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Prenatal fluoride exposure and child IQ: Is tea a key source of fluoride?

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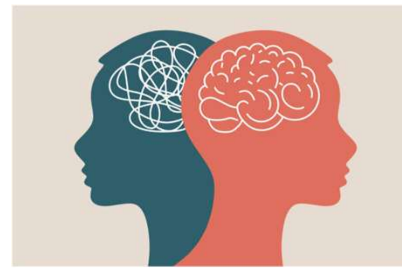
Participants

485 mother-child pairs enrolled in the Maternal-Infant Research on Environmental Chemicals (MIREC) cohort study

Exposure

Maternal fluoride intake from tea (mg/day) was estimated using self-reported beverage consumption (black, green, and herbal tea, coffee, and tap water) from the first and third trimesters.

Outcome



Child Full-Scale IQ (FSIQ) was assessed at 3-4 years of age using the Wechsler Preschool and Primary Scale of Intelligence (WPPSI)-III

Highlights

Prenatal fluoride from tea intake was associated with lower child IQ.
A 0.5 mg/day rise in fluoride intake related to a 2.2-point lower FSIQ.
Tea consumers had higher fluoride exposure than non-tea consumers.
Child sex did not modify any fluoride–IQ associations.
Further study of fluoride-related effects of tea intake is needed.

Conclusions

Fluoride exposure from tea consumption is associated with reduced child FSIQ independent of other beverages.
As tea can be a major source of exposure, pregnant women may consider limiting intake.
Clearer labeling of fluoride content could support informed choices.

Title

Prenatal fluoride exposure and child IQ: Is tea a key source of fluoride?

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Abstract

Background: Tea consumption can substantially contribute to fluoride intake. We examined the association between child intelligence and prenatal fluoride exposure from mother's tea consumption.

Methods: Participants included 485 mother-child pairs from the Maternal-Infant Research on Environmental Chemicals cohort. Maternal consumption of tea, coffee, and water during pregnancy was assessed via self-report. We estimated fluoride intake from tea (mg/day) by combining fluoride content from tea with each 200 mL cup of tap water. We assessed child full-scale IQ (FSIQ) at 3 to 4 years of age. We used multiple linear regression models to examine associations between maternal fluoride intake (from tea and from all beverages) and child FSIQ, adjusting for relevant covariates.

Results: Most participants (61%) reported consuming either green or black tea during pregnancy, with daily consumption reported by 2.3% and 8.4%, respectively. Women who consumed tea during pregnancy had higher mean total fluoride intake levels (0.76 mg/day) than those who did not (0.41 mg/day). Each 0.5 mg/day increase in fluoride intake was associated with a 2.24-point decrease in FSIQ (95%CI: -3.93,-0.55) when estimated from tea alone and a 1.67-point decrease (95%CI: -3.10,-0.25) when estimated from all beverages combined. The association between total fluoride intake and child IQ did not differ between tea consumers and non-tea consumers (*p*-interaction =.58).

Conclusions: Maternal fluoride exposure from tea consumption is associated with reduced child FSIQ independent of other beverages. As tea can be a major source of exposure, pregnant women may consider limiting intake. Clearer labeling of fluoride content could support informed choices.

1. Introduction

A growing body of evidence indicates that systemic fluoride exposure is a developmental neurotoxicant, particularly when exposure occurs during pregnancy and early childhood (Taylor, Eftim, Sibrizzi, Blain, Magnuson, Hartman, Rooney, et al. 2025). Once ingested, fluoride readily crosses the placenta and blood-brain barrier, thereby exposing the fetus during critical windows of neurodevelopment (Bennekou et al. 2025). Nine prospective birth cohort studies from six countries have evaluated the association between prenatal fluoride exposure and children's IQ. Inverse associations between prenatal fluoride exposure and child IQ were found in five of the studies (Goodman et al. 2022; Cantoral et al. 2021; Green et al. 2019; Singh et al. 2025; Valdez Jiménez et al. 2017) whereas the other four studies observed positive (Ibarluzea et al. 2022) or null (Ibarluzea et al. 2022; Grandjean et al. 2024; Kampouri et al. 2024; Dewey et al. 2023) associations. Inconsistencies across studies may reflect differences in exposure levels, the use of different exposure matrices (e.g. water versus urinary fluoride), and variation in how confounders were accounted for.

Fluoridated tap water, consumed directly and in beverages such as coffee and tea, is the primary source of fluoride exposure in people living in fluoridated communities, accounting for approximately 60-80% of total intake in adults (U.S. Environmental Protection Agency 2010; Helte, Vargas, et al. 2021). Tea can also contain high concentrations of fluoride. The tea plant (*Camellia sinensis*) is a bio-accumulator of fluoride, retaining more than 90% of inorganic fluoride absorbed from soil (Helte, Donat Vargas, et al. 2021; H. Li et al. 2009; Wen et al. 2024; Lubojanski et al. 2023; Malinowska et al. 2008) As a result, fluoride becomes concentrated in tea leaves, with concentrations varying widely depending on the natural fluoride content of soils and maturity of the tea plant (Malinowska et al. 2008; Jayasingha et al. 2025; Waugh et al. 2017; Emekli-Alturfan et al. 2009; Cao et al. 2006). The use of fluoride-containing pesticides and fertilizers, particularly phosphate fertilizers and cryolite, is common in tea cultivation and further contributes to higher fluoride levels in soil (Cronin et al. 2000; Zhang et al. 2023). In addition, phosphate fertilizers reduce soil pH, promoting mineral dissociation and fluoride release, thereby enhancing root uptake of fluoride by tea plants (Fung et al. 1999; T. Li et al. 2021; Manoharan et al. 2007; Peng et al. 2021; Ruan and Wong 2001).

Fluoride levels also differ markedly by tea type (Malinowska et al. 2008; Pattaravisitsate et al. 2021; Rajiv et al. 2023; Mazurek et al. 2023; Jayasingha et al. 2025). A recent review reported the highest fluoride concentrations in fully-fermented teas, such as brick tea (4.78 ± 2.15 mg/L) and black tea (2.73 ± 1.89 mg/L), compared with non-fermented green tea (1.37 ± 0.92 mg/L) and white tea (0.49 ± 0.28 mg/L) (Jayasingha et al. 2025; Jin et al. 2001). In contrast, herbal teas contain substantially lower levels of fluoride, averaging 0.17 mg/L (Jayasingha et al. 2025). The concentration of fluoride in tea is further influenced by brewing time (Malinowska et al. 2008; Rajiv et al. 2023; Chan et al. 2013). Depending on all of these factors, consumption of tea can account for up to 48% of total fluoride exposure among adults (Bennekou et al. 2025). Although fluoride concentrations differ substantially across tea types, the fluoride present in tea is inorganic fluoride (F^-), which is the same chemical ion regardless of whether it originates from black or green tea (Helte, Donat Vargas, et al. 2021; H. Li et al. 2009; Malinowska et al. 2008; Wen et al. 2024). Thus, differences between black and green tea reflect variation in fluoride concentration, not differences in the chemical form of fluoride.

