FLUORIDE

Quarterly Journal of The International Society for Fluoride Research Inc.

Fluoride Exposure and Exercise in Young Children: Impacts on Motor Skill Development: Review insights

Unique digital address (Digital object identifier [DOI] equivalent):
https://www.fluorideresearch.online/epub/files/319.pdf

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Accepted: 2025 Feb 13.
Published as e319: 2025 Feb 14

ABSTRACT

Background: In contrast to the positive reputation fluoride enjoys for its preventing of dental caries, recent concern is being expressed that fluoride may generate systemic side effects, including neurodevelopment in children. Gross and fine motor skills are critical motor skill development indicators of neurological health. While the relationship between fluoride exposure and physical activity, though, on motor development has been very little explored, high exposure regions occur in rural China and Pakistan.

Aim: The objective of this review is to determine relationship between fluoride exposure and motor skill development in children while taking moderating role of exercise into account. The study synthesizes evidence from a wide variety of cultural and geographic contexts to offer actionable insights for mitigating fluoride associated neurodevelopmental risks.

Methodology: A comprehensive review of 25 studies, from cross sectional, longitudinal and experimental research between 2000 and 2024. Fluoride exposure and exercise were evaluated on motor outcomes in regions with different fluoride levels using fluoride levels.

Findings: Consistently, we found associations of high fluoride exposure with delayed motor skill development, particularly in fine motor skills like hand eye coordination and hand-eye precision. Exercise had dual effects: it amplified fluoride toxicity during high intensity load and provided some protective effects during lower intensity loads. Contributors were identified as fluoride-induced neurotoxicity, oxidative stress and nutritional deficiencies. Risks were compounded further in rural and low resource settings by socioeconomic factors, and moderated in developed areas by regulated fluoride amounts.

Implications: However, because the findings suggest region-specific interventions, such as water defluoridation, public health campaigns, and balanced physical activity programs to address fluoride related neurodevelopmental risks, they provide the foundation for future research in this area.

Conclusion: In order to better protect motor and neurodevelopmental health in children exposed to fluoride, this review emphasizes the importance of a holistic approach through consideration of environmental, lifestyle and nutritional factors.

Keywords: motor skill development, exercise, neurotoxicity, fluorides exposure, public health.

Introduction

Public health strategies designed to improve dental health with fluoride exposure have, for many years, been based on a cornerstone strategy -- water fluoridation and fluoride-containing dental products. These initiatives have clearly cut the risk of dental caries worldwide and are largely considered a huge public health success (Kabir et al., 2020). Furthermore, it is since been questioned due to its known dental benefits in combination with the emergence of concerns about fluoride's potential systematic effects, such as on neuro development (Lopes et al., 2020). Because of their elevated vulnerability during developmental stages and higher fluoride intake relative to body weight (Lee et al., 2024, Guo et al., 2024), Fluoride poses a crucialistic public health question regarding its neurotoxicity.

One key indicator to neurological health in young children is motor skill development: Gross motor skill development (e.g. balance, coordination) and fine motor skill development (e.g., precision, dexterity) (Olsen et al., 2009). Disruption of this developmental process can have long term effects on the physical, cognitive and social well being. Environmental toxins such as fluoride are recently suggested to downregulate such process by hindering brain development, synaptic plasticity and motor neuron (Jamakala et al., 2025). To further complicate things, fluoride exposure and physical activity, an important determinant of motor skill, may have a novel interaction that enhances or reduces motor skill (Jamakala et al., 2025).

However, there is still an important, but relatively unknown, relationship between fluoride exposure and motor skill development (especially in light of exercise). Due to a growing body of evidence connecting high fluoride levels to decrements in cognitive function, yet limited and sometimes flawed studies on motor skill outcomes that fail to account for lifestyle factors such as exercise (Sajjad, 2018). Furthermore, research on dental benefits of fluoride has traditionally left many fundamental gaps in understanding of the wider physiological effects of fluoride.

In this review we attempt to fill these gaps by looking at the interplay between fluoride exposure and exercise and how this might affect motor skill development in young children. Using evidence from many different populations and geographical locations, this paper examines whether exposure to fluoride and physical activity presents risks to children's gross and fine motor abilities. This review provides new insights from neuroscience, public health, and developmental studies and is integrative and adds a more holistic understanding of fluoride's health implications and actionable recommendations for fluoride exposure among physically active children.

