J Health Rep Technol. 2024 July; 10(3): e148966 https://doi.org/10.5812/jhrt-148966

Published Online: 2024 September 24 **Review Article**

Association Between Exposure to Heavy Metals and Dyslexic Risk Among Children: A Narrative Review

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Received: 20 May, 2024; **Revised:** 19 June, 2024; **Accepted:** 27 June, 2024

Abstract

Context: Developmental dyslexia (DD) is a learning disorder characterized by difficulties in reading due to challenges in sound identification and letter-word association. This study aimed to evaluate the correlation between exposure to heavy metals (HMs) and the risk of dyslexia in children through a narrative review.

Evidence Acquisition: The study adopted a narrative review approach, utilizing keywords to search reputable databases like Google Scholar, Scopus, PubMed, and Web of Science. Relevant research meeting specific criteria were selected for analysis.

Results: In most studies, metals were measured in children's urine. The results indicated that children with DD had lower levels of essential metals such as zinc (Zn), selenium (Se), and cobalt (Co). In contrast, toxic metals like mercury (Hg), cadmium (Cd), silver (Ag), and lead (Pb) were significantly higher compared to the control group. Based on the results of previous studies, no significant variations were observed in other essential and toxic metals between the case and control groups.

Conclusions: Essential metals like Zn, Se, and Co may protect against DD in children, whereas toxic metals such as Pb, Ag, Cd, and Hg could exacerbate the disorder. It is recommended to evaluate essential and toxic metal levels in parents before and during pregnancy and in infants to mitigate dyslexia risk in children.

Keywords: Neurodevelopmental Disorder, Heavy Metals, Dyslexic Risk, Children, Environmental Exposure

1. Context

Developmental dyslexia (DD), a common neurodevelopmental disorder, accounts for most learning disabilities (1), causing students to struggle with some language skills, especially reading skills. Students with DD may also have problems with writing, speaking, learning new languages, and other subjects. When parents or teachers do not identify this disorder and appropriate educational methods and strategies are not used for this group of students, their academic and professional success may be at risk (2). Previous studies have shown that this disorder occurs in 0.5 to 17.5% of schoolchildren in English-speaking countries and 3 to 12.6% in China (3, 4). imposes a substantial social and economic burden on society. Children affected by DD often experience persistent reading difficulties, leading to lower educational achievement and socioeconomic status compared to their peers (5). The causes of dyslexia are multifactorial and unclear, involving genetic and environmental factors. Many studies have emphasized the importance of exposure to environmental pollutants in dyslexia development (6-15).

Heavy metals (HMs) are elements found naturally in environments characterized by high atomic weights. Introducing toxic metals through human activities has polluted many soils and water resources. Industrial, mining, household, agricultural, medical, and technological applications of metals have led to their widespread distribution in the environment. This widespread use has raised concerns about their potential effects on human health and the environment. Heavy metals are persistent and durable environmental pollutants (16), and their toxicity depends on several factors, including dose, route of exposure, chemical properties of the metals, and the age, sex, genetics, and nutritional status of the individuals exposed to these pollutants (17). One necessary consequence is the persistence of these metals in the environment and their bioaccumulation in the food chain (18). These metallic elements are considered systemic toxins because exposure to even lower levels of these pollutants can cause multiple and severe damage to various body tissues. Heavy metal exposure can cause a variety of serious health problems, including carcinogenicity, effects on the central and peripheral nervous systems, impact on the skin, effects on the blood system, effects on the cardiovascular system, kidney damage, and tissue accumulation (19).

Metals are classified into two main groups, essential and non-essential, based on their role in human metabolism. Essential metals play a crucial role in metabolic pathways and include selenium (Se), zinc (Zn), iron (Fe), nickel (Ni), and copper (Cu). Non-essential metals, which do not play a specific role in body metabolism, include lead (Pb), arsenic (As), cadmium (Cd), mercury (Hg), chromium (Cr), and manganese (Mn) (20). Heavy metals can bioaccumulate in the tissues of microorganisms and the human body and cause toxic effects even at low concentrations (16, 17).

Based on past studies, HMs are one of the essential pollutants that have a high impact on neurodevelopmental disabilities (21-23). To date, there has been no comprehensive review study on the effect of HMs on the risk of DD. The main objective of this study was to evaluate the association between exposure to HMs and dyslexia risk in children in a narrative review format.

2. Evidence Acquisition

This literature review gathered findings by evaluating the results of similar studies conducted over the past two decades. The primary and prevalent medical subject headings (MeSH) terms associated with the topic were initially recognized to conduct the study. Then, these terms were searched in reputable and significant databases, including “Google Scholar,” “Scopus, “PubMed,” “Web of Science,” and others. This search identified 46 potentially relevant studies. Subsequently, applying the inclusion and exclusion criteria, the researchers narrowed the selection to 10 studies for data extraction and analysis. Advanced search techniques using "AND" and "OR" operators combined search terms effectively. The reference lists of the final articles were also reviewed for related studies to ensure comprehensive coverage. Table 1 presents the key criteria used for selecting studies.

3. Results

Earlier research has shown that exposure to certain metals, such as As, Pb, and Mn, improves the risk of neurodevelopmental disabilities, neurological defects, or cognitive decline (21-23). A comprehensive review study on the relationship between HMs and autism spectrum disorder (ASD) found that the content of toxic metals was significantly different between people with ASD and healthy people (24).

