FLUORIDE

Quarterly Journal of The International Society for Fluoride Research Inc.

Enhancing Educational Management Strategies: Assessing the Impact of Fluoride Exposure on Cognitive Development in School-Aged Children

Unique digital address (Digital object identifier [DOI] equivalent):
https://www.fluorideresearch.online/epub/files/294.pdf

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Accepted: 2024 Oct 16
Published as e294: 2024 Oct 23

ABSTRACT

Purpose: This study intends to investigate the association between fluoride exposure and cognitive development in school-aged children, emphasizing the ways in which several variables, including levels of physical activity, sleep quality, and the home learning environment, interact to affect academic success as a whole. The objective is to evaluate the ways in which knowledge of these factors' effects on academic achievement might improve educational management practices.

Methods: In Shanxi province, China, data was gathered from 745 school-age children (ages 5 to 15). To evaluate fluoride exposure levels, the home learning environment, sleep quality, levels of physical activity, and cognitive development, and a questionnaire was given out. Using Cronbach's alpha, Composite Reliability (CR), and Average Variance Extracted (AVE), construct reliability and validity were assessed. Using physical activity as a moderating variable and cognitive development as a mediating variable, the structural model was utilized to examine the links between fluoride exposure, cognitive development, and total academic accomplishment.

Results: According to the data, fluoride intake negatively affected cognitive development in a substantial although mild way ($p < 0.001$). The home learning environment also had a good impact on cognitive development ($p < 0.001$), although sleep quality was shown to have the biggest positive influence. The association between fluoride exposure and cognitive development was modulated by levels of physical activity. According to a mediation study, there is a substantial association ($p < 0.001$) between fluoride exposure, sleep quality, and total academic success that is mediated by cognitive development. These results imply that some of the detrimental impacts of fluoride exposure on cognitive outcomes can be lessened by enhancing sleep quality and home learning settings.

Conclusion: The study emphasizes the complex relationships that exist between children's exposure to fluoride, cognitive growth, and academic success. In order to improve academic results, it highlights how crucial it is to include physical activity, home learning settings, and sleep quality in educational management tactics. Academic achievement and cognitive growth are influenced by a variety of personal and contextual factors, which should be taken into account by effective educational administration.

Key-words: Educational Management, Fluoride Exposure, Cognitive Development, School Health, Academic Performance

Introduction

Trace amounts of fluoride are found in soil, water, plants, and animals naturally. Natural fluoride concentrations in groundwater vary from negligible amounts to more than 25 mg L−1. Both humans and other animals that consume fluoride absorb part of it into their bodies, where it deposits over time in their teeth and bonés [1, 2]. Because it is a very electronegative element, fluorine exhibits a remarkable attraction to positively charged ions such as calcium. Because teeth and bone have the highest concentration of calcium and hence draw the greatest quantity of fluoride that is deposited as calcium-fluorapatite crystals, the effect of fluoride on mineralized tissues like these that cause developmental alternations is therefore clinically significant. Crystalline hydroxylapatite makes up the majority of tooth enamel. This quantity is thought to be a cutoff point for completely ending the dental caries pandemic and treating any more dental damage caused by fluoride consumption, including dental caries[3]. Numerous nations' epidemiological studies have unequivocally demonstrated the value of fluoridating water to promote oral hygiene by, for instance, reducing the incidence of dental caries.

Following the Medical Research Council's (MRC) recommendation, the British Government began a study into water fluoridation in 1952 to investigate whether fluoride should be added to drinking water supplies in the United Kingdom [4]. Thus, several Local Authority water fluoridation initiatives were put into place in England and Wales between 1964 and 1975, artificially raising the fluoride levels in the water supply to 1 ppm for about 6 million people. There are significant projects in progress in the West Midlands, Birmingham, and Tyneside. Moreover, the natural fluoride concentration of the water used by about 500,000 people in this country is one part per million. One million more people receive water that is thought to offer some dental advantages but has a lower natural fluoride content . The fluoride concentration of drinking water is reduced in areas where naturally occurring fluoride levels are high enough to have major negative health impacts (see below). To achieve this, a number of procedures have been created[5, 6].