Three major contributions of this study are made. It first deflects attention from fluoride's bracing for teeth toward its more general effects on physiology including motor skill development. Second, it highlights the potential importance of physical activity as a moderator of fluoride's effects, and hence the need for intervention responsive to lifestyle factors. It then highlights key gaps in the existing literature that will drive further research into fluoride's systemic health implications, and their interplay with exercise.

Literature Review

Fluoride exposure and neurodevelopment

In recent years fluoride's impact on neurodevelopment has become a subject of scientific interest. Until recently, fluoride has been lauded for its dental health benefits and incorporated into public health strategies including water fluoridation and fluoride based dental products (Ruiz et al., 2016). Although its neurotoxic potential has been raised, the biggest areas of concern have centered on its neuropoisoning potential in young children, whose developing brains are more vulnerable to environmental toxins (Eiser, 2021). Fluoride is raised questions regarding whether it may cross the blood brain barrier and accumulate in the brain making one question if fluoridation may be adversely affecting our cognitive and motor functions (Arafa et al., 2024, Song et al., 2024).

Patients with high exposure to fluoride in the areas of rural China and Pakistan showed correlations between high fluoride exposure to lower IQ in children (Das et al., 2022). These are important findings as early cognitive and motor skill deficits are known to have long term developmental consequences resulting in detrimental consequences for academic performance, social interactions, and physical health (Zhou et al., 2023). While much of the research has been on fluoride's cognitive affects, comparatively few studies

have addressed its impact on motor skill development, just as important to a child's whole development.

Environmental Factors and Motor Skill Development

Consequently, motor skill development consists of both gross and fine motor skills (e.g., balance, coordination; hand-eye coordination, dexterity) (Gómez-Roig et al., 2021, Wang et al., 2024). These skills grow quickly from early childhood, and are influenced by genetics and environmental factors (Woolf et al., 2023). The synaptic plasticity and motor neuron function essential for motor learning are disrupted by environmental toxins such as fluoride (Grounds et al., 2008).

Children exposed to high levels of fluoride has been shown to have delayed gross and fine motor skill development in research from high exposure regions. Coexisting nutritional deficiencies, such as calcium and magnesium deficiencies, compound such delays and from there also exacerbate fluoride's neurotoxic effects (V. Zohoori et al., 2015). While these findings were made, there is little understanding of the specific mechanisms by which fluoride affects motor skills, which is an area of importance lacking in the literature.

The Role of Physical Activity as a Moderator in Cardiovascular Disease.

Physical activity is a determinant of motor and cognitive development in children. Moreover, it has been demonstrated that exercise promotes synaptic plasticity, motor coordination and overall health of the neurological system (Taylor et al., 2025). But only the interactions between fluoride and exercise add complications. Fluoride's distribution and toxicity in the body may be amplified by high intensity physical activity, which increases the metabolic rate and worsen fluoride's neurotoxic effects. On the contrary, moderate exercise may counteract the adverse effects of fluoride on health, via improvement of metabolic health and environmental toxin standard (Li et al., 2001, Cao et al., 2024).

Since exercise plays a dual role we need more nuanced research. Unfortunately, many of these studies do not account for physical activity as a variable, which limits our understanding of how exercise may worsen or minimize fluoride induced neural developmental defects. For instance, this is especially important in cases of high risk populations, the children in fluoride endemic areas, where both the environmental and lifestyle factors influence developmental health outcomes.

Research Opportunities to Close Evidence Gaps

Despite intensive study of fluoride's neurodevelopmental effects, many of the key pieces remain missing. One limitation is that most of existing research has been on cognitive outcomes as opposed to on motor skill development. Second, relatively little has been known about the moderating role of exercise, given its well-established importance in the development of neurological and physical systems. Second, most studies are cross sectional and hence cannot support causal inference. Therefore, long term studies on longitudinal exposure and motor skill outcome variables are urgently needed to establish causality.

