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The Neurotoxic Impact of Lead on The Appearance of Antisocial Behavior In Batik Dye Workers

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Abstract

Batik home industry waste not managed with standardized WWTP can lead to environmental pollution. It is caused by the remaining synthetic batik dyes containing heavy metal lead. The remaining dyeing waste is disposed of into the river, a water source in the surrounding environment. Waste containing heavy metals causes a neurotoxic effect on the human body. Furthermore, exposure to heavy metals due to synthetic batik dyes is more at risk for workers who do coloring since they do not use personal protective equipment while working and do not live a clean and healthy lifestyle. One of the behavioral disorders associated with the effects of accumulated lead exposure is antisocial personality disorder. In this study, blood lead levels were checked for batik dye workers by taking blood samples using a 3 ml purple vacuum tube and placing them in an ice box to be sent to the Yogyakarta Health Laboratory Center (BLK). The blood sample was then wet destroyed, and the Pb levels were read using an AAS tool. Antisocial tendency scale data was measured using STAB (Subtypes of Antisocial Behavior), where the validity test had previously been carried out with the Pearson product-moment of 0.327-0.786 and the reliability test with the Cronbach alpha technique of 0.936. The results of the data analysis showed a correlation between blood lead levels and antisocial disorder tendencies of 0.690, but no correlation was found between blood lead levels and body mass index (BMI)

Introduction

Lead is a heavy metal that has long been a concern. Lead (Pb), widely found in the environment, is a heavy metal element with a neurotoxic effect. Different from elements like iron and zinc, lead does not provide any benefit to the human body(Wani et al., 2021; Shilpa et al., 2021). The key aspect underlying Pb-induced neurotoxicity is oxidative stress, which is caused by increased activity of oxidative parameters such as lipid peroxidation or alteration of protein chains by reactive oxygen species (ROS) or reactive nitrogen species (RNS). The increase in ROS is caused by the rise in pro-oxidation factors, which support the formation of radicals through the Fenton reaction as a form of metal redox activity and a decrease in antioxidant ability. This process causes changes in membrane biophysics, disruption of cell signaling and neurotransmitters, and substitution for other polyvalent cations(Wang et al., 2020; Narayanan et al., 2020)

Oxidative stress will impact chronic psychological stress, which plays a vital role as a factor associated with the development of depression, which is shown by behavioral, neurochemical, and biological changes(Kiarash et al., 2020). Changes in behavior are influenced by serotonin, where serotonin plays a vital role in regulating aggressiveness and impulsivity, especially in individuals with behavioral disorders. Most of the data shows an inverse relationship between serotonin levels and levels of aggressiveness and impulsivity, where serotonin deficiency is caused by aggressive and impulsive behavior and vice versa(Yagishita,

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2020; da Cunha-Bang & Knudsen, 2021; Leshem & Weisburd, 2019). Besides affecting impulsivity, serotonin levels also lead to compulsive behavior and addiction(Leshem & Weisburd, 2019)

Research on the harmful effects of accumulated exposure to lead in the blood has been developed abroad. The study was conducted on some pregnant women in locations with high lead exposure. Examinations were carried out periodically from the age of newborns until they were 18 years old. The results showed that increased exposure to lead in the blood correlates with high crime rates in the region. The study results stated that every 5 mg/dl increase in exposure to lead in the blood of children aged six years increases the risk of antisocial behavior in adolescence by 50%(Fruh et al., 2019; Rodríguez-Carrillo, et al., 2022; Desrochers-Couture et al., 2019a; Desrochers-Couture et al., 2019b)

Lead is one of the chemicals that can disrupt the endocrine, which is related to the function of the hypothalamic-pituitary-adrenal (HPA), thyroid hormone, and bone metabolism(Fan et al., 2023; Wu et al., 2023; Bjørklund et al., 2020). A study on adults conducted by Wang *et al.* (2018) showed that blood lead levels would increase body weight based on NHANES 2003–2014. The study results showed a correlation significantly associated with other obesity measures, including BMI, skinfold thickness, and total body fat, as well as obesity-related chronic conditions, hypertension, and T2DM, independent of other important risk factors(Wang et al., 2018). In a prospective study conducted in the United States that examined nail metal alloys in relation to body mass index (BMI), findings showed that all non-essential metals had quartile increases linked to a higher BMI, while all essential metals had quartile increases linked to a lower BMI (Niehoff et al., 2020)

