

Comments on the Aggeborn & Öhman (2021) study of drinking water fluoride effects on cognition in Sweden

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Aggeborn & Öhman (2021) conducted an econometric analysis examining the association between drinking water fluoride (F) exposure and several types of outcomes [[Aggeborn 2021a](#), [2021b](#)]:

- military conscription aptitude test scores at age 18-20 years
- other outcomes they considered proxies for cognitive ability or neurological health for age 16 and adults
- annual income for adults
- dental care utilization measures for adults

The primary study population was males in Sweden who had taken a compulsory military service aptitude test at ages 18-20 years. The primary fluoride exposure measure was lifetime average drinking water F concentration based on estimates of local area drinking water F concentrations for each year of residence. Sweden is divided into about 8,500 local census-designated areas called SAMS (Small Areas for Market Statistics) [[Statistics Sweden 2005](#)]. The authors obtained water F concentration data for public water treatment plants and assigned those levels to all subjects who resided in the local SAMS. However, 84% of SAMS contained no water treatment plant so the authors extrapolated from plants in other SAMS located in the same municipality. The reliability of this extrapolation is unknown, and water F can change dramatically even between adjacent water treatment plants, as can be seen in their map of SAMS-level F before extrapolation (their Figure 1A). The nationwide sample of about a half million young adults born between 1985 and 1992 had an average lifetime water fluoride concentration of 0.35 mg/L which is half the level of artificially fluoridated areas of the United States.

The study used linear regression models to assess associations between F exposure and outcomes, examining a wide variety of models, including many sensitivity analyses described as robustness checks. The primary goal was to determine whether an adverse association could be observed between water F and IQ or other neurobehavioral outcomes in Sweden, as has been found in recent studies in other populations [[Bashash 2017](#), [Green 2019](#), [Riddell 2019](#), [Till 2020](#), [Malin 2024](#), [National Toxicology Program 2024](#)]. In contrast, Aggeborn & Öhman concluded that fluoride had a “zero effect on cognitive ability” in their study.

A recent editorial in the *Journal of the American Dental Association (JADA)* by its editor-in-chief, Tim Wright, DDS, cites only the Aggeborn & Öhman study on IQ to support its

conclusion that “The data and results of studies continue to show CWF [Community Water Fluoridation] ... is safe, with no evidence of negative health effects” [[Wright 2024](#)]. Summarizing Aggeborn & Öhman, the editorial says: “Results of a study conducted across Sweden, where there are varying levels of naturally fluoridated water, showed no association between fluoride levels below 1.5 ppm and IQ, math test scores, and taking medications for attention-deficit disorders, depression, or other neurobehavioral outcomes.”

The present review of Aggeborn & Öhman will describe the limitations that likely hampered its ability to detect significant associations and will highlight several of its findings that contradict the claims that it found no evidence of adverse effects on cognitive ability.

The authors were both economics students and conducted their study within an econometric rather than an epidemiological framework. The two fields use similar methods but their terminology and emphases differ. This review will apply an epidemiological and environmental health framework to be consistent with the large majority of research on fluoride’s adverse health effects.

Fluoride cognitive ability effects

Despite the abstract’s claim that it found “zero effect on cognitive ability,” there are, within the 121 combined pages of the main article and appendices, results supporting an adverse effect of fluoride on IQ. Furthermore, in the outcomes that are the most directly relevant to cognitive ability, there was substantial consistency of adverse associations. Out of 90 such models, 84 found reductions in IQ scores or lower achievement levels associated with fluoride in drinking water. Figure 1 displays the results of these models in graphical table format, with numerical regression coefficients and red shading for models with adverse effects and green shading for models showing beneficial effects. All coefficient values have been converted from the scales used in the original tables to the commonly used IQ scale with a mean of 100 and standard deviation of 15 points. The deepness of the color reflects the magnitude of effect. Models with statistically significant results are outlined in black.