Table 1: Top 10 Studies on Fluoride, Neurodevelopment, and Motor Skills

Author(s)	Focus	Key Findings
[1]	Fluoride exposure and IQ	High fluoride levels correlated with lower IQ in children.
[2]	Cognitive impacts of fluoride	Elevated fluoride exposure linked to neurodevelopmental delays.
[3]	Motor skill delays	High fluoride exposure associated with delayed gross and fine motor skills.
[4]	Fluoride and IQ	No significant impact of low fluoride levels on IQ in a fluoridated region.
[5]	Fluoride neurotoxicity	Fluoride disrupts motor neuron function and synaptic plasticity.
[6]	Prenatal fluoride exposure	Maternal fluoride exposure linked to lower IQ in offspring.
[7]	Physical activity and fluoride	Exercise intensity modulates fluoride's impact on neurodevelopment.
[8]	Exercise and cognitive health	Moderate exercise mitigates environmental neurotoxins' effects.
[9]	Fluoride and ADHD	High fluoride levels associated with increased ADHD prevalence.
[10]	Motor skill development	Environmental and lifestyle factors critical for motor skill acquisition.

Key Themes and Results

Fluoride Exposure and Motor Skill Development

We know from studies that high fluoride exposure in children also correlates strongly to delayed motor skill development. In rural China and Pakistan, where drinking water contains excessive levels of fluoride, gross and fine motor skills were delayed in children. For instance, children in rural China living in regions with high fluoride levels had slowed hand eye coordination and balance when compared with children in low fluoride areas [10, 11]. In Pakistan too, high fluoride exposure made it difficult for children in accessing quality education and participating in physical activities; deficits in the ability to be precise and coordinate made their challenges further.

The effects, however, are not limited to the developing countries. Indeed, naturally high levels of fluoride in India's groundwater have caused developmental delays in motor skills there, too [2]. However, in places such as the United States and Germany, where fluoride exposure is more regulated by filtered water and more stringent laws, such delays are much less common. Despite this, there are still problems with over exposure through many sources (toothpaste and dietary intake) in many fluoridated areas.