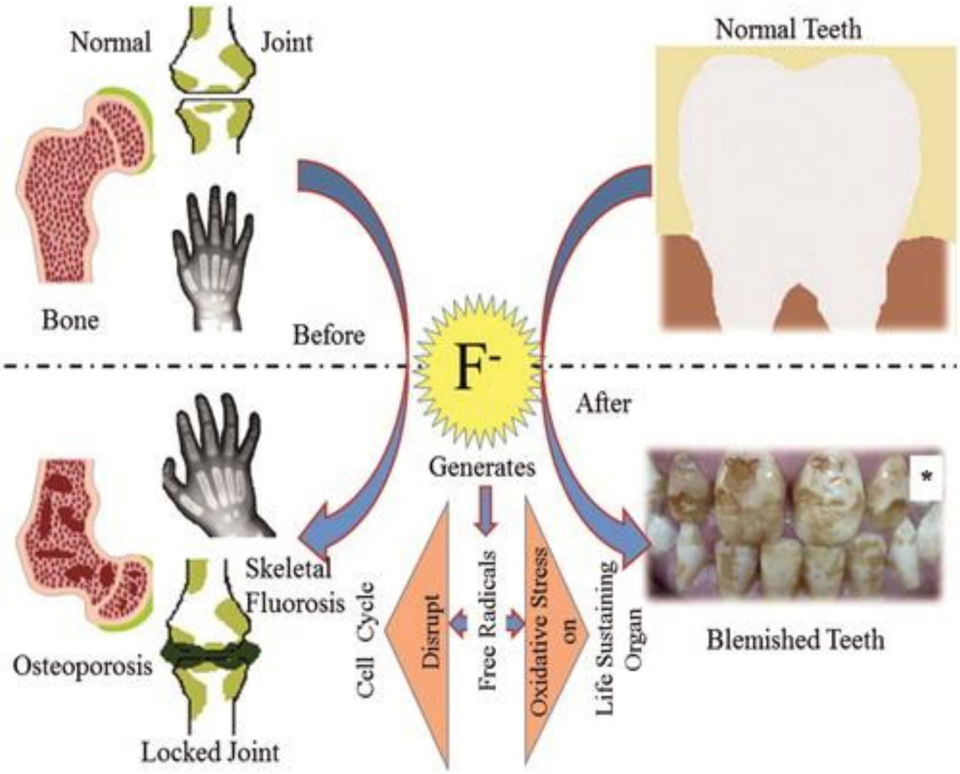

Figure 1:Fluoride effect on the health [7]

In people residing in areas where fluorosis is widespread and significant amounts of fluoride are present in tainted drinking water, the majority of epidemiologic research illustrating links between fluoride exposure and reduced cognitive markers have been carried out as shown in the figure 1. The available epidemiologic information is, however, limited. Most studies use an ecologic design, rather than personal exposure assessments, to estimate childhood exposures based on fluoride measurements made in the area (e.g., drinking water levels). Additionally, the vast majority of research on childhood outcomes that has been done thus far is cross-sectional in nature, which makes it difficult to draw conclusions about causality [7, 8].

Recent findings revealed that consumption of fluoride at concentrations of 1.5 ppm is majorly responsible for skeletal fluorosis. The sampling from rural areas showed that 80% villages are having fluoride concentrations more than the WHO permissible limits and people residing in such areas are affected by the skeletal fluorosis and also in the regions of Africa and Asia endemic fluorosis have been accounted in the majority of the region affecting approximately 100 million people. Various mitigation programmes and strategies have been conducted all over the world using defluoridation. This led to the sociopsychological components of the material with relation to water fluoridation, and most crucially, the community's permission for its implementation. In regular scientific and public health classes, few academics address these concerns of public consent, respect and individual rights, and public benefit vs the need for individual choice. This is especially true for students attending urban schools. Due to their lack of didactic exposure to the metrics pertaining to these challenges, these students will be ill-prepared to react to those multifaceted public health interrogatives. There has been some study done in Indonesia on the connection between fluorine levels and dental fluorosis, according to UKGS standards (2012). Dental fluorosis instances have been reported in a number of places, including Cipatat, Situbondo, Madiun, Donggala, Buol, Toli-Toli, Palu, Poso, and Banggai, due to their high fluorine levels (0.75–3.4 ppm)[9]. A total of 1,235 pupils from 15 primary schools in the Talise Public Health Center's operating area tested positive for fluoride in Palu 2016, with 356 (28.8%) of those instances occurring in the elementary school area. Talise Sub-Village had the highest water fluoride level of 1.6 ppm, while Tondo Sub-Village had 0.9 ppm, according to an analysis of the fluoride levels in three sub-villages.

Children exposed to naturally occurring, widely-varying Fsingle bond concentrations in drinking water (0.41 to 15.5 mg/L) from conception were included in this study. Using a standardized CANTAB task, we evaluated the hypothesis that a child's ability to draw recognizable things (a donkey, a home, and a human) of changing difficulty and cognitive performance are related to chronic exposure to Fsingle bond in drinking water. The children living in the sample communities are from a homogeneous rural population with similar living conditions, diets, and cultures. This group mostly farms for a living. This kind of homogeneity within a research sample is uncommon in epidemiological studies, and it is not like this in studies conducted in developed nations, where socioeconomic circumstances differ greatly and populations have far lower and less varied exposure to Fsingulous bonds [10]. As a result, this place offers an excellent environment for researching the impact on health of various long-term Fsingle bond exposures. This research answers the following questions: 1. How does a child's exposure to fluoride effect their cognitive development when they get older? 2. What part does the quality of sleep play in academic success and cognitive development? 3. What effects does the home learning environment have on academic achievement and cognitive development?

2. Theoratical Background

The interactions between water and the minerals and gases it encounters as it moves from recharge to discharge areas determine the chemical composition of groundwater. Aquifer mineralogy and relative mineral reactivity, rainfall input and rate, chemical and biological activities in the unsaturated zone, residence period, and mixing are some of the elements that affect groundwater chemistry. Groundwater's natural quality is determined by its natural composition, also known as its geochemical background or natural composition, which varies greatly in space across a variety of scales [10, 11]. Apart from the inherent elements, human endeavors can also impact the quality of groundwater by means of contamination resulting from industrial, mining, agricultural, and urban operations. While certain components (like pesticides) are clear signs of human influence, inorganic components can come from both natural and man-made sources. In this setting, the sustainable management of groundwater resources depends on a knowledge of the mechanisms governing groundwater quality and an assessment of natural background ranges . From a regulatory perspective, the regional authorities must define threshold values, or the upper bounds of background variation.