Aggeborn & Öhman 2021

Fluoride Associated with Reduced IQ and adverse achievement outcomes

Consistent adverse effect direction:
Out of 90 models, 84 are lower IQ or achievement

Math test scores at age 16y:
All 8 models adverse, 6 statistically significant
IQ-equivalents from -0.3 to -1.8 points per 1 mg/L water F

Outcomes controlled for family and genes:
very large IQ-equivalents from -10.5 to -15.9 per 1 mg/L

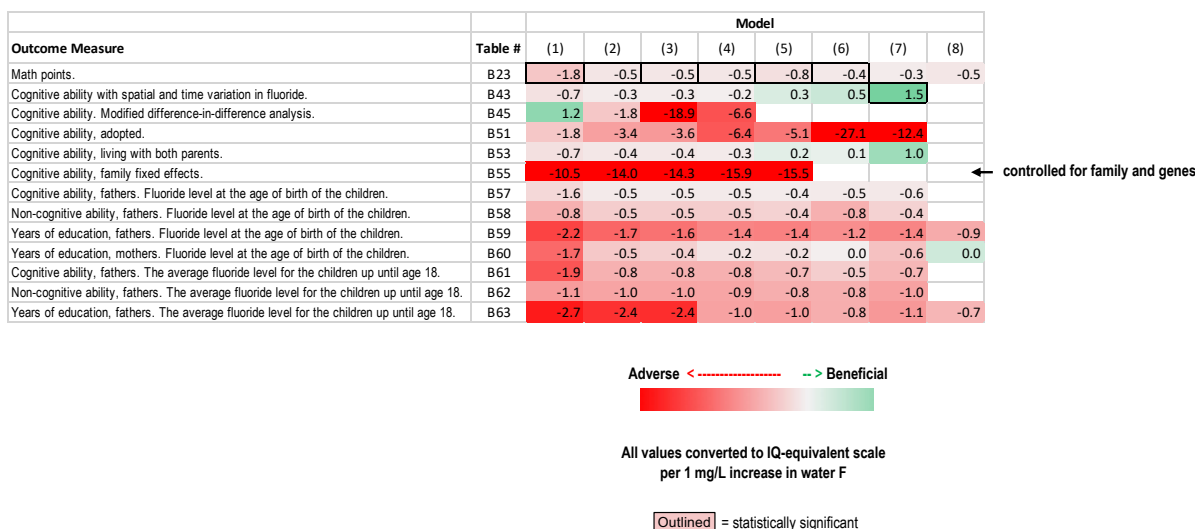


Figure 1. Visual summary of results for outcomes most closely related to cognitive ability.

In Figure 1, the 13 outcomes were chosen as the most relevant to cognitive ability or achievement. Not included are outcomes on dental services utilization and adult income, which would have only indirect associations with child cognitive performance, at best.

In the original paper's tables, most Beta coefficients are standardized with a mean of 0 and a standard deviation of 1. To convert these values to a commonly used IQ scale (mean = 100, SD = 15), they were multiplied by 15. Additionally, all the Beta coefficients in the original tables correspond to an increase in water fluoride exposure of 0.1 mg/L. Since the models used linear regression, and to standardize the exposure increase to 1 mg/L, we applied an additional factor of 10. As a result, the original Beta coefficients were multiplied by a combined factor of 150 to obtain Beta coefficients on an "IQ-equivalent" scale per 1 mg/L increase in lifetime averaged water F concentration.

Unlike most outcomes, Aggeborn & Öhman did not scale the Beta coefficient for the outcome "Math points" to a mean of 0 and SD of 1, but instead retained the raw math test score scale. However, their 2021 published paper does not include the mean, SD, and range of the math test scale to allow conversion to IQ-equivalents. Therefore, it was necessary to look to prior posted versions of their study to find this information. Their jointly written PhD dissertation chapter from 2016 appears to be the most recently available version that contains all this information. Its Table 3 on page 33 lists the mean math test points as 26.18 with SD of 8.57 and the text says the maximum number of points was 45 [Öhman 2016] (p.