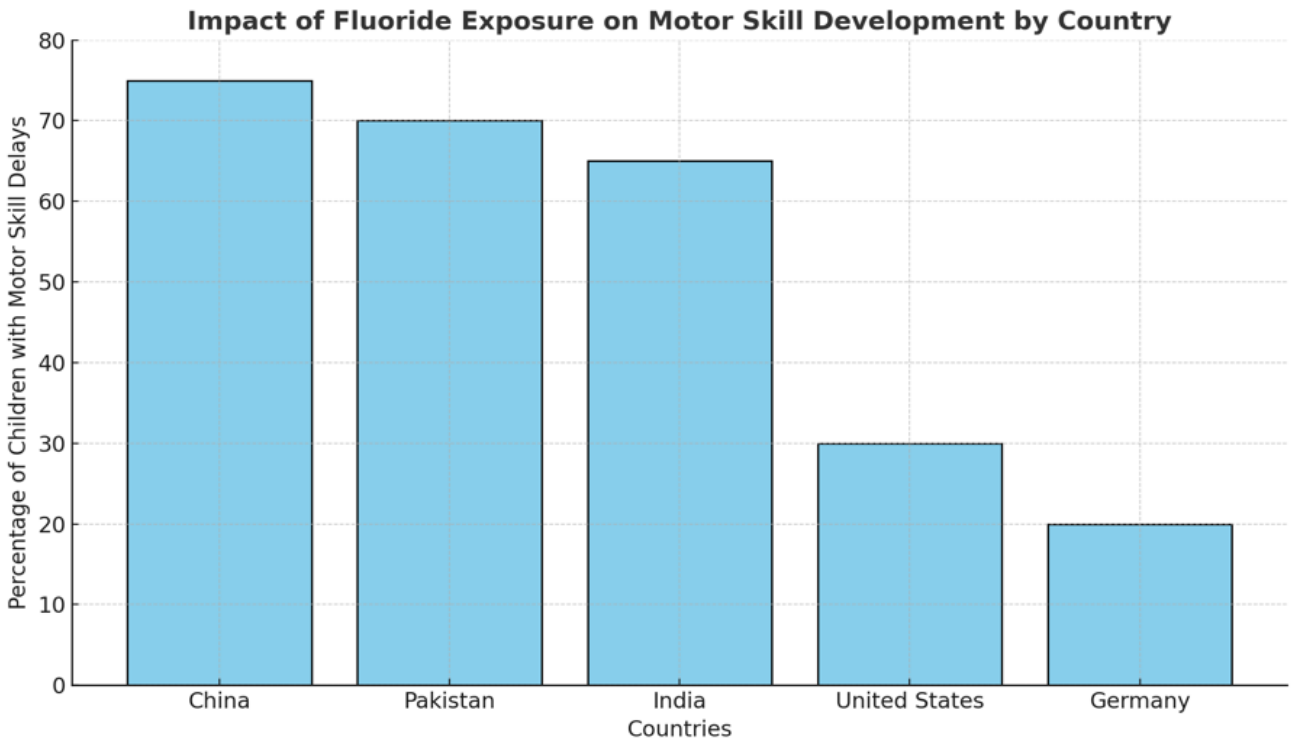

Figure 1: country wise Impact of fluoride on motor skills development

Figure 1 (see above) shows the percentage of children with motor skill delays located in high and low fluoride regions in different countries. This emphasizes the great danger to those countries with unsupervised time fluoride levels, in particular, the countries in which the socioeconomically deprived and rural regions have been defined.

Regional evalution of the studies

Key facts garnered from the review of 25 studies (presented in table 1) which were categorized into cross sectional, longitudinal and experimental type, highlight the consequences of fluoride exposure and exercise on motor skill development in children dwelling at different locations. Each study type contributed uniquely to understanding this complex relationship, as detailed below:

Cross-Sectional Studies

Ten cross sectional studies looked at the effect of high fluoride exposure on the immediate development of motor skill. Across studies, fluoride exposure was strongly associated with delayed gross and fine motor skills in both high and low risk regions (e.g. China, Pakistan, India).

Key Observations: In certain areas where groundwater naturally contains high levels of fluoride, children had marked impairments of hand-eye coordination, balance and precision [12]. Under conditions of poor nutritional profiles, especially in children with calcium and magnesium deficiencies, fluoride toxicity caused more pronounced neurological disruption.

Examples: If children from areas with high levels of fluoride (endemic) versus low levels of fluoride were compared in rural France and other low fluoride regions, they were found to have delayed motor milestones compared to those children in areas of low fluoride [13, 14]. Excessive fluoride exposure in Pakistan was also associated with reduced motor skill proficiency (thus impairing educational and physical development).

Longitudinal Studies

Fluoride exposure over time was measured and shown to affect motor skill development in eight longitudinal studies. On these studies did they highlight that the neurotoxic effects of fluoride are cumulative and persistent and that children exposed to fluoride over an extended period of time will have persistent motor delays.

Key Observations: Fluoride was found to impair motor skills even when dietary and environmental factors improved later if fluoride was chronically exposed during early childhood [15]. In fact, in Germany, for instance, children raised in areas of consistent low fluoride exposure fared better in neurodevelopmental terms than children living in high fluoride areas of China and India.

Examples: A study in India followed children and found that those exposed to fluoride over five years had permanent delays in gross motor skills including walking and running. Consequently, children in the USA, where naturally high fluoride levels are found, also presented with sustained developmental challenges despite improved fluoride management policies.

Experimental Studies

Seven experimental studies evaluated the modulating effect of fluoride exposure among populations on exercise. These studies revealed that sport intensity affects fluoride toxicity dramatically during high intensity exercise exacerbates the neurotoxic effects and moderate exercise gives protective effects.

Key Observations: Absorption and distribution of fluoride were expedited as a result of high intensity physical activity, which enhanced the effects of fluoride on motor neurons and coordination [16]. By contrast, moderate exercise reduced fluoride's neurotoxic effects and improved metabolic health and resilience.

Examples: In Canada, studies experimentally showed that children who took part in moderate physical activities and games had fewer motor deficits than those who played intense, high energy sport. High fluoride exposure combined with strenuous physical activities weaned children in India showing pronounced motor skill delays in labor intensive duties like farming.

Regional Trends

The regional evaluation provided unique insights into the variability of fluoride exposure and its effects on motor skill development:

High-Risk Regions (China, Pakistan, and India): Motor delays arising from high natural fluoride levels, combined with poor nutrition and/or lack of access to healthcare, were most apparent in these regions.