Epidemiological studies indicate that habitual tea consumption is strongly associated with increased systemic fluoride exposure, as evidenced by higher plasma and urinary fluoride concentrations among tea consumers compared with non-tea consumers (Helte, Donat Vargas, et al. 2021; Carwile et al. 2020; Riddell et al. 2021). In a sample of 1,566 pregnant women in Canada, maternal urinary fluoride concentrations were correlated with the number of cups of black tea consumed during the first and third trimesters ($r = .32$) (Till et al. 2018). Furthermore, pregnant women who consume black tea regularly show higher urinary fluoride levels compared with non-consumers (Krishnankutty et al. 2022), underscoring tea as an important dietary source of prenatal fluoride exposure.

Prior research on the developmental neurotoxic effects of fluoride has primarily examined prenatal fluoride exposure in relation to child IQ using urinary fluoride or water fluoride concentrations, without accounting for specific dietary sources of fluoride or identifying contributors to higher exposure levels. This represents a critical gap in knowledge, particularly given that tea is both a substantial source of fluoride and is widely consumed by pregnant women across cultures. To address this gap, we used tea-specific fluoride concentrations derived from a comprehensive review by Jayasingha et al. (2025), which synthesized data from 88 global studies, allowing for a well refined and evidence-based calculation of fluoride intake from black and green tea. The potential for excessive fluoride intake is especially pronounced among those who regularly consume black tea and reside in fluoridated communities. Accordingly, the present study examines how fluoride intake from tea during pregnancy predicts child IQ. To rule out the possibility that any effects of fluoride from tea intake are driven by caffeine intake, we controlled for caffeine content. By isolating tea as a distinct source of fluoride exposure, this study addresses a key research question and strengthens the evidence base for targeted public health recommendations.

2. Methods

2.1. Study cohort and participants

This study utilized data from the Maternal-Infant Research on Environmental Chemicals (MIREC) cohort, a Canadian prospective birth study that originally enrolled 2,001 pregnant participants from 10 cities between 2008 and 2011. Of these, 1,983 consented to participate. The aim of the MIREC study was to examine potential effects of prenatal exposure to environmental chemicals on maternal and child health. Women were eligible for recruitment if they could communicate in English or French, were < 14 weeks gestation, ≥ 18 years old, planning to deliver at a local hospital, and agreed to provide a cord blood sample. Further information about the study design and recruitment process are detailed in the cohort profile (Arbuckle et al. 2013). For the MIREC-Child Development (CD Plus) follow-up study, 1,459 participants from six eligible sites consented to future research contact. Of these, 1,207 families were successfully reached by phone and 808 agreed to participate with their singleton-born children in the neurodevelopmental assessment, as previously described (Fisher et al. 2023). Among the 808 women who consented, 610 agreed to child IQ testing, 601 of whom completed the neurodevelopmental testing. Data on maternal tea consumption (black and green tea) were available for 595 mother-child pairs, of which 542 reported consuming water from public sources (as opposed to well water or bottled water, n = 53). Among these 542 women, information about water consumption habits was available for 485 women (see Figure 1 for flow chart). The 53 women excluded due to not consuming tap water had similar distributions of all covariates compared with the 485 included participants (Table S1). All individuals enrolled in the MIREC study provided informed consent for both their own participation and that of their children. Ethical approval for the secondary data analysis was secured from multiple institutional review boards, including those at Health Canada, CHU Sainte-Justine Research Center, the ethics committees of participating hospitals, and York University.

2.2. Beverage consumption during pregnancy

Maternal fluoride intake (mg/day) was estimated using self-reported beverage consumption collected from questionnaires administered during the first and third trimesters of pregnancy. The questionnaires assessed intake of commonly consumed beverages that can contribute to fluoride exposure, including black tea, green tea, herbal tea, regular and decaffeinated coffee, and tap water. At each time point, and for each beverage type, participants reported the number of cups consumed and the frequency of intake (daily, weekly, or monthly). To standardize these responses, weekly frequencies were converted to daily equivalents by dividing by seven, and monthly frequencies were divided by thirty. For each beverage, daily intake values from the first and third trimesters were averaged to estimate overall daily consumption during pregnancy; participants were classified as 'non-consumers' if they reported no intake of the beverages (i.e. 0 cups per day) or 'consumers' if they reported consuming any amount (i.e. more than 0 cups per day). Among consumers, 'regular consumers' were defined as individuals who reported consuming at least one cup per day, equivalent to seven or more cups per week. This categorization allowed us to examine fluoride exposure specifically from black or green tea, beverages known to have high fluoride content, and to assess whether the association between total fluoride intake (i.e. from all beverages) and child IQ differed between tea consumers and non-tea consumers.

2.3. Assessment of maternal fluoride intake

2.3.1. Estimation of fluoride intake from tea consumption: We used average fluoride concentrations found in black tea (2.73 mg/L) and green tea (1.37 mg/L) as reported by Jayasingha et al. (2025). Thus, for a standard 200 mL cup of tea, we estimated that the average fluoride content would be 0.546 mg for black tea and 0.274 mg for green tea; for women who reported consuming tap water in pregnancy, we added the fluoride content of a 200 mL cup of tap water to the per-cup tea estimates. For example, if an individual's tap water fluoride concentration is 0.7 mg/L, then we would add 0.14 mg fluoride from water to the 0.546 mg per 200 mL cup of black tea. Water fluoride concentrations were based on municipal water consumption reports that were averaged over the course of each woman's pregnancy, as described previously (Till et al. 2018). Participants who reported no tea consumption were assigned a value of zero for the tea-derived fluoride intake variable; We used the following equation to estimate maternal fluoride intake from black and green tea (mg/day):

$$= [(\text{Total cups of green and black tea per day}) \times (\text{Tap water fluoride concentration})] + (\text{Total cups of black tea per day} \times 0.546) + (\text{Total cups of green tea per day} \times 0.274)$$