33). The assumption that the distribution is roughly normal is supported by the mean score of 26.18 being about half-way between the maximum of 45 and the presumed minimum of 0 points. A history of the Swedish national math tests also suggests their goal was to have a scale that was normally distributed [[Kirkpatrick 1994](#)]. To convert the Beta values in math points in Aggeborn & Öhman 2021 to IQ-equivalent points per 1 mg/L increase in water F the following steps were performed:

- The original Beta value was multiplied by 10 to convert the basis from 0.1 mg/L to 1 mg/L
- Divide the result by the math test SD of 8.57 to get a value in standard deviations
- Multiply the resulting standard deviations by 15 which is the SD for IQ tests to get IQ-equivalent Beta values per 1 mg/L water F

The results for the outcome “Math points” reflect scores on nationwide math tests taken by all 9th graders at age 16 years in Sweden. Aggeborn & Öhman considered the math scores “a fairly good proxy ... for cognitive ability” [[Aggeborn 2021b](#)] (p. 36). All eight models had lower math scores with higher fluoride, with effect magnitudes ranging from -0.3 up to -1.8 IQ-equivalent points per 1 mg/L increase in water F exposure. Six of the eight models were statistically significant. The mean effect size of all eight models is -0.65 IQ-equivalent points per 1 mg/L water F.

Dr. Wright’s editorial incorrectly stated the math scores “showed no association” with “fluoride levels.” While the effect size was small, it may be an underestimate due to bias toward the null from non-differential exposure measurement error, as described below. The authors claim that it was “in economic terms ... a zero-effect” [[Aggeborn 2021b](#)] (p. 49). However, economists and the EPA consider an average effect of just -1 IQ point to result in lifetime earnings losses of about \$20,000 and to be an unacceptable health harm [[Gould 2009](#)]. A recent federal court decision about IQ loss from fluoridation noted, “Reduced IQ poses serious harm. Studies have linked IQ decrements of even one or two points to, e.g., reduced educational attainment, employment status, productivity, and earned wages.” [[Food & Water Watch v EPA 2024](#)] (p. 6).

The outcomes labeled “Cognitive ability” in Figure 1 are based on the military conscription aptitude test, which the authors considered similar to an IQ test. The outcome “Cognitive ability, family fixed effects; Table B55” is noteworthy for its very large adverse effect size in all models, ranging from -10.5 to -15.9 IQ-equivalents per 1 mg/L increase in water F concentration. This outcome is the only one that controls for family influences and genetic factors. It does so by comparing only brothers within the sample, who grew up with the same parent(s) and family environment but may have had different lifetime F exposures if the family moved between SAMS with different F levels in drinking water. By limiting the sample to just these brothers, the analysis ensures that family environment and genetic factors are controlled for. Since family environment and genetics are known to strongly influence IQ, controlling for these factors helps isolate the impact of fluoride exposure, reducing variances that could otherwise obscure fluoride’s effects [[Bouchard 1998](#)]. This may explain why this outcome, “Cognitive ability, family fixed effects,” found much larger adverse associations with F than most of the other outcomes that did not control for family

and genes. The smaller sample size of those who had a brother in the sample may also explain why these models did not reach statistical significance despite the large magnitude of the effects. These models had samples of less than 27,000, while the math test samples that reached statistical significance had sample sizes from about 300,000 to 500,000.

Several of the models provide evidence that not just child IQ, but also parental IQ may be adversely associated with water F, as found in the outcomes in Tables B57-B63. These are outcomes for fathers' IQ score on the conscription aptitude test, the fathers' years of education, the fathers' score on the so-called "non-cognitive" military conscription test, and mothers' years of education. Virtually all models for these seven parent outcomes found lowered test scores or fewer years of education were associated with higher F exposure.