Baranowska-Bosiacka et al. showed that exposure to Pb during early life reduced glycogen metabolism in the mouse brain and led to further dysfunction (25). In addition, findings from studies in various populations have shown that Mn exposure is directly and positively associated with cognitive function (26-28). Based on another study in the United States, there is a robust correlation between soil strontium levels and Parkinson's disease (29). The results of specific studies indicated that silver (Ag) nanoparticles exert toxicity on brain function by disrupting the antioxidant defense mechanisms of the human body (30, 31). Some metals, such as Fe and Se, may help improve cognitive function, memory capacity, and early language abilities (32-35). The findings of one study showed that increased maternal Se concentrations during pregnancy and breastfeeding are directly and positively associated with improved child cognition (36). Based on the findings of a prospective cohort study in Bangladesh (2017), prenatal Se levels are directly linked with more mental ability at ages 5 and 10 (37).

Several studies have been conducted on the relationship between HMs and DD. In a case-control study by Xue et al., the association between urine metals and DD was evaluated in Chinese children. The study showed a substantial association between the metals Se and Argentum with DD in multivariable single-metal models. Argentum was found to have a positive association with DD risk, whereas Se exhibited a negative association. In the joint association analysis, children with higher levels of argentum and lower levels of Se in their urine were significantly more likely to have DD than those with lower levels of urine argentum and Se (OR = 5.06, 95% confidence interval (CI: 1.67 - 18.84). At the end of the study, the researchers concluded that exposure to Se and Argentum may

Table 1. The Key Criteria Used for Selecting Studies

Selection Criteria	Inclusion/Exclusion Criteria
Focus on studies	Studies focused solely on DD were included; only studies that evaluated the effect of HMs on DD were considered. Research examining the association of other pollutants with DD was excluded.
Sample size	Studies with small sample sizes were excluded.
Journal quality	Studies published in non-reputable journals or scientific databases were not considered.
Publication medium	Articles presented on public websites were excluded.

Abbreviations: HMs, heavy metals; DD, developmental dyslexia.

potentially correlate with an elevated risk of DD in China (10).

Excess exposure to Mn is harmful to neurodevelopment and can Pb to intellectual disability, cognitive decline, and decreased language scores (15, 21-23). In this regard, Zhu et al. reported that urine Mn is associated with reading scores in Chinese children with DD, and exposure to higher levels of Mn may increase the risk of DD (15). In addition, another case-control study in China by Huang et al. found that urine Pb levels were positively associated with DD, meaning that increased exposure to Pb metal increases the risk of DD in children. Additionally, an interesting finding of the study was that the association of cobalt (Co) and Zn concentrations with DD was negative, meaning that Co and Zn metals had a protective effect against DD, and a deficiency in these metals can increase the risk of DD in children (6).

Grant et al. compared metal levels in the sweat and hair of children aged 6 to 14 years old, distinguishing between those with DD (case group) and those without (control group). The findings revealed significant disparities in sweat Zn concentration between the two groups. Moreover, the case group exhibited significantly higher sweat Zn and Cr concentrations than the control group ($P < 0.05$). At the same time, the sweat Pb, Cu, and Cd concentrations were significantly higher in the case group than in the control group ($P < 0.05$). The study's results on the concentrations of metals evaluated in hair showed that the sweat Zn concentrations of the two study groups did not differ significantly ($P > 0.05$). In contrast, the sweat Cd concentration was significantly lower in the control group than in the case group ($P < 0.05$). In addition, similar to the sweat metal levels, Cu, Pb, and Cd concentrations were significantly higher in the case group than in the control group ($P < 0.05$). Hg was only measured in hair, and its mean was significantly higher in the case group than in the control group ($P < 0.05$) (38).

Further supporting these findings, another study by Liu et al. revealed that urine Zn concentration is significantly associated with the risk of DD in children (39). Zinc deficiency in animals during pregnancy can result in cognitive impairments, behavioral abnormalities, and compromised immunological function that persist throughout multiple generations. Offspring of zinc-deficient animals have persistent microscopic abnormalities in the hippocampus, a region crucial for working memory, and elevated amounts of catecholamines and Cu in their brains (40-42). A Zn deficit in parents before conception can influence familial dyslexia. Research on Zn levels and the effects of preconception, pregnancy, and childhood supplementation is necessary (38).

4. Conclusions

Several studies have investigated the link between dyslexia (DD) and metal levels in children. Researchers typically measured metals in urine samples from children with DD (case group) and healthy children without DD (control group). The results showed that the concentration of some essential metals, including Zn, Se, and Co, was significantly lower in the case group than in the control group, suggesting a protective role of these metals against DD in children. Conversely, the concentration of some toxic metals, including Pb, Ag, Cd, and Hg, was significantly higher in the case group than in the control group, indicating an aggravating role in causing DD. Based on previous studies, no significant differences were observed between the case and control groups for other essential and toxic metals. In conclusion, these findings suggested that evaluating essential elements and toxic metal levels in parents before pregnancy and monitoring these levels in infants might be beneficial for potential future control of DD in children.

Footnotes

Authors' Contribution: A. S.: Designing the study; T. M.: Searching for past studies; H. S.: Extracting and recording the raw results; A. K. and A. S.: Writing the initial draft and revising the final manuscript.

Conflict of Interests Statement: Authors confirm this study has no relevant financial or non-financial competing interests.

Data Availability: The dataset presented in the study is available on request from the corresponding author during submission or after publication.

Funding/Support: The authors funded this study but did not receive financial support from any institution (self-funding).

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