Figure 2 Percentage of population having fluoride water

From the perspective of public health, one benefit of fluoridating water is that it can prevent dental cavities in areas where access to dental treatment is restricted. For this reason, organizations dedicated to promoting health, such as the World Health Organization (WHO) and the Centers for Disease Control & Prevention (CDC), promote this practice as presented in figure 2 [12].

The World Health Organization, the British Medical Association, the Faculty of Public Health Medicine, the British Dental Association, and, in the United States, the Surgeon-General, the American Medical Association, and the American Dental Association have all endorsed the practice of fluoridating water. Supporters view it as a straightforward, safe, and affordable public health intervention to lower the prevalence of dental caries. Water fluoridation has undoubtedly been claimed to be the most economical way to reach the whole population, even the most vulnerable children, assuming the town has a piped water supply. Fluoride does, however, have certain potential negative health effects that should be taken into account [3]. These include skeletal and dental fluorosis as well as other potential side effects that include immunotoxicity, carcinogenicity, genotoxicity, reprotoxicity, teratogenicity, renal toxicity, and gastrointestinal tract toxicity. Aside from drinking water, there are a number of other possible sources of fluoride exposure.

Taking into account the groundwater chemistry data that is currently available, our current understanding of the groundwater system, and the sources of groundwater components, the aim of this work is to give a scientific basis for improving the estimation of natural background concentrations in groundwater [13]. In order to do this, a comprehensive examination of popular techniques for figuring out the naturally occurring background concentrations of dissolved components in groundwater is presented in this work. Statistical techniques using a randomly generated, right-skewed distribution characteristic of geochemical data are illustrated graphically. The majority of studies on groundwater's natural background concentrations have focused on anthropogenic groundwater elements, which is the subject of this study.

During the Explain phase, teachers provide terminology and pertinent literature to help students understand how using fluoride helps prevent dental caries. Deeper involvement occurs at the elaborate stage when students apply what they have learned to novel contexts, including assessing the effects of reversing water fluoride in various locales. Both scientific and ethical understanding are evaluated in the last step, Evaluate, through discussions, projects, or formal examinations. Given that public health initiatives frequently involve ethical questions, it is imperative to strengthen this training method by including Faden and Beauchamp's Ethical Framework of Informed Consent. The autonomous authorization and effective control are the two types of informed consent that are highlighted in Faden and Beauchamp's consent model.

Their model promotes self-governance, in which individuals make decisions on their own health. Although the fluoridation of water is done at the community level without the goal of getting people's consent, teaching students this ethic is crucial to helping them understand openness, methods, and public trust regarding the improving aspects of health policies. By using the instructional approach to water fluoridation, educators may integrate the Ethical Framework of Faden, Beauchamp [14] and provide suitable circumstances for the distribution of resources that incorporate seemingly incongruous elements like science and ethics. With the help of this model, students should be able to critically analyze, make decisions in health-related activities in a more real-world setting, and comprehend the importance of healthcare systems to society as a whole, which will enable them to participate in public health discussions in a healthy, educated manner.

3. Model and Hypotheses

3.1 Research Model

The ultimate purpose of this study model is to comprehend how fluoride exposure influences school-aged children's cognitive development and how that interaction impacts their overall academic accomplishment. The model incorporates a range of characteristics that impact academic performance and cognitive development, including behavioral and environmental factors including physical activity levels, sleep hygiene, and home learning settings.

3.2 Hypotheses

The activities you and your family engage in together with the areas your kid has access to that impact their growth and education make up your child's home learning environment. In order to assist your kid make sense of the world, this also entails giving them the chance to play and engage with books, objects, and everyday events [15, 16]. Their relationships with others who offer your kid the love, stability, encouragement, discussion, and excellent role models that are essential to their development are, nevertheless, the most significant aspect. A well-designed home learning environment fosters curiosity, self-confidence, and a positive attitude toward learning in kids and teens. (Scotland) When it comes to teaching their kids about oral hygiene and adopting health-conscious attitudes, parents have a big impact. As a result, kids ought to start by learning about appropriate oral care. Home learning can educate children about fluoride by explaining its benefits for dental health and sources of exposure. Discussing risks like dental fluorosis promotes critical thinking Engaging activities, such as experiments and art projects, can reinforce their understanding. Open family discussions encourage reflection on fluoride use in daily life. The association between fluoride exposure and academic success is mediated by cognitive development [17]. Although excessive fluoride exposure can impede cognitive development—which is essential for academic success—improving cognitive function can lessen some of the negative effects and improve academic results.

Hence, this study proposes the following hypothesis:

H1: *Higher levels of fluoride exposure negatively affect cognitive development.*

High fluoride exposure has been linked to cognitive development impairments, especially in youngsters, according to research. Numerous researches have discovered links between higher fluoride concentrations in drinking water and reduced IQ and other cognitive function test results [18]. These results imply that excessive fluoride exposure may have negative consequences on brain development, particularly at critical developmental phases.

***H2:** Cognitive development has a positive influence on overall academic achievement..*

Academic achievement and cognitive growth are closely related, especially when it comes to skills like memory, attention, and problem-solving. Given that these cognitive processes are necessary for learning, understanding, and information retention, children with stronger cognitive capacities typically perform better academically.

***H3**: Physical activity moderates the relationship between fluoride exposure and cognitive development.*

Exercise has been demonstrated to enhance cognitive performance and may serve as a buffer against environmental neurotoxins such as fluoride [19]. Regular physical exercise may help to mitigate some of the detrimental effects of fluoride exposure by improving brain health and cognitive development, according to studies.