Multiple sources of non-differential exposure measurement error cause bias toward the null ("no effect")

The importance of non-differential exposure measurement error in Aggeborn & Öhman deserves emphasis. Investigations of the attenuation of effect size from random exposure measurement error by Blair et al concluded "relatively small amounts of misclassification can bias relative risks substantially towards the null" [Blair 2007]. For example, an epidemiological study with a typical amount of non-differential exposure measurement error that had a true relative risk of 3.0 would be attenuated so that its observed relative risk would be as small as 1.3, an effect size much less likely to reach statistical significance. Blair et al concluded:

... exposure misclassification probably occurs in nearly every epidemiologic study. For nondifferential misclassification, the type of misclassification most likely in cohort studies, the direction of the bias is largely predictable, that is, a bias of relative risks toward the null. In addition, the magnitude from relatively small amounts of misclassification can be sufficient to lead to an interpretation of no effect. [Blair 2007]

Aggeborn & Öhman's study likely contains substantial F exposure measurement error because 84% of SAMS in Sweden had no water F data, necessitating extrapolation of undetermined reliability. This measurement error is further compounded by the use of average lifetime water fluoride exposure instead of early childhood exposure, which is probably the most relevant period for cognitive development. Exposure during later years (up to age 18-20) may have had little effect on cognitive ability, potentially diluting the F exposure metric and adding more error. Additionally, the study only considered fluoride exposure from drinking water, ignoring other sources such as tea, diet, and dental products. Given that the average water F concentration was only 0.35 mg/L, these other sources could contribute a substantial portion of total fluoride intake. The lack of information on these non-water sources likely introduces further non-differential error into the exposure metric used in the study.

The multiple causes of non-differential F exposure measurement error are likely to result in a relatively large amount of random error in the exposure estimates. This contrasts

with the more precise measures used in the high-quality prospective cohort studies, which typically had individual-level maternal urine F concentrations during pregnancy. Urinary F is an individual-level rather than ecological-level measure. It also reflects total F intake from all sources, not just drinking water. Moreover, maternal urine F measured during pregnancy reflects fetal exposure during the prenatal period, which is likely the most sensitive life stage to fluoride's developmental neurotoxicity.

The consistency of adverse effects among models in Figure 1—sometimes of large magnitude, despite likely attenuation due to exposure measurement error—suggests that this study should not be seen as exonerating fluoride. In fact, it could reasonably be interpreted as supporting the many studies finding fluoride has an adverse effect on cognitive ability.

Other outcomes: adult income and dental health

Aggeborn & Öhman, in addition to studying outcomes of cognitive ability and achievement, also examined associations between lifetime average water F concentration and adult income. They found some significant positive associations. However, adult income is a very indirect measure of IQ, let alone IQ in childhood which is the outcome assessed by nearly all other studies of F neurotoxicity. Many factors besides child IQ can affect adult income, including confounders that were not adjusted for. The authors acknowledge that they don't believe fluoride **increased** their subjects' childhood IQ, subsequently leading to increased adult incomes. They instead theorize that fluoride reduced tooth decay (caries) and that led to higher income in adulthood.

This theory relies on finding that higher fluoride reduced the number of cavities. But as discussed in the section below, the most relevant dental outcome available to Aggeborn & Öhman suggests the number of cavities was not reduced with higher water F, and may have actually increased slightly. Aggeborn & Öhman focused on dental outcomes of questionable or indirect relevance to lifetime caries count. These included (1) the number of dental office visits, (2) the number of dental risk evaluations, and (3) the number of disease preventions billed by dental offices. Such outcome measures are only speculatively related to the lifetime number of cavities, and the direction of the relationship is not obvious either. For example, those people who are very conscientious about their oral health may visit the dentist more often, but instead of their dental visits being a proxy for a greater number of caries, they may have fewer caries than those who visit less often. A more relevant measure of lifetime caries experience was available but Aggeborn & Öhman relegated it to the Appendix and downplayed the finding when it showed no benefit from higher water F concentration, as discussed more fully in the section below.