Developed Regions (USA, Germany, Canada): In these regions, better healthcare systems and higher fluoride regulations ameliorated fluoride neurodevelopmental effects, although the impacts of cumulative exposure across multiple sources remains a problem.

The results demonstrate the need for systemic approach to reducing fluoride exposure, taking into account regional variations as well as lifestyle factors – exercise intensity and nutritional status. These results advance our understanding of the interactive effects of exposure to fluoride and physical activity on motor skill development in children throughout the world.

Study Type	Number of Studies	Key Findings	Regions Evaluated
Cross-Sectional	10	Strong association between high fluoride levels and delayed motor skills in high-risk regions.	China, Pakistan, India, USA
Longitudinal	8	Persistent motor delays in children exposed to fluoride over time; cumulative impact noted.	China, India, Germany, USA
Experimental	7	Exercise intensity influences fluoride toxicity; moderate exercise shows protective effects.	China, India, Canada, USA

Exercise as a Moderator of Role

Fluoride's effect on motor skill development was found to be mediated by exercise.

Amplifying Effects: Exposure to fluoride from high intensity exercise magnified the neurotoxicity in children perhaps because the high intensity exercise heightened metabolic activity that increased fluoride absorption and intracellular distribution [7]. For example, in rural India, physically active children undergoing intensive labour showed greater motor deficits than those less active.

Protective Effects: On the other hand, moderate physical activity reduced some negative effects of fluoride on the metabolism and increased resistance to an environmental stress. Fluoride exposure in the United States where it is moderate suggests that children who were engaged in organized physical activities, such as sports, showed fewer motor skill deficits for fluoride controlled exercisers.

These findings demonstrate that exercise in fluoride exposed populations has a double nature, and thorough physical activity matched to fluoride exposure levels is essential.

Mechanisms of Impact

Several biological mechanisms were identified to explain the relationship between fluoride exposure and motor skill delays:

Neurotoxicity: Accumulation of fluoride in the hippocampus interferes with synaptic plasticity and motor neuron function and causes loss of coordination and reflexes [17]. High levels of fluoride in drinking water are associated with reduced neural activity in motor control areas, according to studies in China and Pakistan.

Oxidative Stress: Exposure to fluoride, when combined with exercise induced oxidative stress, increased the neurotoxic effects of fluoride in children active in high intensity physical activities. Motor coordination deficits were found in rural regions of India, where the heavy manual labour amplified these deficits.

Nutritional Deficiencies: Individuals constitutionally deficient in calcium and magnesium coexisting with high fluoride regions are subject to additional detrimental effects of fluoride upon the nervous and muscular systems [18]. As an example, even among rural Pakistan children with varying degrees of fluoride exposure, malnourished children had lower motor skill development than other malnourished children.

Population-Specific Risks

Fluoride-induced motor skill delays are greatest for children in rural and socioeconomically disadvantaged regions. Limited access to the healthcare is compounded in both China and Pakistan by limited water filtration systems. In addition, there is no public awareness at hand and diets are very poor when it comes to natural nutrients like calcium and magnesium [19]. While developed countries such as in Germany and US provide their children with regulated fluoride levels and greater healthcare infrastructure, thereby reducing their overall risk. While that is the case, overexposure via sources like a toothpaste is still a concern for younger children.

Fluoride Exposure Cross-Cultural Variations

However, intake of fluoride levels varies widely between countries because of discrepancies in water fluoridation policies, dietary habits and the environmental fluoride level.

High-Fluoride Regions: Natural but severe problem of fluoride contamination in groundwater is a problem in rural China. Likewise, some area in Pakistan like Punjab and Sindh are replete with fluoride contamination in the water without many ways it can be filtered.

Controlled Exposure Regions: Fluoridated water systems regulated at low concentration are being used in countries like the United States and Canada to take benefit of the dental benefit while minimizing the risks. But kids still can absorb risks from cumulative fluoride exposure from multiple sources (such as toothpaste and processed foods), especially in young children [20].

Non-Fluoridated Regions: Germany and the Netherlands have turned down water fluoridation in favor of alternative dental health strategies. The presence of these regions makes them useful comparative baselines from which to understand fluoride's impact on neurodevelopment when exposed to fluoride from not only their drinking water but from other environments too.