2.3.2. Estimation of fluoride intake from coffee consumption: We used the average fluoride concentration found in caffeinated (0.17 mg/L) and decaffeinated (0.14 mg/L) coffee made with distilled water, as previously reported (Warren et al. 1996). Thus, for a standard 200 mL cup of coffee, the average fluoride content would be 0.034 mg for regular coffee and 0.028 mg for decaffeinated coffee, with additional fluoride exposure from tap water incorporated by adding the measured tap water fluoride concentration. Total daily fluoride intake from coffee was calculated as the sum of fluoride contributions from regular and decaffeinated coffee, multiplied by number of cups consumed per day. We used the following equation to estimate total maternal fluoride intake from coffee (mg/day):

$$= [(\text{Total cups of coffee per day}) \times (\text{tap water fluoride concentration})] + (\text{Total cups of regular coffee per day} \times 0.034) + (\text{Total cups of decaffeinated coffee per day} \times 0.028)$$

2.3.3. Estimation of total fluoride intake from all water-based beverages consumption: In addition, we estimated total maternal fluoride intake (mg/day) from all water-based beverages by summing the fluoride content from black tea, green tea, herbal tea, coffee, and tap water using the following equation:

$$= [(\text{Total cups of all beverages per day}) \times (\text{tap water fluoride concentration})] + (\text{Total maternal fluoride intake from tea}) + (\text{Total maternal fluoride intake from coffee}) + (\text{Total cups of herbal tea per day x } 0.034)$$

2.4. Maternal Urinary Fluoride Concentration

Maternal urinary fluoride (mg/L) concentrations were measured in spot urine samples collected during each trimester, adjusted for specific gravity, and averaged across trimesters as described by Till et al. (2018). Urine samples were analyzed at the Indiana University School of Dentistry using a modified hexamethyldisiloxane (HMDS; Sigma Chemical Co., St. Louis, MO, USA) micro-diffusion method (Martínez-Mier et al. 2010). Fluoride concentrations were quantified using a fluoride ion-specific electrode and referenced against a standard calibration curve prepared under identical conditions. All urine samples had fluoride concentrations above the limit of detection (0.02 mg/L).

2.5. Assessment of intelligence outcomes

We evaluated children's intellectual abilities between 3 and 4 years of age using the Wechsler Preschool and Primary Scale of Intelligence, Third Edition (WPPSI-III); a standardized tool widely used in developmental research (Wechsler 2002). For preschool-aged children, five WPPSI-III subtests were administered (Receptive Vocabulary, Information, Block Design, Object Assembly, and Picture Naming) and combined to derive composite scores for Full-Scale Intelligence Quotient (FSIQ), Verbal IQ (VIQ), and Performance IQ (PIQ). We included FSIQ as our main outcome variable, and VIQ and PIQ as secondary outcomes. These composite scores were age-standardized using Canadian norms (mean = 100, SD = 15), with higher scores indicating better cognitive performance. Standardized IQ scores are widely used by regulatory agencies as a common metric for risk assessment (U.S. Environmental Protection Agency 2008).

2.6. Covariates

Guided by a directed acyclic graph (Supplemental Figure S1) and theoretical considerations, covariates were retained if $p < 0.20$ or if their inclusion in the model resulted in a 10% change or more in model estimates for fluoride intake. We considered the following maternal, child, and household characteristics as potential confounders: race/ethnicity (White vs. Other), maternal education (college diploma or less vs. university undergraduate or graduate degree), child sex (male vs. female), study site, pre-pregnancy Body Mass Index (BMI), second-hand smoke exposure (yes/no), alcohol consumption (none/any), and the Home Observation Measurement of the Environment (HOME) score (Caldwell and Bradley 1984), a measure of the quality of the child's home environment. We also considered total caffeine intake (mg/day) which was estimated based on reported daily consumption of black tea, green tea, and coffee (regular and decaffeinated). The number of cups of each beverage was multiplied by reference values for caffeine content as previously reported (van Dam et al. 2020). The reference values per cup were 78 mg for regular coffee, 0.17 mg for decaffeinated coffee, 40 mg for black tea, and 24 mg for green tea.

2.7. Statistical Analysis

Spearman's rank correlations were used to examine associations between maternal urinary fluoride concentration and fluoride intake variables derived in the current study, including total fluoride intake, fluoride intake from tea, and fluoride intake from coffee (mg/day). Multiple linear regression models were used to evaluate the associations between maternal fluoride intake from tea (mg/day) and child IQ. Both unadjusted and covariate-adjusted models are presented, with results reported as unstandardized regression coefficients (B) and corresponding 95% confidence intervals (CIs). Covariates included race/ethnicity, maternal education, child sex and study site. To explore whether the association between fluoride intake from tea and child IQ differs across subgroups, we tested for effect modification by child sex, pre-pregnancy BMI, race/ethnicity, maternal education, and HOME score. Previous fluoride studies have identified interactions with child sex (Green et al. 2019), race/ethnicity (Khan, Franks, et al. 2025; Khan, Mattia, et al. 2025) and BMI (Khan, Mattia, et al. 2025). Maternal education and HOME score were also examined as potential effect modifiers because socioeconomic factors have been shown to modify the association between exposure to neurotoxicants, like lead, and child IQ (Bellinger 2000). BMI and HOME score were analyzed as continuous variables, whereas sex, maternal education, and race/ethnicity (White/non-White) were analyzed as categorical variables. Each modifier was tested by adding an interaction term with fluoride intake from tea in both the unadjusted and primary adjusted models. If the interaction term was not statistically significant, the final model was estimated without the interaction. In a secondary model, we examined the association between total maternal fluoride intake (i.e. from all beverages) and child IQ, and included an interaction term to assess whether this association differed between tea consumers and non-tea consumers. In all regression models, fluoride intake was rescaled to a 0.5 mg/day increment, such that coefficients represent the expected change in outcome per 0.5 mg increase in fluoride intake. This amount is approximately equivalent to the fluoride content of one cup of black tea (0.546 mg) or two cups of green tea (0.274 mg).

In a sensitivity analysis, we re-estimated the primary model after adding secondary covariates, including pre-pregnancy BMI, HOME score, caffeine intake, second-hand smoke exposure, and alcohol consumption, to evaluate whether the association was robust to additional potential confounders. Further, to determine the robustness of our findings, we re-ran the primary model using lower fluoride concentration estimates for tea as reported by Krishnankutty et al. (2022). All assumptions of linear regression were met, with no evidence of collinearity or influential outliers based on Cook's distance. We used STATA NOW/BE version 19.5 (StataCorp LLC, College Station, Texas, USA) for data analysis. The level of significance was set at $p < .05$ for main effects and $p < .10$ for interactions. All statistical tests were two-tailed.