The authors relied on their finding of what they interpreted as a beneficial effect of F on dental health to support the validity of their water F estimates, saying: "The results both reconfirm the long-established positive effect of fluoride on dental health and provide credibility to the mapping of fluoride to the SAMS districts." However, even if water F had been associated with lower tooth decay rates (it was not, see below) the statement incorporates the logical fallacy: Post hoc ergo propter hoc, if 'B' occurred after 'A' then 'A'

must have caused ‘B’ [Wikipedia 2024]. In the authors’ reasoning, ‘A’ is higher water F exposure and ‘B’ is fewer decayed teeth. They then rely on this false reasoning to argue that ‘B’ (fewer decayed teeth) is evidence that ‘A’ (water F exposure) was measured “credibly” and is suitable for analyzing associations with cognitive outcomes. However, even if higher water F had **caused** lower caries rates, that would only provide a qualitative indication that the authors’ estimates of F exposure were positively associated with true F exposure. It says little about the degree of measurement error in their water F exposure estimates. As described above, there is likely to be a relatively large degree of non-differential F exposure error. The bias toward the null this produces may explain why many of the adverse cognitive effects did not reach statistical significance.

Most relevant dental outcome shows increasing tooth decay (DMFT) with increasing water fluoride, not decreasing

Among the available dental health outcomes was the number of “intact teeth” which is the number of teeth without decay or fillings [Ljung 2019]. Since the normal full adult dentition is 32 permanent teeth, the difference between 32 and the number of intact teeth is the number of decayed, filled, or missing teeth, abbreviated as DMFT. “Intact teeth” is the converse of DMFT. Of all the dental outcome measures available to Aggeborn & Öhman, DMFT (or “intact teeth” count) is the most relevant for assessing the effectiveness of water F against caries. Yet the authors didn’t mention results for “intact teeth” in the main text but relegated it to the last dental outcome in Tables B19 and B21 of the Appendix. Instead of DMFT the authors focused on the following five dental outcomes, reported in Table 3 of the main text:

- rate of dental visits
- rate of dental risk evaluation procedures
- rate of disease prevention procedures
- rate of repair procedures
- rate of root canal procedures

The authors assumed that lower rates of these outcomes indicated better dental health, in particular lower caries rates. But none of these measures is as direct, specific, or accurate a measure of caries history as DMFT (and its corollary “intact teeth”). Also, these five measures represent a single year’s dental health care utilization at age 20 whereas DMFT reflects lifetime cumulative caries experience.

Furthermore, the results for these five dental outcomes (in Aggeborn & Öhman’s Table 3) are from unadjusted models while the results for “intact teeth” and “remaining teeth” in the Appendix are adjusted for a wide range of covariates and fixed effects. Another limitation of the dental outcome data in the main text and in the Appendix was that it was only available at the SAMS group level rather than the individual level, making all analyses ecological in both outcome and exposure.

Almost all the dental outcomes in Table 3 show what the authors consider to be better “dental health” associated with higher water F. But given the lack of adjustment for potential confounders and indirectness of these to the outcome of primary interest, which is DMFT, the dental outcomes “intact teeth” and “remaining teeth” deserve at least as much weight.

Affirmation that “intact teeth” is a good measure of oral health is given by researchers who assessed the measure’s validity while evaluating outcomes available in the Swedish Dental Health Register, the same source of data used by Aggeborn & Öhman. They concluded, “... remaining intact teeth is a simple and very useful measure of oral health ...” [[Ljung 2019](#)].

Yet Aggeborn & Öhman argue that the results for “intact teeth” are not reliable because extraction of wisdom teeth can reduce the “intact teeth” count for reasons other than decay. However, they offer no reason why those with higher F exposure should be more or less likely to have wisdom teeth removed than those with lower F exposure. Therefore, the uncertainty of whether “intact teeth” includes wisdom teeth represents a non-differential measurement error, which will be another source of bias toward null results rather than a cause of spurious overestimate of effects.