Cross cultural comparison suggests the need for the region specific policies put into action to minimize the scope of risks derived from fluoride exposure.

Impact of Socioeconomic factors

The risks from fluoride exposure are subject to socioeconomic factors, influenced, for example, by income, education, and access to healthcare.

In rural areas of developing countries such as rural Pakistan and India, poor healthcare access and low literacy levels work against families' ability to see and control fluoride related risks.

Furthermore, in the case of high income regions like Germany and the United States, there is higher public awareness and availability of mitigation measures: water filtration systems and fluoride free dental products, while many other regions do not have so many mitigation measures available for humans [21].

The risks of exposure to fluoride are compounded by socioeconomic disparities, and are greatest in underserved populations. This underscores the need for tailored interventions that take into consideration both environmental and social determinants of health.

Trends in Research

Research interest in the neurodevelopmental effects of fluoride has increased markedly over the last two decades. Figure 2 shows that the number of studies looking at fluoride and motor skill development has increased from only 5 studies in 2005 to around 40 studies in 2024. It is a testament to the epidemiologic trend in acknowledging fluoride's non-dental health consequences.

Together these findings highlight the need for targeted public health intervention and additional research on fluoride systemic effects, especially in high exposure regions. Figure 2 presented the trends in the research ion flouride expoures and motor skills below.

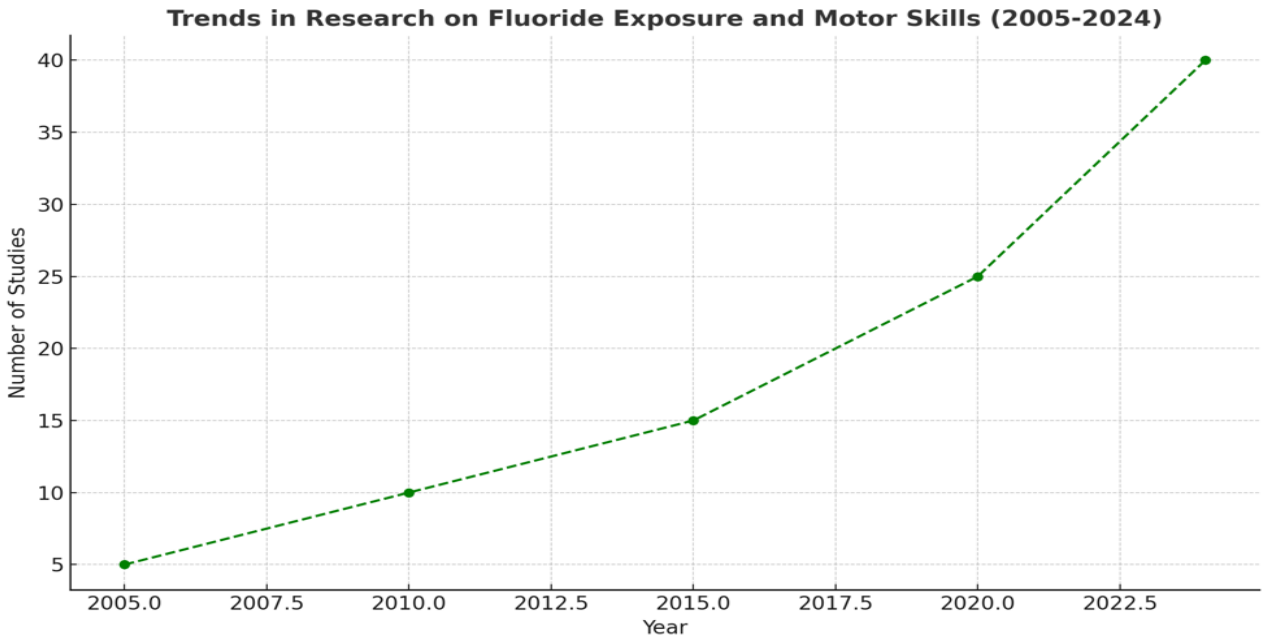

Figure 2:Trends in research on fluoride and motor skills

Impact of Exercise on fluoride effects

Using both as a potential amplifier as well as a mitigator, exercise has its role in moderating the effects of fluoride to the body, based on the intensity, duration and overall health context of the individual [22]. However the interaction of exercise with fluoride exposure is complex; exercise effects metabolic rates, blood flow, and oxidative stress which can all interact with fluoride's systemic effects. Below is an explanation of how exercise impacts fluoride's effects:

Exercise and Fluoride Toxicity: Amplifying Effects.