3. Results

A total of 485 mother–child pairs had complete data on fluoride intake from tea, child IQ, and covariates and were included in the primary analysis. For analyses of total fluoride intake from all beverages, the sample was reduced to 464 mother-child pairs as water consumption data was unavailable for 21 participants.

Sociodemographic characteristics (Table 1) indicated that most mothers identified as White (87.8%) and over two-thirds (67.8%) had attained a university-level education. The sample was evenly distributed by child sex (male 49.7%) and reflected a geographically diverse cohort recruited from six cities in Canada. Maternal health and home environment indicators showed a mean pre-pregnancy BMI of 25.0 (SD = 6.0) and the mean HOME score was 47.3 (SD = 4.39). Cognitive performance was assessed in children with a mean age of 3.44 years (SD = 0.31); the mean FSIQ score was 107.1 (SD = 13.7), indicating average cognitive performance. Urinary fluoride concentration adjusted for specific gravity (for all three trimesters) was available for 428 of the 485 women. Mean (SD) urinary fluoride concentration was 0.55 (0.39) mg/L. Maternal urinary fluoride concentration was moderately correlated with maternal fluoride intake from all water-based beverages (ρ = .59, p <.001) and weakly correlated with maternal fluoride intake from tea (ρ = .29, p < .001) and very weakly correlated with coffee consumption (ρ = .10, p = .03). Fluoride intake from black tea only was strongly correlated with fluoride intake from both black and green tea (ρ = .91, p < .001), suggesting that black tea is the main contributor to the fluoride intake from tea derived variable.

3.1. Beverage consumption during pregnancy

The distribution of consumption for each type of beverage is presented (Table 2), with participants categorized into non-consumers (0 cups/week), consumers (>0 to <7 cups/week), and regular consumers (≥7 cups/week). Coffee was the most frequently consumed beverage, with 22.7% of women reporting at least daily consumption and 42.9% reporting occasional consumption (i.e., 1 to 6 cups per week). In comparison, 8.4% and 2.3% of women reported at least daily consumption of black tea and green tea, respectively, while 42.7% and 27.2 % reported consuming these beverages occasionally. Among the 296 participants who reported drinking black or green tea, 153 consumed black tea only (52%), 48 (16%) consumed green tea only, and 95 (32%) consumed both types (Supplemental Figure S2).

Table 3 presents the estimated daily maternal fluoride intake, calculated from self-reported beverage consumption and stratified by non-tea consumers versus tea consumers. Among the entire sample, 296 (61.0%) were classified as tea consumers, defined as individuals reporting any consumption of black or green tea or both (i.e., >0 cups/day). Tea consumers had significantly higher total fluoride intake from all beverages (mean = 0.76 mg/day, SD = 0.56, range = 0.03-3.95) compared to non-tea consumers (mean = 0.41 mg/day, SD = 0.33, range = 0.01-1.35) (p < .001), primarily from consuming black tea. No significant differences in fluoride intake from consumption of coffee, herbal tea, or water were found when comparing the tea consumers and non-tea consumers.

3.2. Maternal fluoride intake and child IQ

Higher fluoride intake from tea (N = 485) was significantly associated with lower IQ scores in children. Each 0.5 mg/day of maternal fluoride intake (equivalent to consuming approximately one cup of black tea) was associated with a 2.57-point decrease in FSIQ (95% CI: –4.38, –0.76; p = .005) in the unadjusted model, and a 2.24-point decrease in FSIQ in the primary-covariate adjusted model (95% CI: –3.93, –0.55; p = .009) (Table 4; Figure 2A). Fluoride intake from tea was also significantly associated with VIQ (B = –1.93; 95% CI: –3.53, –0.33; p = .018) in the primary adjusted model, but was not significant with PIQ (B = –1.76; 95% CI: –3.65, 0.12; p = .067). Finally, there were no statistically significant interactions between fluoride intake from tea and potential modifiers child sex, pre-pregnancy BMI, race/ethnicity, maternal education, and HOME score (p-values for all interaction terms > 0.10).

Total maternal fluoride intake from all beverages (N = 464) was also significantly associated with lower FSIQ scores in the unadjusted model (B = –1.77; 95% CI: –2.97, -0.58; p = .004) and the primary-covariate adjusted model (B = –1.67; 95% CI: –3.10, -0.24; p = .022) (Table 4). However, the associations for the primary-covariate adjusted models were non-significant for VIQ (B = –1.25; 95% CI: –2.61, -0.12; p = .072) and PIQ (B = –1.52; 95% CI: –3.12, 0.08; p = .062) (Table 4). Notably, the interaction term involving tea consumption status (yes/no) was not significant (p = .58), suggesting that both tea consumers (n = 283) and non-tea consumers (n = 181) show a similar association between total fluoride intake and lower child FSIQ scores (Figure 2B).

3.3. Sensitivity analysis

All associations persisted when secondary covariates were added to the models, including caffeine intake, pre-pregnancy BMI, HOME scores, exposure to second hand smoke, and alcohol consumption (Table 4). Finally, to assess the robustness of our findings, we repeated the analyses using the lower fluoride concentration estimates for tea reported by Krishnankutty et al. (2022), as detailed in the eMethods. Recalculating maternal fluoride intake from tea with these lower concentrations produced a larger effect estimate, with each 0.5 mg/day of maternal fluoride intake from tea associated with a 3.27-point decrease in child FSIQ (95% CI: –5.77, –0.78; p = .010) (Table S2).

4. Discussion

This study examined the association between fluoride exposure from tea consumption during pregnancy and childhood cognitive outcomes within a prospective Canadian pregnancy and birth cohort. Our analysis revealed a significant inverse association between maternal fluoride intake from tea during pregnancy and child FSIQ at 3 to 4 years. Specifically, each 0.5 mg/day of fluoride intake from tea, approximately equivalent to one standard cup of black tea, was associated with a 2.2- to 3.3-point lower FSIQ score depending on how fluoride in black and green tea was estimated. A similar pattern was observed for VIQ and PIQ, with a significant association for VIQ and a trend in the same direction for PIQ. We did not find evidence of effect modification by child sex, consistent with our previous findings in this cohort when using water fluoride concentration as the exposure metric, but not when urinary fluoride was used (Green et al. 2019).