All seven models of the association between water F exposure and “intact teeth” in 2013 are negative values, meaning there were fewer intact teeth (and higher DMFT count) with increasing F exposure. This is the opposite of the author’s expected effect and implies water F increased rather than decreased tooth decay. Some of the models were statistically significant. For an increase of 1 mg/L water F, the DMFT increased by about 8%. In absolute terms, this represents about 0.5 greater DMFT per 1 mg/L higher water F.

Another dental outcome, “remaining teeth” count, was less with higher water F in all 14 models, 12 of which were statistically significant (Tables B19 and B21). This again is an adverse effect of water F on caries, not a beneficial effect. Both of these dental outcomes are arguably the most relevant to the effect of water F on caries rates, and both suggest an adverse rather than a beneficial effect.

The authors also evaluated these two dental outcomes for older adults in age groups 40-90 and 60-90 years, with results shown in Table B22. “Remaining teeth” in the 40-90 years group was the only statistically significant result and it was again an adverse rather than beneficial association with water F. The Beta value reflects 4.5% fewer remaining teeth per 1 mg/L increase in water F.

These findings contradict the author’s conclusion in the main text that water F has a beneficial effect on dental outcomes, at least for the dental outcomes that are most directly related to caries rates.

Recent US econometric study of fluoridation and health outcomes in youth and adults: Roberts 2024

A study similar to the Aggeborn & Öhman study was published just a few weeks before Dr. Wright’s editorial [[Roberts 2024](#)]. It is an econometric study of artificial fluoridation in the United States based on a sample of 29 million individuals. The study used longitudinal data on residence at birth and historical county-level fluoridation status records to assess

exposure during the first few years of life and its associations with health, labor, and education outcomes during youth and adulthood. It used a stacked differences-in-differences design to control for potential confounders and birth cohort effects.

The study found statistically significant adverse effects on all outcomes and confirmed them with numerous robustness checks. The outcome most directly related to cognitive ability was high school graduation rates, with results of a robustness check described in this summary:

“... the marginal impacts of fluoride [on high school graduation rate] are concentrated during early childhood (age 0–5), showing that exposure during those years has the largest impact on educational attainment. These results provide strong support for the hypothesis that early fluoride exposure negatively impacts cognitive development.” [Roberts 2024] (p. 11)

In contrast to the Aggeborn & Öhman study’s use of lifetime average F concentration from birth to age 18-20 years as its exposure measure, this robustness check of Roberts evaluated effects of fluoridation exposure starting at different ages, from birth up through first exposure at age 15 years. It found that if fluoridation started at age 5 through 15, there was no effect on high school graduation rates (Fig. 6 in Roberts 2024). But if fluoridation started before age 5 years, the magnitude of the adverse effect increased with younger age of first exposure to a maximum when fluoridation started at birth or existed prior to birth. The same exposure-age-dependent pattern was seen for other outcomes.

With no observable adverse effects from exposures after age 5 years, Roberts’ findings support concerns that Aggeborn & Öhman’s exposure metric that included all years up to age 18-20 would dilute any effects from the most susceptible years. This would bias Aggeborn & Öhman’s results toward the null.

Compared to the Aggeborn & Öhman study, the Robert’s study had several advantages:

- a much larger sample size
- conducted in the United States where there were clear exposure contrasts between artificially fluoridated areas and non-fluoridated areas
- used a primary exposure metric based on just the first five years of life instead of the average over 18-20 years
- did robustness checks examining effects of first exposure to fluoridation at intervals of one year from birth up to age 15 to see whether earlier years were more sensitive to adverse effects than later years
- used a stacked differences-in-differences design that allowed better control of potential confounders and birth cohort effects

CONCLUSION

In conclusion, the Aggeborn & Öhman study does not provide strong reassurance that water F concentrations below 1.5 mg/L are perfectly safe. Math test scores showed consistently adverse associations with water F, most of which were statistically significant.

Many of the other cognitive outcome measures were also in the adverse direction, although they did not reach statistical significance. The multiple sources of non-differential exposure error may explain the lack of statistical significance and may have produced underestimates of true effect sizes.

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