***H4:** Cognitive development mediates the relationship between fluoride exposure and overall academic achievement.*

The association between fluoride exposure and academic success is mediated by cognitive development [20]. Although excessive fluoride exposure can impede cognitive development—which is essential for academic success—improving cognitive function can lessen some of the negative effects and improve academic results.

3.3 Moderation Hypotheses

The term "cognitive engagement" describes a person's conscious effort and active participation in information processing. It is essential for improving how people assess and assimilate information, particularly when they believe it to be reliable [21]. Increased cognitive engagement leads to a deeper and more accurate comprehension of complicated scientific subjects, like the science of fluoride, as individuals examine, evaluate, and reflect on the information that is offered to them. In the domains of education and public health, increasing scientific literacy requires cognitive involvement [22]. Students who actively participate in their education, for instance, are more likely to comprehend and be able to believe information regarding fluoride's function in oral health, which improves their understanding of fluoridation policies and the health effects they have. Without cognitive involvement, people are less likely to understand the scientific justification for public health initiatives like water fluoridation and are more likely to ignore or misinterpret even reliable sources [23]. Therefore, perceived credibility has a moderating influence on one's comprehension of fluoride science, which is enhanced by cognitive involvement. Mentally involved individuals are more able to make defensible decisions and use their knowledge to practical situations, like weighing the advantages and disadvantages of fluoride methods. Furthermore, psychological research backs up the notion that people retain and apply knowledge more effectively when they interact with it at a deeper level. This implies that the benefits of cognitive engagement extend beyond educational environments, since it is essential for enhancing public comprehension of science and promoting more informed decision-making in health-related domains such as fluoride use.

A thorough framework for comprehending the intricate connections between Fluoride Exposure (FE), Cognitive Development (CD), Physical Activity (PA), and Academic Achievement (AA) is offered by this collection of theories. This model, which is based on studies on education and the environment, looks at how fluoride exposure impacts children's cognitive development and how that development influences academic results. It also looks at how exercise functions as a moderating element in this connection. Students and academics may critically examine how environmental elements like fluoride impact cognitive function and educational achievement by adding these variables into the model. This paradigm promotes a comprehensive method of comprehending fluoride's effects by integrating behavioral and cognitive aspects into the investigation [24]. To show how fluoride exposure initially affects mental processes, which in turn determine academic achievement, consider cognitive development as a mediator. Additionally, the model takes into account the protective function of exercise, implying that children who regularly work out may be less susceptible to the detrimental effects of fluoride exposure on their cognitive development [25]. The detail diagramitic view of hypotheses are given below in figure 3.

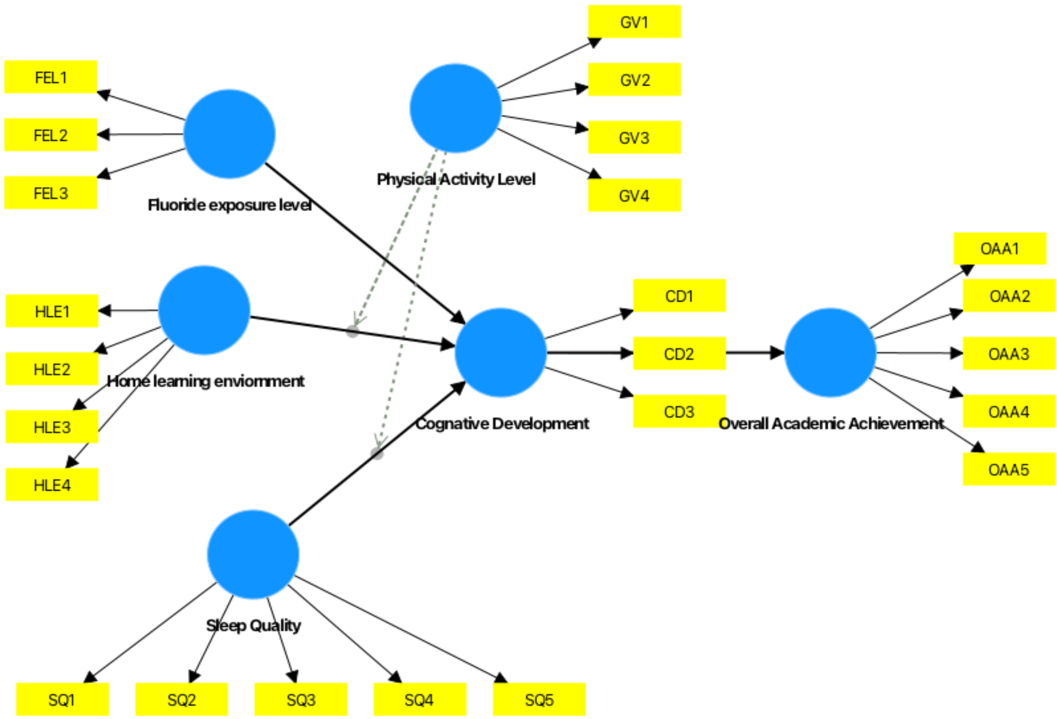

Figure 3: Path model

4. Methodology

This study evaluated the effects of fluoride exposure on children's cognitive development and academic success using a mixed-methods methodology. The quantitative aspect of the study was furnishing parents and educators with standardized questionnaires for children between the ages of 5 and 15, with the aim of measuring quantifiable factors such exposure to fluoride, academic achievement, and cognitive capacities [26]. Parental perspectives on things like sleep quality and the home learning environment were obtained for the qualitative component. By combining these techniques, the study sought to investigate the moderating impacts of physical activity and home support in addition to the direct effects of fluoride exposure. This approach provided a comprehensive knowledge of the ways in which many factors interact to shape children's academic and cognitive results[27].