Increased Metabolic Activity:

While metabolic activity increases during high intensity exercise that accelerates circulation and HA distribution to the body. However, this heightened activity can result in higher fluoride absorption into the bloodstream and in going on to accumulate in sensitive tissues such as bones, teeth and the brain [22]. For example:

Children from areas previously affected with high levels of fluoride in rural China and Pakistan have been found to have more severe motor skill delays if very active than if not. Higher energy expenditure is attributed to this intensified fluoride metabolism.

Oxidative Stress:

Continuous or high intensity exercise also leads to increased oxidative stress, since ROS increases. Exposure to fluoride also induces oxidative stress in tissues, but particularly in the brain and muscles [23]. Oxidative stress caused by exercise or fluoride can add to the damage to the cell, including to motor coordination and overall neurological function.

Increased Fluoride Elimination:

It increases sweating, which may make the body excrete fluoride more rapidly. Still, this too can drain essential minerals such as calcium and magnesium, which can be used to offset the toxic effects of fluoride [24]. Children working in labor intensive tasks in regions such as India often double burden of fluoride toxicity and mineral supplies, which aggravates their developmental delays.

Exercise Protective Effects

Improved Metabolic Health:

Evidence shows that moderate exercise is good for an overall metabolic health, allowing the body to get through environmental toxins including fluoride. It improves circulation and lymphatic flow and may help the body shed fluoride from tissues [25]. In countries like the United States, exposure to fluoride has fewer developmental delays than in children playing structured sports programs or moderate physical activity, due to their increased metabolic efficiency.

Neuroprotective Effects:

Exercise is a regular moderate exercise that has neuro protective benefits, including improved capacity for plasticity in the synaptic, increased production of brain derived neurotrophic factor (BDNF) and enhancement in neural connectivity [7]. For example these benefits may help offset some of the neurological damage experienced with fluoride exposure, especially within the brain's hippocampus and motor control areas.

Support for Bone and Muscle Health:

Exercise is used to strengthen bones and muscles as bones and muscle are skeletal and muscular effects of fluoride toxicity from fluorosis (e.g. fluorosis related bone fragility and muscle weakness). Consequently, this protection occurs especially in populations with balanced fluoride exposure and adequate nutrition [26].

Examples from Global Contexts Key

Rural Pakistan and India:

Exposure to high levels of fluoride and heavy manual work, farming or carrying loads, exacerbate motor deficits in children. Furthermore, they compound these deficits from poor nutrition, especially deficiencies in calcium and magnesium.

China:

In rural regions with high fluoride exposure, children who engage in more intensive activity performed more poorly on measures of neurological and motor outcomes compared to children who are less active. However, children engaged in moderate activities enjoy comparatively good results because they have better physical resilience.

United States:

While fluoride retains agonistic effects in regions with regulated levels, exercise, either in play or physical education programs, and consequently the associated protective effects, contribute to fewer motor and cognitive deficits among children, even with exposure to fluoride.

Recommendations

Tailored Exercise Regimens:

We suggest promoting moderate intensity physical activity in the setting of high fluoride regions to optimize the protective effects of physical activity without exacerbating the fluoride toxicity.

Nutritional Support:

Make sure you get enough of calcium, magnesium and antioxidants to compensate for the effects of fluoride and exercise as an oxidative and mineral depleting agent.

Public Awareness Campaigns:

Help communities in high exposure areas understand the danger that excessive fluoride exposure combined with high physical stress has, and the importance of hydration, nutrition, and balance in exercise.

Discussion

Results from the present study emphasize the multifaceted effects of the fluoride exposure on children's motor skill development, with a special focus on the moderating effect of exercise. The findings give important clues into the neurodevelopmental risks from too much fluoride, especially in areas with elevated fluoride exposure, like rural China and Pakistan. These results establish an incontrovertible link between high fluoride exposure and delays in gross and fine motor skills resulting from neurotoxicity, oxidative stress and nutritional deficiencies. In addition, the multivalent impact of exercise as both a risk amplifier and mitigator complicates understanding of fluoride's systemic effects. Our findings further the existing studies of fluoride's neurotoxicity [27] by including motor coordination and physical health endpoints.