Our findings are consistent with prior epidemiological studies examining the association between prenatal fluoride exposure and IQ scores in children. In a recent meta-analysis of five high-quality prenatal studies (Green et al. 2019; Goodman et al. 2022; Grandjean et al. 2024; Kampouri et al. 2024; Singh et al. 2025), the National Toxicology Program found that a 1 mg/L increase in maternal urinary fluoride concentration was associated with a 1.6-point decrement in child IQ (95% CI: -3.45, 0.10) (Taylor, Eftim, Sibrizzi, Blain, Magnuson, Hartman, Bucher, et al. 2025). Importantly, our results extend the literature by demonstrating that fluoride derived from tea, a modifiable dietary source, produces effect sizes similar to those observed for total fluoride exposure urinary biomarkers measured in pregnancy. While a reduction of 1 or 2 IQ points would not be noticeable at the individual level, such small effects on IQ can have measurable and economic implications at the population level by increasing the proportion of individuals who require additional educational and support services (Bellinger 2012). Moreover, a 1-point decrement in IQ is used as a benchmark for risk assessment by regulatory agencies such as the European Food Safety Authority (EFSA) and the U.S. Environmental Protection Agency (EPA) (Grandjean 2019; U.S. Environmental Protection Agency 2008; EFSA 2010; Budtz-Jørgensen et al. 2013). Consequently, the 2-point reduction observed in our study exceeds the benchmark that has been identified as meaningful for population-level risk assessment, underscoring the potential public health relevance of this association.

Tea can contain considerable amounts of fluoride, ranging from 0.32 to 6.68 mg/L (Jayasingha et al. 2025), depending on type, brewing method, and the fluoride content of the water. Regular tea consumption, especially when tea is prepared with fluoridated water, can increase systemic fluoride exposure enough to exceed the “safe level of intake” of 3.3 mg/day for pregnant women as established by the European Commission’s Scientific Committee (National Institutes of Health 2020; Bennekou et al. 2025). Habitual tea consumers, particularly those consuming multiple cups per day of high-fluoride tea types (e.g. brick or black tea), are at particular risk of surpassing recommended dietary intake levels (Jayasingha et al. 2025; Krishnankutty et al. 2022). In our study, only one tea consumer exceeded this level. However, tea consumers had nearly double the total fluoride intake of non-tea consumers (mean= 0.76 vs. 0.41 mg/day), consistent with prior evidence that pregnant (Krishnankutty et al. 2022; Till et al. 2018) and non-pregnant women (Helte, Donat Vargas, et al. 2021; Riddell et al. 2021) who consume tea regularly show higher urinary fluoride levels. These findings confirm that tea can be an important dietary contributor to total fluoride intake.

In our study, adjusting for maternal caffeine intake did not alter the association between fluoride intake from tea and child FSIQ. Nonetheless, maternal caffeine intake has been investigated as a potential contributor to adverse birth outcomes as well as behavioural and neurodevelopmental outcomes in children (Rohweder et al. 2024; Chen et al. 2018; Okubo et al. 2015). Because caffeine readily crosses the placenta and the fetus has limited capacity to metabolize it, exposure may be prolonged. High levels of exposure have been associated with increased fetal catecholamines, reduced placental blood flow, and hypoxia, which may disrupt fetal growth and development (Okubo et al. 2015). Additional studies are needed to clarify whether caffeine contributes independently to neurodevelopmental risk or interacts with other prenatal exposures.

As shown in Figure 2B, the association between total maternal fluoride intake (i.e., from all beverages) and child FSIQ did not significantly differ between tea consumers and non-tea consumers (i.e. no evidence of interaction). Although the association was statistically significant among tea consumers but not among non-tea consumers, this likely reflects the lower levels and a narrower range of exposure in the latter group rather than a true difference in effect. These findings suggest that higher fluoride intake among tea consumers increases the ability to detect neurodevelopmental effects, consistent with toxicological evidence that fluoride ions exert similar biological activity regardless of source (NRC 2006; Bennekou et al. 2025).

Among tea consumers, weekly and exclusive consumption of black tea was approximately three times more common than weekly and exclusive consumption of green tea (Figure S2). These differences in consumption patterns, together with the higher fluoride concentrations in black tea than in green tea, explain the strong correlation between fluoride intake estimated from both black and green tea and fluoride intake estimated from black tea alone ($\rho = .91$, $p < .001$). Thus, black tea appears to be the primary contributor to the maternal tea-derived fluoride intake variable in our analytic sample.

We did not directly compare fluoride intake from black versus green tea because only 2.3% of participants reported drinking green tea on a daily basis. This small subgroup limited our ability to draw robust conclusions about whether the association between fluoride intake and child IQ differed by tea type.

Multiple mechanistic pathways plausibly link prenatal fluoride exposure with neurodevelopmental outcomes. Fluoride readily crosses the placenta and the blood-brain barrier, exposing the developing fetus during critical windows of neurodevelopment (Till et al. 2025). Experimental studies and integrative reviews consistently identify oxidative stress, mitochondrial dysfunction, synaptic and neurotransmission disruption, and altered calcium signaling as recurring mechanisms of fluoride neurotoxicity, with accumulating evidence of hippocampal vulnerability and associated structural and functional changes relevant to learning and memory (Grandjean 2019). Fluoride has also been linked to thyroid-axis perturbation (Hall et al. 2023; Iamandii et al. 2024), a pathway of particular relevance during pregnancy given fetal dependence on maternal thyroxine for early brain development. While not a fluoride study per se, one rat study found that increasing concentrations of green tea extract enlarged the thyroid gland (goitre) and induced hypothyroidism (Chandra and De 2010). Together, these findings suggest a multi-mechanistic model of fluoride neurotoxicity that may involve oxidative, mitochondrial, synaptic, and thyroid function pathways.

This study has several methodological strengths. First, the use of the MIREC prospective birth cohort measured tea consumption habits across different types of teas (black, green, and herbal) in both the first and third trimesters, providing a more robust characterization of prenatal exposure than would be possible with a single time-point measure. Second, child cognitive outcomes were assessed using the WPPSI-III, a standardized instrument with strong reliability and validity for research use (Wechsler 2002). Third, the analytical approach incorporated sensitivity analyses, adjusting for relevant covariates, including maternal caffeine intake and the quality of the home environment (HOME score), and verifying the stability of the findings across multiple tea-fluoride estimation methods.