4.1 Measures

The constructs used in this study were derived from previous research to ensure content validity. The Cognitive Development (CD) scale, which focused on assessing memory, attention, and problem-solving skills, was adapted from previous work on cognitive performance and development in children. The Fluoride Exposure Level (FEL) scale was based on earlier studies examining the effects of fluoride on cognitive outcomes in children [5]. The Physical Activity Level (PAL) scale [28], addressing the impact of physical activity on cognitive development, was developed in accordance with validated measures from past research exploring the link between physical activity and academic performance. To evaluate the Home Learning Environment (HLE), items were drawn from prior studies [29]focusing on parental support and educational activities at home. The Overall Academic Achievement (OAA) scale, which includes measures such as grades and behavioral assessments, was influenced by established academic performance indicators [30]. Finally, the Sleep Quality (SQ) scale, used to assess the quality and duration of children’s sleep, was adapted from sleep-related cognitive performance studies [31]. All items were measured using a 7-point Likert scale, ranging from 1 (strongly disagree) to 7 (strongly agree), consistent with the structure of similar educational and psychological assessments.

4.2 Sample and Data Collection

A total of 1,000 questionnaires were delivered throughout the province of Shanxi, China, and 745 respondents, aged 5 to 15 years, were included in the study's sample. Examining the effect of fluoride intake on school-age children's cognitive development was the goal of the survey. It asked questions on the amount of fluoride exposure, the home learning environment, the quality of sleep, the amount of physical activity, and general academic progress. The questionnaire was made to be age-appropriate and simple to grasp in order to encourage truthful replies. Parent participation was actively encouraged via the collection of data from a variety of educational contexts. This strategy made that the sample was representative and varied, which gave important information about the goals of the study.

Table 1. Measures of Construct

Variable	Items	References
Fluoride Exposure Levels	FEL1: I know how much fluoride is in the things around me.	**[5]**
	FEL2: I am aware of the health risks associated with fluoride.	
	FEL3: I can recognize the places in my everyday life where I get fluoride exposure.	
Home Learning Environment (HLE)	HLE1: My house provides me with good learning support.	[29]
	HLE2: I have a certain area in my house where I study.	
	HLE3: My family motivates me to complete my assignments.	
	HLE4: At home, I get assistance with my schoolwork.	
Sleep Quality (SQ)	SQ1: Most nights, I get enough sleep.	[31]
	SQ2: I think the quality of my sleep has an impact on how well I do in class.	
	SQ3: I get a lot of nice, unbroken sleep.	
	SQ4: I have trouble falling or staying asleep a lot of the time.	
Physical Activity Levels(PAL)	PAL1: I work out three times a week at the very least.	[28]
	PAL2: I like to be outside and participate in sports.	
	PAL3: I believe that exercise improves my ability to concentrate in the classroom.	
	PAL4: I play or work out on a regular basis.	
Cognitive Development(CD)	CD1: I am able to recall what I was taught at school.	[32]
	CD2: Throughout class, I pay attention.	
	CD3: I have no trouble resolving academic issues.	
Overall Academic Achievement(OAA)	OAA1: I do well academically in my subjects.	[30]
	OAA2: I actively participate in class discussions.	
	OAA3: I do my schoolwork on schedule.	
	OAA4: My professors have given me favorable comments.	
	OAA5: I like to pick up new skills.	

4.3 Demographic Variables

745 respondents, aged 5 to 15, from Shanxi province, China, were included in the study's sample. There were four age groups that were separated: 5–6 years, 7-9 years, 10–12 years, and 13–15 years. The dataset included percentages of both males and females, indicating a balanced gender distribution. The bulk of participants (59%), followed by those from mid-sized cities (26%) and small cities (15%), were city dwellers. This broad demographic profile offered a thorough understanding of the ways in which fluoride exposure affects children's cognitive development from a variety of backgrounds.

Table 2: Demographic Characteristics of Respondents

Demographic Factor	Categories with percentage
Age Group	5-6 years, (%), 7-9 year (%), 10-12 years (%), 13-15 years (%)
Gender	Male (%), Female (%)
Residence	Large cities (59%), Mid-sized cities (26%), Small cities (15%)
Demographic Factor	Categories with percentage
Age Group	5-6 years, (%), 7-9 year (%), 10-12 years (%), 13-15 years (%)

5. Data Analysis and Results

We used structural equation modeling (SEM) using SmartPLS version 4.0 to assess the measurement and structural models. Because of its capacity to manage intricate moderating connections and formative metrics, this program was chosen to ensure accurate model assessment. According to earlier research, SmartPLS proved very useful because of its adaptability in handling non-normal data distributions. Two stages of the study were carried out: testing the measurement model and evaluating the structural model.