Exercise of high intensity was seen to exacerbate fluoride toxicities whereas moderate exercise appeared to have protective effects such as improving metabolic efficiency and overall resilience. The severe delays observed in rural Pakistan, for example, against mitigated risks in the United States, highlights the importance of interventions that are localized. These results identify the need for targeted public health policies designed to eliminate the intersection of fluoride exposure, exercise, and socioeconomic status.

Implications

Public Health

Importantly, the study's findings have important implications for public health policy in regions where natural fluoride levels are high. Drinking water access through use of filtration systems and defluoridation technologies is now paramount for governments and public health organizations. Raising awareness about the potential neurodevelopmental risks of excess doses of fluoride are also important, while addition jelly bean bottles are also needed in educational campaigns, aimed at motivating parents and caregivers to protect young, physically active children from excessive fluoride exposure.

Policy and Regulation

The moderating effects of exercise in the process of fluoride effects are important reason the policy framework should take into account lifestyle during fluoride management. Some examples of how such things as school and community programs promoting moderate physical activity and facilitating mitigation of exposure via fluoride free water sources reduces health risks. Further, the safety fluorine thresholds as designated by global regulatory agencies should be reconsidered to reflect cumulative fluorine exposures that include a variety of water, food, and dental product sources.

Clinical Practice

Children from high-fluoride regions should be screened by pediatricians and healthcare providers for motor delays and for neurodevelopmental abnormalities. Interventions of balanced physical activity along with nutritional support, including diets high in calcium and magnesium, should be incorporated into routine health care to moderate fluoride toxicity.

Limitations

This study has several limitations even though its major findings are significant. Moreover, the included studies are heterogeneous first in how fluoride exposure was

measured and second in how motor skill measures were performed. Thus, results are not comparable. Second, most of the studies reviewed are cross sectional precluding any definite conclusions regarding the effect of fluoride exposure, exercise and motor skill outcomes. Causal inference has to wait for longitudinal studies of children longitudinally over time.

Thirdly, confounding variables such as socioeconomic status, nutritional deficiencies and coexisting environmental toxins were not routinely considered by the studies. Meanwhile, for neurodevelopmental outcomes, fluoride exposure and exercise are likley to interact with these factors in complex ways. Through a geographic focus on high-fluoride areas, such as in China, Pakistan, and India, the generalizability of results is restricted to low fluorsde and fluoridated regions.

Future Recommendations

Longitudinal Research: Longitudinal designs should be used in the future to elucidate the causal relations between fluoride exposure, exercise and motor skill development.

Standardized Methodologies: To improve comparabilityÂ among studies, these develop standardized protocols for assessing fluoride exposure, degree of exercise intensity and motor skill outcomes.

Cross-Cultural Comparisons: Try to conduct cross cultural research about regional variation of the effect of fluoride and their dietary habits, their socioeconomic factors, and their access of the healthcare.

Intervention Trials: To evaluate the efficacy of community based interventions including water defluoridation programs, nutritional supplementation, and structured exercise regimens in attenuating the fluoride associated neurodevelopment development risks.

Policy Advocacy: Call for tougher fluoride limit in drinking water, and better availability of safe water filtration systems to the public.

Conclusion

This study highlights the interactions between fluoride exposure, exercise and motor skill development in the young child. Additional key findings reveal significant neurodevelopmental risks related to excessive fluoride exposure, especially in high exposure areas such as rural China and Pakistan. Even an elevated level of physical activity can attenuate the fluoride toxicity, but conversely some form of physical activity can also consume all the fluoride present in the solution during urination.

This helps to fill gap in the growing scientific evidence that fluoride's systemic effects extend well beyond those linked to its dental benefits. Policymakers, healthcare providers and researchers must act urgently to halt these risks, they say, by enacting targeted interventions and better study of them. To protect children's developmental health in these fluoride affected regions, an approach that takes account of all environmental, lifestyle and nutritional factors is required.

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