In addition, the government must screen children's blood lead levels at the study site. The implementation of educational programs for young parents is important to raise awareness about the importance of the health status of pregnant women and infants, as well as the family environment to children's cognitive development.

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