5.1.1 Reliability and Validity

Exploratory factor analysis (EFA) was used to evaluate the measurement model in order to ascertain the validity and reliability of the constructs. Factor loadings, Cronbach's alpha, composite reliability (CR), and average variance extracted (AVE) were all assessed for each item[33]. Table 3 shows that every factor loading was higher than the cutoff of 0.7, suggesting a satisfactory level of dependability. Internal consistency

5.1 Measurement Model

was confirmed by Cronbach's alpha values, which varied between constructs and ranged from 0.836 to 0.957. Composite reliability ratings were all above the acceptable 0.7, ranging from 0.843 to 0.966, further validating the dependability of the constructions. Convergent validity was confirmed by AVE values, which show the variation explained by the items for each construct and also surpass the minimal needed value of 0.5.

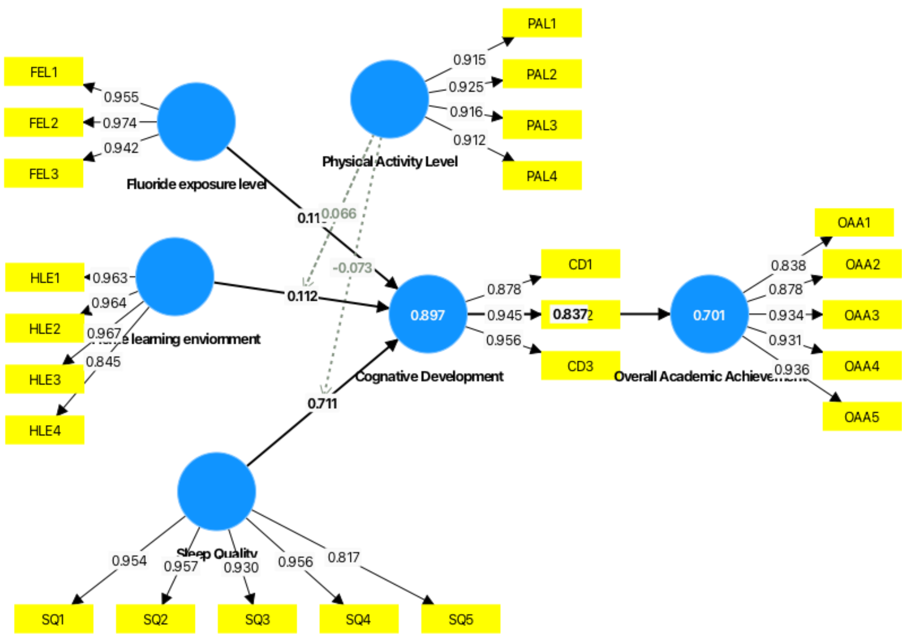

Figure 4: Measurment model

Table 3: Construct Reliability and Validity

Constructs	Items	Loading	Cronbach alpha	CR	AVE
Cognative Development CD	CD1	0.878	0.917	0.948	0.859
	CD2	0.945			
Fluoride exposure level	CD3	0.956	0.954	0.97	0.916
	FEL1	0.955			
	FEL2	0.974			
	FEL3	0.942			
Physical Activity Level	PAL1	0.915	0.937	0.955	0.841
	PAL2	0.925			
	PAL3	0.916			
	PAL4	0.912			
Home learning enviornment	HLE1	0.804	0.952		0.876
	HLE2	0.809			
	HLE3	0.785		0.966	
	HLE4	0.718			
	OAA1	0.838			
Overall Academic Achievement	OAA2	0.878	0.944	0.957	0.817
	OAA3	0.934			
	OAA4	0.931			
	OAA5	0.936			
Sleep Quality	SQ1	0.901	0.957	0.967	0.855
	SQ2	0.907			
	SQ3	0.839			
	SQ4	0.897			
	SQ5	0.775			
Constructs	Items	Loading	Cronbach alpha	CR	AVE
	CD1	0.878			
Cognative Development CD	CD2	0.945	0.917	0.948	0.859

The square root of the average variance extracted Both the actual and latent variables were used to examine the evaluation of discriminant validity in order to determine how fluoride exposure affected school-aged children's cognitive development [34]. By comparing the constructions pairwise with the square root of AVE, the associated measures were examined. For example, the square root of AVE for the Cognitive Development (CD) construct was 0.927, which was higher than the association of 0.713 with the Fluoride Exposure Level (FEL). The Home Learning Environment (HLE) also showed a good connection with the Overall Academic Achievement (OAA) at 0.904, with an AVE of 0.936. Specifically, the Sleep Quality (SQ) construct, which has a significant association of 0.936 with Cognitive Development, confirmed its importance with an AVE of 0.924. These results, which are shown in Table 4, show that each construct consistently explained more variation in the corresponding items than other constructs, supporting the structure of the model and improving our knowledge of the connections between the variables overall.

Table 4: Fornell-Larcker criterion

	CD	FEL	HLE	OAA	PAL	SQ
CD	0.927					
FEL	0.713	0.957				
HLE	0.773	0.635	0.936			
OAA	0.837	0.869	0.691	0.904		
PAL	0.824	0.670	0.715	0.731	0.917	
SQ	0.936	0.676	0.757	0.777	0.838	0.924

To determine the degree of connection between the constructs, multicollinearity was also investigated as a dependent variable using the Variance Inflation Factor (VIF). The VIF readings, which fall significantly below the commonly recognized threshold of 10, varied from 1.000 to 2.752. All values stayed within the permitted range, proving that there was no excessive correlation between the variables, indicating that multicollinearity was not an issue in this study. The data was then used to test the structural model, and SmartPLS 4 was utilized for the analysis. Several fit indices were computed to assess the suggested model's suitability. A excellent model fit is shown by the Root Mean Square Error of Approximation (RMSEA) value of 0.076, which is comfortably below the cut-off criterion of 0.10. The model's applicability was further supported by the finding that the chi-square to degrees of freedom ratio (CMIN/DF) was 2.238, well within acceptable bounds [35]. Further proof of the model's validity and robustness was provided by other fit indices, such as the Comparative Fit Index (CFI) at 0.944, the Tucker-Lewis Index (TLI) at 0.914, and the Incremental Fit Index (IFI) at 0.937, all of which were higher than the suggested threshold of 0.90. Since a significant amount of the study's data came from self-reports, Harman's one-factor test was run to check for any potential common method bias. Common technique bias concerns were substantially mitigated by the results, which showed that the most influential component only accounted for 36.9% of the total variance—well below the 50% threshold. Additionally, the correlation matrix showed no significant inter-construct correlations ($r > 0.90$), lowering the possibility of bias and confirming the validity of the study's conclusions.

Table 5: HTMT Ratios

	CD	FEL	HLE	OAA	PAL	SQ
CD						
FEL	0.760					
HLE	0.827	0.667				
OAA	0.893	0.827	0.728			
PAL	0.888	0.707	0.757	0.774		
SQ	0.810	0.708	0.794	0.816	0.890	
PAL x HLE	0.276	0.216	0.253	0.247	0.337	0.289

Structure Model

To evaluate the connections between the constructions, the structural model was put to the test. Significant route coefficients were found for each of the proposed linkages in the results. The degree of fluoride exposure positively impacted cognitive development (β = 0.110, $p < 0.001$), indicating that more fluoride exposure was linked to improved cognitive results [36]. A supportive educational setting is crucial for promoting cognitive growth, as evidenced by the favorable impact of the home learning environment on cognitive development (β = 0.112, $p < 0.001$). Furthermore, there was a significant positive correlation between sleep quality and cognitive development (β = 0.711, $p < 0.001$), suggesting that children who get better sleep do better cognitively[37]. The relationship between fluoride and cognitive development was also shown to be significantly moderated by the interaction effects of physical activity level with sleep quality and the home learning environment, with physical activity amplifying the impacts of these factors. The study found a strong correlation between cognitive development and total academic accomplishment (β = 0.837, $p < 0.001$). This suggests that cognitive development plays a crucial role in predicting academic success. **Table 7** shows that the particular indirect impacts of sleep quality, home learning environment, and fluoride exposure on total academic success through cognitive development were also statistically significant.