Nonetheless, this study had some notable limitations. The study cohort is predominantly White (87.8%) and highly educated (67.8%), limiting the generalizability of findings to socioeconomically and racially diverse populations where exposure patterns and susceptibility may differ. Next, although parental IQ is an important predictor of child cognitive outcomes, this variable was not collected in the MIREC cohort. To mitigate potential residual confounding, we adjusted for maternal education and the HOME score, which serve as proxies for socioeconomic context and cognitive enrichment in the home. Maternal beverage consumption was self-reported, which may introduce recall bias and exposure misclassification; however, the observed correlation ($\rho = 0.59$) between total fluoride intake from all beverages and maternal urinary fluoride levels in the study cohort supports the validity of our estimates of fluoride intake from dietary sources. While this study utilized published values to estimate fluoride concentrations in tea and coffee beverages, it is important to note that actual levels are highly variable; for tea, fluoride content may be influenced by environmental and agricultural factors such as soil pH, leaf maturity, specific farming conditions, and individual brewing techniques (Fung et al. 1999; Li et al. 2021; Manoharan et al. 2007; Peng et al. 2021; Ruan and Wong 2001). Furthermore, variations between tea brands and the common practice of adding milk or sweeteners may further modulate the systemic impact by altering the bioavailability of fluoride during digestion (Waugh et al. 2017; Trautner and Siebert 1986). Finally, beyond the beverages assessed in the current study, other types of foods (e.g. seafood) and beverages that were not measured (e.g. iced tea, grape juice) may have contributed to overall fluoride exposure (Jáudenes-Marrero et al. 2024; Ganta 2015). Future studies should consider other important dietary sources, comparison of black tea versus green tea, and other possible adverse health outcomes associated with systemic fluoride exposure in pregnancy, such as emotional and behavioural functioning in children. Continued research is needed to refine assessment of dietary fluoride sources across the lifespan and to strengthen the evidence base informing public health guidance.

5. Conclusion

We found that prenatal fluoride exposure from maternal tea consumption in pregnancy is associated with reduced IQ scores in early childhood. By identifying tea, particularly black tea, as a major and potentially modifiable contributor to fluoride exposure during pregnancy, our findings translate evidence on fluoride-related developmental neurotoxicity into specific exposure pathways that may inform public health guidance. These findings highlight the need for systematic monitoring of fluoride levels in tea beverages and greater transparency regarding the fluoride content of different tea products given the substantial variability in concentrations. Such information is rarely disclosed on packaging, yet it is essential for supporting informed decision-making. Replication of our findings in more representative cohorts is needed to determine whether similar associations are observed across different demographic contexts.

CRediT authorship contribution statement

Durdana Khan: Writing – original draft, Methodology, Investigation, Formal analysis, Writing – review & editing. **Meaghan Hall**: Data curation, Methodology, Investigation, Formal analysis, Writing – review & editing. **Keira Ayoub**: Writing – review & editing. **Richard Hornung**: Supervision, Writing – review & editing. **David Flora**: Supervision, Formal analysis, Writing – review & editing. **Bruce Lanphear:** Supervision, Writing – review & editing. **Christine Till:** Writing – original draft, Writing – review & editing, Supervision, Funding acquisition, Resources, Methodology, Conceptualization, Project administration.

Co–first authorship: **Durdana Khan** and **Meaghan Hall** contributed equally to this work.

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Ethics approval and consent to participate

This study obtained approval from Research Ethics Boards at Health Canada, Centre hospitalier universitaire (CHU) Sainte-Justine Research Center, ethics committees at participating hospitals, York University, and the University of Toronto for the analysis of secondary data. All participants completed informed consent for themselves and children.

Data availability

The authors do not have permission to share data, but data may be accessed through an application to the MIREC Biobank.

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Figure captions

Figure 1: Study sample flow chart of participants from the MIREC study

Figure 2: Adjusted associations between maternal fluoride intake (mg/day) and child Full-Scale IQ. Top panel (A) shows the association between maternal fluoride intake from tea for the full sample (N=485). Bottom panel (B) shows the association between total maternal fluoride intake from all beverages for tea-consumers (red line; n=283) and non-tea-consumers (blue line; n=181)

Table 1. Demographic characteristics of study sample (N = 485).

Demographic Characteristic	Mean (SD)
Mothers	
Maternal age (years)	32.66 (4.69)
Born in Canada (n, %)	390 (80.41)
White (n, %)	426 (87.84)
Bachelor's Degree or higher (n, %)	329 (67.84)
Pre-pregnancy BMI (kg/m^2) (N=446)	25.04 (6.01)
HOME score (n=470) (n, %)	47.31 (4.39)
Household income >$100,000 CAD (n,%)	191 (39.38)
Second hand smoke in trimester 1 (n, %)	
Yes	16 (3.30)
No	469 (96.70)
Alcohol consumption (n, %) (N=465)	
None	386 (83.01)
Any	79 (16.99)
Tea consumption (n, %)	
None	189 (38.97)
Any	296 (61.03)
Estimated caffeine intake (mg/day)	36.68 (42.48)
Site of participation (n, %)	
A	52 (10.72)
B	68 (14.02)
C	66 (13.61)
D	93 (19.18)
E	117 (24.12)
F	89 (18.35)
Living in a fluoridated community (n;%)	223 (45.98)
Urinary fluoride concentration, adjusted for specific gravity (mg/L)(n=428)	0.55 (0.39)
Children	
Male (n, %)	241 (49.69)
Age at testing (years)	3.44 (0.31)
Full Scale IQ	107.12 (13.65)
Performance IQ	102.81 (14.95)
Verbal IQ	109.95 (13.07)

Abbreviations: BMI = Body Mass Index; CAD = Canadian dollars; HOME = Home Observation Measurement of the environment.

Table 2. Frequency of pregnant women reporting tea and/or coffee consumption during pregnancy (N = 485). Each type of beverage is sorted by number of cups consumed per week.

Type of beverage	0 cups/week	>0 and <7 cups/week	≥ 7 cups/week
Black tea; n (%)	237 (48.9)	207 (42.7)	41 (8.4)
Green tea; n (%)	342 (70.5)	132 (27.2)	11 (2.3)
Herbal tea; n (%)	237 (48.9)	228 (47.0)	20 (4.1)
Coffee; n (%)	167 (34.4)	208 (42.9)	110 (22.7)

Table 3. Daily maternal fluoride intake (mg/day) estimated from self-reported beverage consumption, categorized by tea consumption status. All estimates are based on fluoride content reported by Jayasingha et al. (2025) and include fluoride content found in the individual's tap water used to make the tea or coffee.