One industry that uses lead compounds in the production process is the batik industry, where lead is used as a dye mixture in the coloring process. In the textile industry, Lead (Pb) is used as a dye mixture, which produces a yellow color by adding chromium or PbCrO4, a white color from white lead [$Pb(OH)_2.2PbCO_3$] and a red color from red lead (Pb_3O_4) (Deliza et al., 2021; Putri et al., 2022). One area in Surakarta that has been producing batik for a long time and marketing it abroad is the batik village. Based on the background above, a study was conducted on the correlation between blood lead levels and the appearance of antisocial behavior in batik dye workers. The results of this study are expected to increase public awareness of the negative impact of lead on the environment.

Methods

This study uses a correlational quantitative research design. The research took place in the Batik village by taking a sample of 72 workers through purposive non-random sampling. The sample criteria were taken from workers in the batik coloring division. This research has obtained an Ethical Clearance certificate with the number KEPK/UMP/12/XI/2023 issued by the Health Research Ethics Commission at Universitas Muhamadiyah Purwokerto. Secondary data is in the form of records obtained from questionnaires as a research control to find out personal data related to research, activity, and history of illness of research sample workers. Blood lead levels were checked by taking a blood sample using a 3 ml purple vacuum tube and placing it in an ice box to be sent to the Yogyakarta Health Laboratory Center (BLK). Then, the blood sample was wet destroyed, and the Pb level was read using a graphite furnace atomic absorption spectrometry tool. The appearance of antisocial behavior data was measured using STAB (Subtypes of Antisocial Behavior), where the validity test had previously been carried out with the Pearson product-moment of 0.327-0.786 and the reliability test with the Cronbach alpha technique of 0.936. Normal lead levels in the blood, according to the Centers for Disease Control and Prevention or the CDC (2012) are Adults: < 10 g/dL and children: < 5 g/dL. Data analysis techniques for blood lead (Pb) levels and the appearance of antisocial behavior were analyzed using a correlation test using SPSS 26.

Result and Discussion

This study involved 72 batik workers consisting of 57 (79,17%) male workers and 15 (20,83%) female workers. Heavy metals exist in nature but will increase along with human activities in industry. An industry that is vulnerable to high heavy metals from the dye sources used is the batik industry. The heavy metals in the batik industry act as a color binder to be absorbed into the fabric or present as a dyeing impurity (Juliani, 2021; Birgani et al., 2016). Previous analysis detected heavy metal types Cd, Pb, Fe, Cu, Zn, Al, Mn, Mg, Ca, Cr, and Si in batik waste samples in Malaysia and Indonesia (Sungur & Gülmez, 2015; Juliani, 2021). It is essential to note that the concentration of each heavy metal element varies significantly based on the stage of production.

The batik industry in Indonesia is produced on a small and medium scale, including in the category of household industry, with limited capacity like occupational safety and environmental management. Batik workers will be at risk of exposure to chemicals used in production due to the minimum use of personal protective equipment supported by the habits of workers who feel that using personal protective equipment will slow down their work. On the other hand, batik waste from most factories is released into the environment without proper treatment. While many batik factories are located around residential areas, improper handling of this wastewater can release pollutants into the soil and groundwater (Juliani, 2021). It would pose a health risk to humans from direct use and exposure to contaminated soil, water bodies, and groundwater.

In humans, heavy metals enter the body in various ways, such as contaminated food, water, skin, and inhalation. These metals are absorbed through the intestines, mainly soluble in water, and transmitted to several organs through the circulatory system. However, at low concentrations, heavy metals affect the respiratory tract and many cells such as endothelium, epithelium, and so on (Kiran et al., 2022). The measurement of blood lead (Pb) levels in batik dye workers showed normal results for the 72 (100%) respondents. 15 (20.83%) had below-normal body mass index, 35 (48.61%) had normal body mass index, 17 (23.61%) had above-normal body mass index, and 5 (6.94%) had obesity. 14(19.44%) had a low appearance of antisocial behavior, 39 (54.17%) had a moderate appearance of antisocial behavior, 16 (22.22%) had an upper appearance of antisocial behavior, and 3 (4.17%) had a very high of appearance of antisocial behavior (Tabel 1)