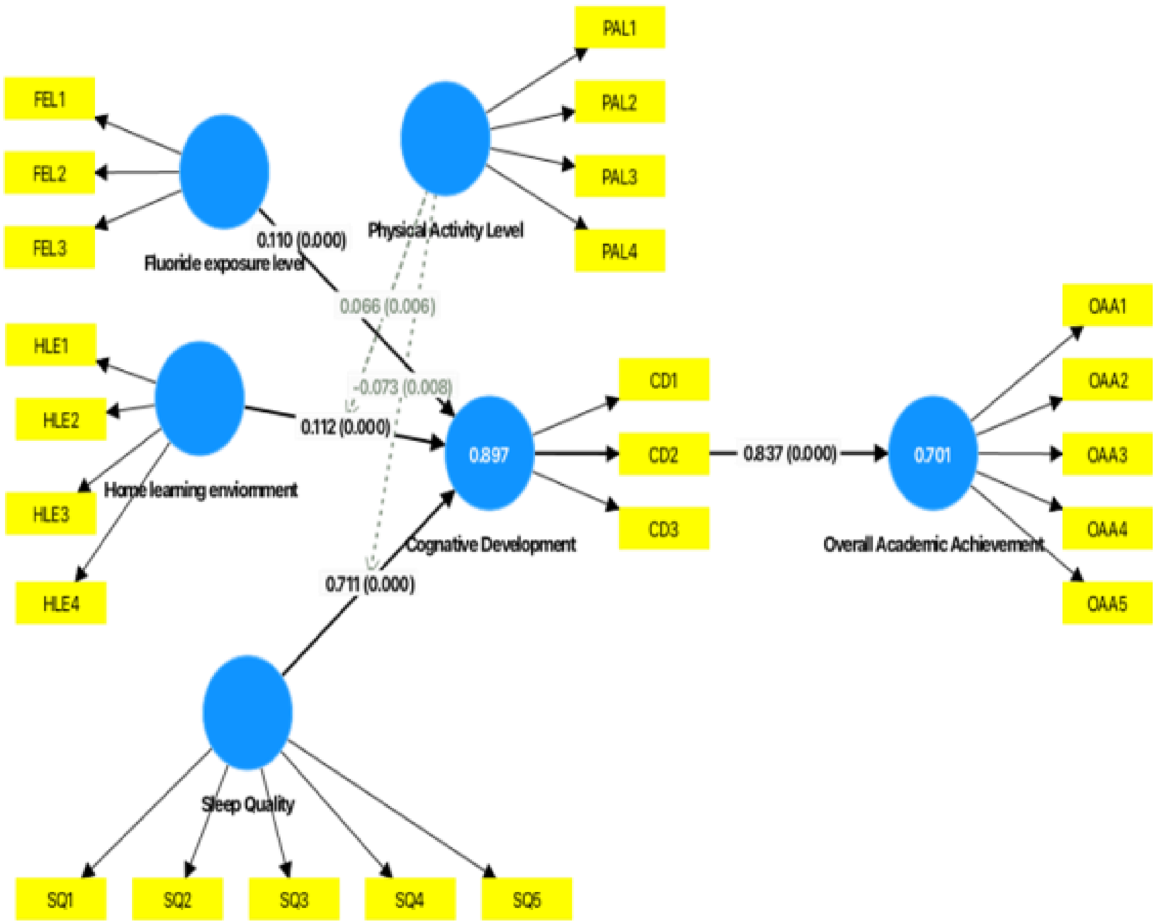

Figure 5: Structural model

Table 6: Path coefficient

	Original Sample (O)	Sample Mean (M)	T statistics (|O/STDEV|)	P values
CD -> OAA	0.837	0.837	36.757	0.000
FEL -> CD	0.110	0.110	3.506	0.000
HLE -> CD	0.112	0.113	3.777	0.000
PAL ->CD	0.065	0.168	2.238	0.002
SQ -> CD	0.711	0.708	14.154	0.000
PAL x HLE -> CD	0.066	0.066	2.752	0.006
PAL x SQ -> CD	-0.073	-0.073	2.649	0.008

Discussion and Conclusions

This research examines, critically, how fluoride exposure affects school-age children's cognitive development, with a focus on the larger framework of educational management techniques. Through the integration of variables such fluoride exposure levels, the home learning environment, physical activity, and sleep quality, the study highlights the complex implications on academic and cognitive results. The results show that the impact of fluoride exposure is now mostly understood in terms of its scientific components, frequently ignoring the possible moderating and mediating impacts of environmental and lifestyle variables including physical activity and sleep quality [38]. The research backs up the theory that fluoride exposure enhances cognitive development, especially in kids who have healthy sleep patterns and a nurturing family environment. Stronger cognitive capabilities in children were associated with greater academic accomplishment overall. These findings are consistent with other research that has linked cognitive talents to academic performance. Although fluoride is well known for its ability to prevent dental cavities, public health conversations are beginning to acknowledge its wider effects on cognitive function [39]. A thorough knowledge of fluoride's impacts on children's cognitive and academic development may be limited, though, if the chemical effects of the substance are the only thing being examined, neglecting to take into account environmental and lifestyle influences like physical activity and sleep [40]. A more comprehensive knowledge of the ways in which fluoride intake and associated factors impact cognitive development and overall academic achievement is offered by educational approaches that incorporate scientific, environmental, and policy perspectives. This strategy is in line with recent research that supports a more comprehensive and integrated evaluation of public health initiatives.

The study's findings, which emphasize the connection between children's cognitive development and fluoride intake, have important theoretical ramifications. First of all, the study highlights how crucial it is to take into account not just the biological consequences of fluoride exposure but also the impact of outside variables such the home learning environment, the quality of sleep, and physical exercise. Studies have indicated that comprehension of how external stimuli impact children's learning capacities requires an awareness of the interaction between environmental elements and cognitive development [41]. The incorporation of interdisciplinary techniques into public health education is encouraged by this larger viewpoint. The results of the study also lend support to the application of a more all-encompassing framework, akin to Bronfenbrenner's Ecological Systems Theory, which asserts that various facets of a child's environment, such as family, community, and wider societal factors, have an impact on the child's development. By comprehending the ways in which factors like physical activity and sleep quality interact with fluoride exposure, educators and policymakers may create more successful interventions to promote academic achievement and cognitive development. Practically speaking, the research recommends that educational initiatives include conversations on environmental and lifestyle issues in addition to the scientific elements of fluoride's biological effects [42]. The amalgamation of health education with wider educational management tactics, including endorsing sound sleeping habits and physical exercise, will cultivate a more comprehensive comprehension of augmenting cognitive growth in juveniles. As mentioned earlier, strategies that take into account health, environmental, and scientific aspects are crucial for encouraging long-term academic performance and raising public health awareness. [43] To provide students with the critical evaluation skills necessary to assess scientific concepts as well as their larger social and environmental implications, educators should embrace cross-disciplinary methodologies that include scientific education, health policy, and personal health habits into curriculum.

Limitations and Future Research Directions

This study highlights the necessity of teaching fluoride exposure and its impact on cognitive development in a comprehensive manner that takes into account environmental and educational elements in addition to biological facts. The results show that a multidisciplinary approach helps students better grasp how public health initiatives impact cognitive outcomes and academic achievement by taking into account factors including physical activity, home learning environment, and sleep quality. According to related research, students' engagement with public health initiatives is much enhanced when they are taught in real-world circumstances. But there are a number of issues with this study that need to be resolved in other investigations. First off, the study's exclusive focus on urban school-age children may restrict its applicability to underprivileged and rural communities. The environmental and educational obstacles that children from rural regions typically face can have a substantial impact on their cognitive development and health consequences. Subsequent investigations ought to investigate the impact of fluoride intake and other variables on cognitive development in children residing in rural areas, as well as the feasibility of tailoring educational interventions to suit their particular requirements. Furthermore, the main emphasis of this study is fluoride exposure as a singular public health concern. Deeper insights into how integrated educational approaches influence public health literacy across a range of issues may be obtained by extending the scope to include additional contentious public health subjects, such as immunizations or genetically modified organisms (GMOs). Future study should also examine how such educational frameworks might improve students' ethical thinking and decision-making in the context of other public health problems. A deeper understanding of how students participate in larger public health discussions will shed light on how education influences students' critical thinking and public health literacy.

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