Estimated fluoride intake	**All** N=485 Mean (SD)	**Non-Tea consumers** N=189 Mean (SD)	**Tea consumers** N=296 Mean (SD)	**Test statistic*** *t* (df) *p-value*
From black and green tea [a, b]	0.17 (0.33)	0	0.27 (0.39)	t (483) = 9.52 **p <.001**
From coffee [b]	0.05 (0.07)	0.04 (0.06)	0.05 (0.07)	t (483) = 1.65 p =.09
From herbal tea [b]	0.01 (0.03)	0.01 (0.03)	0.02 (0.03)	t (483) = 1.80 p =.07
From drinking water only[†]	0.39 (0.34)	0.35 (0.30)	0.41 (0.36)	t (462) = 1.78 p =.08
From all beverages[†] (black tea, green tea, herbal tea, coffee, and cups of drinking water, and water used to make beverages)	0.62 (0.51)	0.41 (0.33)	0.76 (0.56)	t (462) = 7.69 **p < .001**

[†] Sample size (N=464) due to missing data related to cups of water consumed (tea non-consumers: n=181 and tea consumers: n=283)
[*]t-statistics are computed using two-sample t-tests comparing tea drinkers and non–tea drinkers. Tests were conducted allowing for unequal group sizes and unequal variances (Welch's t-test). Statistically significant results are shown in bold (p < .05)
[a] When fluoride values from Krishnankutty et al. (2022) are used, estimated fluoride intake from black and green tea is 0.11 (0.23) for total sample and 0.19 (0.26) for tea consumers (p<.001).
[b] The estimated maternal fluoride intake from beverage includes the fluoride concentrations from the tap water used to make the beverage
Tea consumers are defined as individuals reporting any consumption of black or green tea (>0 cups/day).

Table 4. Unadjusted and adjusted differences in IQ scores at 3-4 years of age per 0.5 mg of maternal fluoride intake per day. Fluoride content in tea was estimated using values reported by Jayasingha et al. (2025).

Models	**N**	**Fluoride intake from tea B (95% CI), *p*-value**	***Sex p-int***	**N**	**Total fluoride intake B (95% CI), *p*-value**	***Sex p-int***
Full-Scale IQ						
Unadjusted	485	-2.57 (-4.38, -0.76), .005	--	464	-1.77 (-2.97, -0.58), .004	--
+ Primary covariates	485	-2.24 (-3.93, -0.55), .009	.986	464	-1.67 (-3.10, -0.24), .022	.387
+ Primary & secondary covariates	414	-2.29 (-4.31, -0.26), .027	.213	413	-1.89 (-3.58, -0.20), .029	.837
Performance IQ						
Unadjusted	480	-2.61 (-4.61, -0.62), .010	--	459	-3.04 (-4.33, -1.74),<.001	--
+ Primary covariates	480	-1.76 (-3.65, 0.12), .067	.801	459	-1.52 (-3.12, 0.08), .062	.379
+ Primary & secondary covariates	409	-1.67 (-4.00, 0.67), .161	.361	408	-1.57 (-3.50, 0.38), .114	.935
Verbal IQ						
Unadjusted	484	-1.72 (-3.46, 0.02), .051	--	463	-0.15 (-1.31, 1.00), .791	--
+ Primary covariates	484	-1.93 (-3.53, -0.33), .018	.793	463	-1.25 (-2.61, 0.12), .072	.445
+ Primary & secondary covariates	413	-2.00 (-3.95, -0.05), .044	.234	412	-1.50 (-3.12, 0.13), .071	.928

Primary covariates include: race/ethnicity, education, child sex and site of participation
Secondary covariates include: body mass index, Home Observation for Measurement of the Environment (HOME) score, caffeine intake, second-hand smoke exposure, and alcohol consumption
Sample with total fluoride intake data is smaller than fluoride intake from tea sample because 21 participants had missing water consumption information.
Sex p-int for sex x fluoride interaction