The average value for Blood lead (Pb) levels is 11.770 ± 1.376 μg/L. Blood lead levels of workers are still within normal thresholds because batik workers are not permanent workers and only work when there is demand from consumers. The average value appearance of antisocial behavior is 42.38 ± 0.90; while their average Body Mass Index is 22.802 ±

Tabel 1. Frequency Distribution of Body Mass Index and Blood Lead (Pb) Levels Values in Batik Dye Workers

Categories	Frequency	Percentage
Body Mass Index (Kg/m^2)		
Below Normal (≤ 18.5)	15	20.83%
Normal (18.5–24.9)	35	48.61%
Above Normal (25–29.9)	17	23.61%
Obesity (≥ 30)	5	6.94%
Blood lead (Pb) levels (μg/dL)		
Normal (<10)	72	100 %
Abnormal (≥10)	0	0 %
Appearance of Antisocial Behavior		
Very low (<25)	0	0.00%
Low (25-35)	14	19.44%
Moderate (36-46)	39	54.17%
Upper (47-57)	16	22.22%
Verry high (58-70)	3	4.17%

0.531% (Table 2).

The analysis results did not show a significant correlation between blood lead levels and BMI, with a proportional correlation coefficient. This directly proportional correlation coefficient indicates that an increase in blood lead levels will impact an increase in BMI. Research conducted by Firoozichahak *et al.* (2022) also shows no significant relationship (P> 0.01) between workers exposed to lead and those not exposed to lead. The results showed that BLL and the levels of bilirubin, lactate dehydrogenase, aspartate transaminase, alkaline phosphatase, and alanine transaminase were positively and significantly correlated (P<0.01). Additionally, a substantial and negative connection (P<0.01) was seen between BLL and levels of total protein, albumin, globulin, triglycerides, and globulins (Firoozichahak et al., 2022). Research in China shows that women in rural areas with increasing economies have higher lead pollution from industry. Lead sourced from drinking water or rice contaminated with lead shows high levels of lead in the blood, positively related to BMI and a tendency to obesity (Ningjian et al., 2015).

Lead exposure early in life is at risk of affecting intelligence and increasing the risk of ADHD. Exposure in adolescence is at risk of showing symptoms of delinquent behavior (juvenile delinquency), while exposure in adulthood indicates criminal behavior (breaking the law. The existence of a causal relationship between lead exposure and behavioral disorders in children, adolescents, and adults is evidenced in cross-sectional epidemiological studies of criminal behavior in prisoners. The association between lead exposure and behavior was observed in populations with mean blood lead levels (BLL) of 7–14 µg/dL; association with

Table 2. Distribution of Descriptive Statistics of Lead Levels, Appearance of Antisocial Behavior, and BMI

Variables	Mean	Median	SD	Min	Max	95% Confidence Interval		Significance
						Lower Bound	Upper Bound	
Blood lead (Pb) levels (µg/L)	11.770	9.646	11.675	0.019	48.965	9.027	14.514	-
Appearance of Antisocial Behavior	42.38	40.00	7.642	32	63	40.58	44.17	0.032
Body Mass Index	22.802	21.675	4.509	15.94	32.96	21.742	23.862	0.731

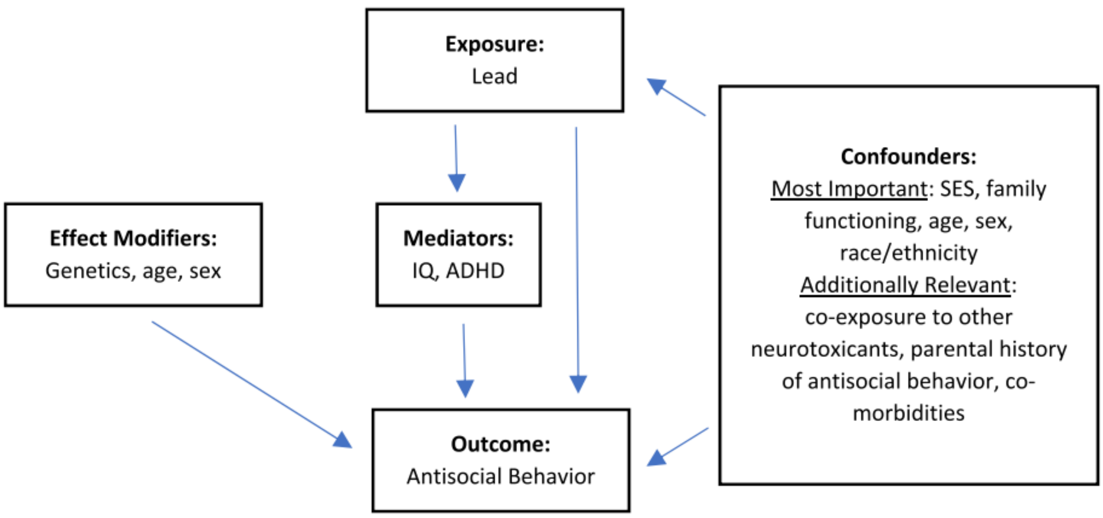

Figure 1. Logic Model for the Link Between Lead Exposure and Antisocial Behavior, IQ = Intelligence Quotient; ADHD = Attention-Deficit Hyperactivity Disorder; SES = Socioeconomic Status (Shaffer *et al.*, 2022)

lower BLL was also observed in cross-sectional studies. Behavioral disorders tend to be affected by higher levels of lead exposure early in life (Shaffer et al., 2022)

Environmental pollution can damage the central nervous system. Environmental pollution can be caused by air pollution from motor vehicle fumes, soil pollution by adding chemical pesticides in agriculture, and water pollution from industrial area waste, e.g., the batik industry, which produces synthetic dye waste discharged into rivers. The social environment is the primary concern for the emergence of problematic behavior so far. It includes parenting patterns and social environment. However, it turns out that a broader understanding is needed regarding the environment. The environment that influences behavior is the social environment and the physical environment. Internally, the physical environment that becomes an important concern is the impact of lead toxicology, i.e., lead exposure, which causes damage to the brain and nerves, resulting in behavioral changes. Lead is a heavy metal that can be a source of free radicals when it enters the body. Lead can enter the body through the digestive tract, respiratory tract, or skin (Budi et al., 2024; Patel et al., 2021). The toxicology of lead becomes harmful to the body due to the ionic mechanism with lead's ability to replace other bivalent cations such as Ca^{2+}, Mg^{2+}, and Fe^{2+} and monovalent cation ions such as Na^{+}. It will affect the fundamental biological processes in the human body(Massa & Siaka, 2022; Fu & Xi, 2020). The accumulation of lead exposure in the body significantly impacts various processes, including disruption of signal transmission between cells, causing cell adhesion, protein folding and maturation, apoptosis, ionic transport, enzyme regulation, the release of neurotransmitter amounts and types, and so on (Briffa et al., 2020; Singh et al., 2024)

Particularly, the ionic mechanism contributes to the depletion of the neurotransmitter by displacing calcium ions and their ability to cross the blood-brain barrier (BBB). After passing BBB, the lead will accumulate in astroglial cells (protein lead bonds). Then, the lead will damage immature astroglia cells and inhibit the formation of myelin sheaths. Even in small amounts, lead can replace calcium, affecting key neurotransmitters such as protein kinase C. This protein plays a role in regulating nerve excitation and memory storage. Lead also influences the concentration of sodium ions responsible for vital biological activities, such as responses to actions in excitatory tissues for intercellular communication, uptake of neurotransmitters (choline, dopamine, and GABA), and regulation of calcium use and retention by synaptosomes. The interaction between lead and sodium then impairs the normal function of sodium (de Souza et al., 2018; Rocha & Trujillo, 2019). Compared to the effect of lead on organs, the nervous system is the main target and is more sensitive to inducing lead toxicology(Singh et al., 2018). Both the central and peripheral nerve systems will be impacted by lead exposure. Adults are more likely to notice effects on their peripheral nervous system, whereas children are more likely to notice effects on their central nervous system.(Boskabady et al., 2018; Tshala-Katumbay et al., 2015)

Lead poisoning in children can decrease intelligence, growth, hearing, and anemia, and can lead to attention disorders and behavioral lapses(Agudelo et al., 2024). High exposure can result in severe brain damage, even death. Children are susceptible to lead poisoning because they can absorb more lead from the environment than adults. Besides that, the central nervous system in children is still in the developmental stage, so it can disrupt development. Lead can also poison the reproductive system, resulting in disruption of the formation of red blood cells. High blood lead levels are associated with delayed puberty in girls. It is because lead poisoning suppresses the production of hormones in the ovaries that function to prepare a woman's body to ovulate and release an egg. Exposure to lead throughout pregnancy, stored in bones and blood, eventually leads to across the placenta and causes fetal death. Short-term exposure to high lead levels can cause brain damage, movement disorders, anemia, and gastrointestinal symptoms. Long-term exposure can cause damage to the kidneys, reproductive system, immune system, and nervous system. The impact of low-level lead exposure on the nervous system is related to intellectual development in early childhood. The same analogy as mercury, lead crosses the placenta and accumulates in the fetus. Short-term and low-level lead exposure in children affects neurobehavioral disorders (Musfirah & Rangkuti, 2019).

The accumulation of lead in the central nervous system leads to the emergence of structural and functional disorders. Lead poisoning is known to affect different parts of the brain, namely the cerebral cortex, cerebellum, and hippocampus. Lead exposure in adult mice and growing mice showed increased oxidative stress in the cortex, hippocampus, cerebellum, and medulla. This increase in oxidative stress is characterized by a decrease in the activity of the enzymes Superoxide Dismutase (SOD), Xanthine Oxidase (XO), and Catalase (CAT), as well as increasing levels of lipid peroxidase (LP) enzymes. The area in the brain most early affected by lead exposure is the gray matter of the prefrontal. The reduction of gray matter in the prefrontal is related to the appearance of criminal behavior in individuals and antisocial personality disorder. Elevated levels of lead in the blood affect the process of delivering neurotransmitters at the synapse. It leads to inhibition of neurotransmitter release, including at serotonergic synapses, which are synapses that have the neurotransmitter serotonin. Serotonin is one of the neurotransmitters that is also responsible for influencing individual behavior. Serotonin, in normal levels, maintains emotional stability. Disturbances in the serotonin can lead to increased aggressive and impulsive behavior. Decreased serotonin levels were found to occur in people with antisocial behavior disorder. Although it is recognized that antisocial behavior is due to the interaction of various socio-hereditary variables, there is increasing research evidence that exposure to the heavy metal lead plays a role in its epigenesis, namely as a trigger for stimulus. Increased blood lead levels will have implications for the structure, enzyme system, and neurotransmitters of the nervous system, which implicates the emergence of behavioral changes (Marianti et al., 2015).

Lead exposure directly causes encephalopathy or the progressive degradation of specific brain regions. Symptoms include headaches, tremors in the muscles, dull skin, irritability, poor focus, memory loss, and hallucinations. Seizures, ataxia, psychosis, lack of coordination, paralysis, and coma are examples of more severe symptoms (Reuben, 2018; Eid & Zawia, 2016; Bakulski et al., 2020). The importance of the research topic on the link between lead exposure and antisocial behavior has several reasons. First, there has been a lot of relationship between the two variables, but there has not been a concern related to policy. Second, there are no documents that specifically address delinquency and criminality (part of the symptoms of antisocial disorder). It needs to be included in theories of human development. This perspective is vital, given that the trajectory of the results achieved can have an impact. Third, a recent evaluation of the evidence for the role of lead etiology in antisocial behavior can inform an updated quantitative assessment of the effect of the global burden of lead and evidence-based policy interventions aimed at reducing exposure worldwide, particularly early in life and reducing the harmful effects of lead and other neurotoxicants in achieving the sustainable development goals.

Conclussion

The industry of batik produces waste from dyeing residue, which causes environmental pollution if it is not managed properly. Environmental pollution contains the heavy metal lead neurotoxic to the human body. Accumulated exposure to lead in the blood of dye workers in the batik industry has a positive and significant correlation with the appearance of antisocial behavior, yet does not correlate with body mass index.

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