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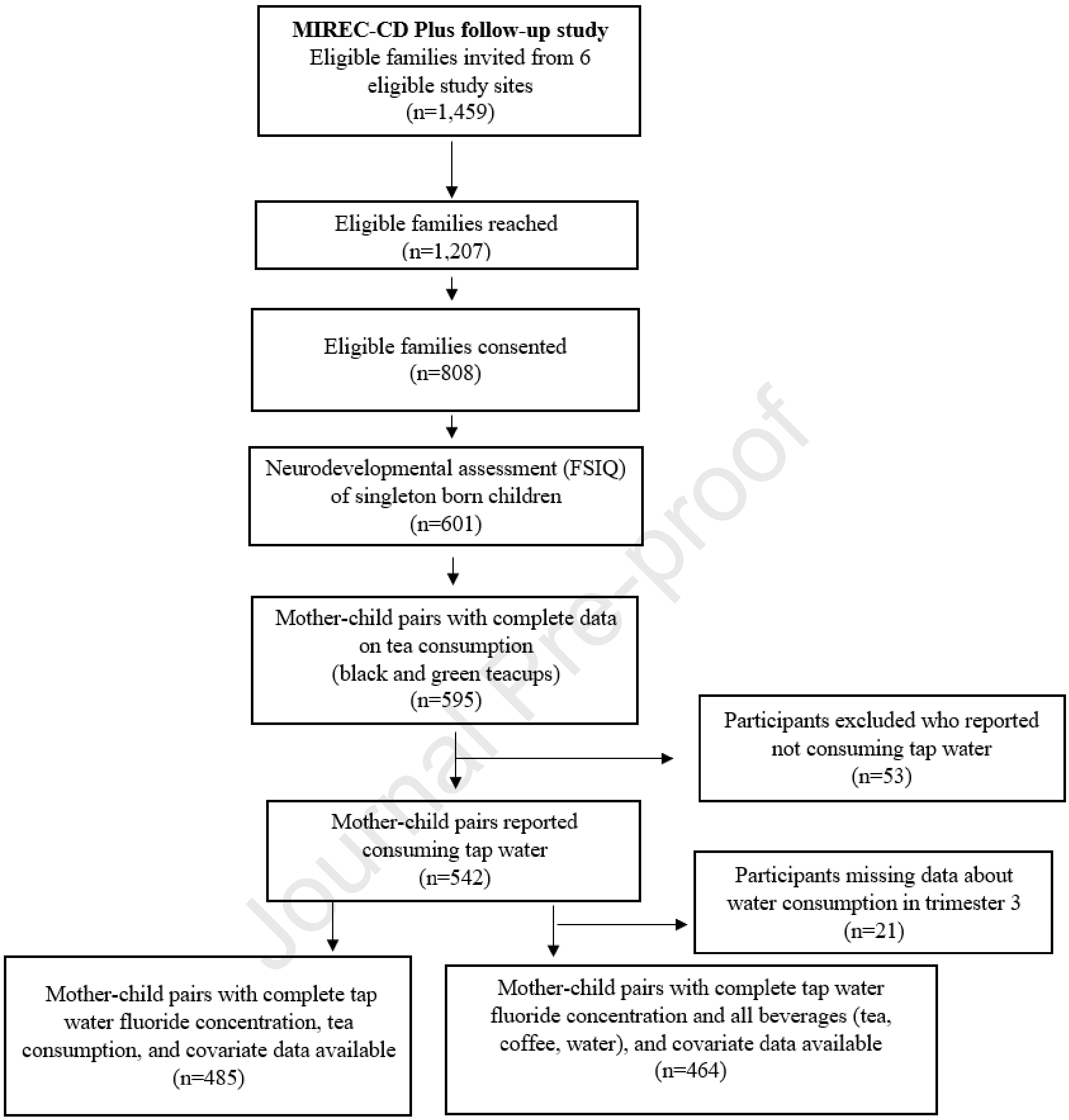
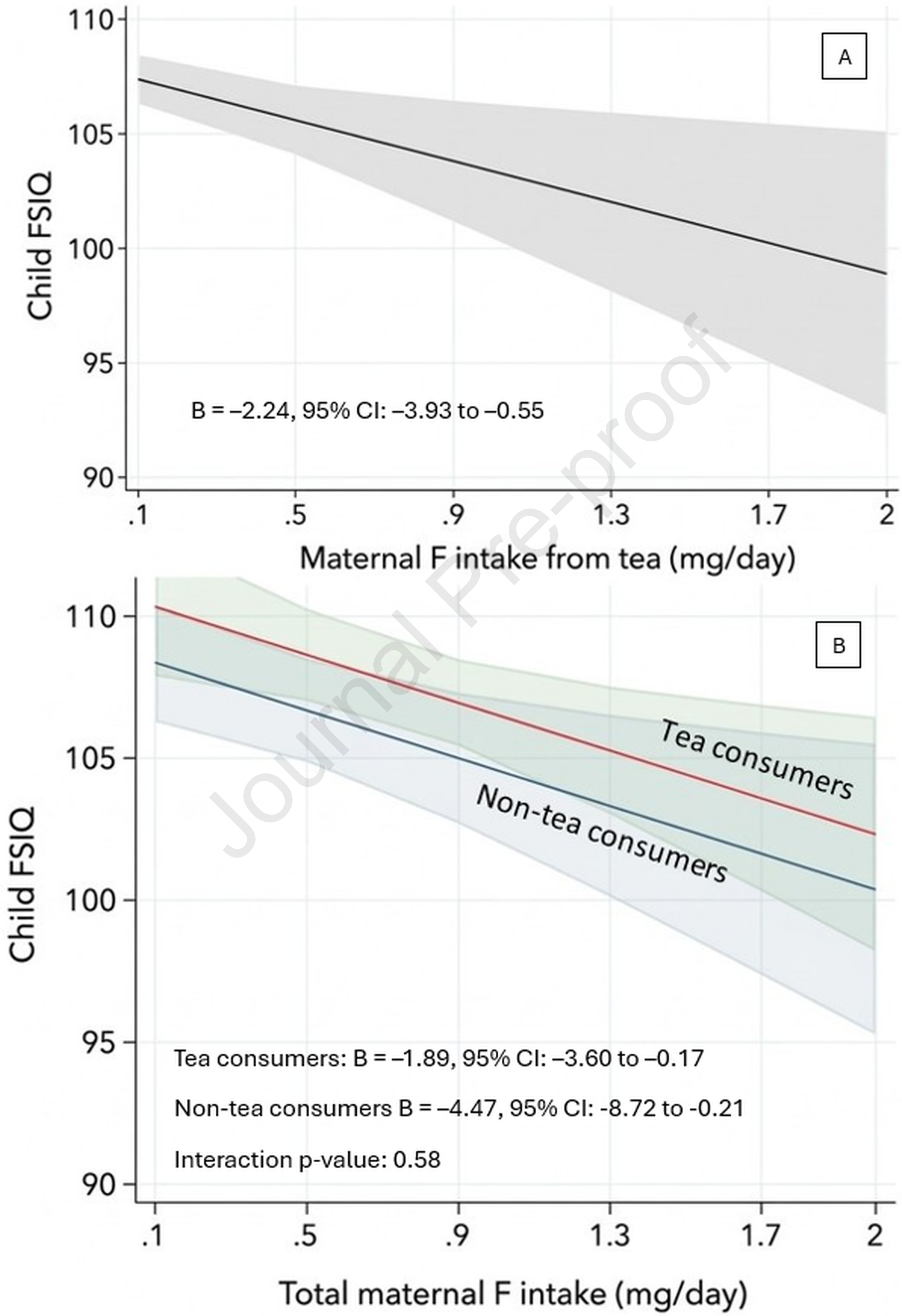

MIREC-CD Plus follow-up study
Eligible families invited from 6 eligible study sites (n=1,459)
Eligible families reached (n=1,207)
Eligible families consented (n=808)
Neurodevelopmental assessment (FSIQ) of singleton born children (n=601)
Mother-child pairs with complete data on tea consumption (black and green teacups) (n=595)
Participants excluded who reported not consuming tap water (n=53)
Mother-child pairs reported consuming tap water (n=542)
Participants missing data about water consumption in trimester 3 (n=21)
Mother-child pairs with complete tap water fluoride concentration, tea consumption, and covariate data available (n=485)
Mother-child pairs with complete tap water fluoride concentration and all beverages (tea, coffee, water), and covariate data available (n=464)


A
Child FSIQ
110
105
100
95
90
B = –2.24, 95% CI: –3.93 to –0.55
.1
.5
.9
1.3
1.7
2
Maternal F intake from tea (mg/day)
B
Tea consumers
Non-tea consumers
Child FSIQ
Tea consumers: B = –1.89, 95% CI: –3.60 to –0.17
Non-tea consumers B = –4.47, 95% CI: -8.72 to -0.21
Interaction p-value: 0.58
Total maternal F intake (mg/day)

Highlights

- Prenatal fluoride from tea intake was associated with lower child IQ.
- A 0.5 mg/day rise in fluoride intake related to a 2.2-point lower FSIQ.
- Tea consumers had higher fluoride exposure than non-tea consumers.
- Child sex did not modify any fluoride–IQ associations.
- Further study of fluoride-related effects of tea intake is needed.

Declaration of interests

☒ The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

☐ The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: