Hibbeln, J. R., Gregory, S., Iles-Caven, Y., Taylor, C., Emond, A., & Golding, J. (2018). Total mercury exposure in early pregnancy has no adverse association with scholastic ability of the offspring particularly if the mother eats fish. Environment International, 116, 108-115. [ENVINT_2017_1791_R1]. https://doi.org/10.1016/j.envint.2018.03.024

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Total mercury exposure in early pregnancy has no adverse association with scholastic ability of the offspring particularly if the mother eats fish

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\textbf{A R T I C L E  I N F O}

Handling editor: Martí Nadal

\textbf{Keywords:}

ALSPAC
Prenatal mercury
Prenatal fish consumption
Reading
Mathematics
Science

\textbf{A B S T R A C T}

There is a public perception that relatively low doses of mercury found in seafood are harmful to the fetal brain but little consistent evidence to support this. In earlier publications we have shown no adverse associations between maternal total blood mercury levels and child behaviour, early development or cognitive function as measured by IQ. However, for IQ the lack of adverse association was conditional upon the mother being a fish eater.

In this paper we analyse further data from the Avon Longitudinal Study of Parents and Children (ALSPAC), this time examining whether prenatal exposure to total mercury is associated with the child’s scholastic abilities in reading, spelling, phoneme awareness, mathematics and science; the number of participants with prenatal mercury and relevant test results varied from 1500 to 2200. Multiple regression was used to assess relationships between prenatal total blood mercury concentrations and 16 different test results, after taking account of a variety of potential confounders; in parallel, logistic regression was used to determine associations with the risk of the child being in the lowest 15% of each score. Analyses were repeated stratifying for fish consumption and sex of the child.

There was no evidence of harm associated with the level of total mercury, provided the mother ate fish during pregnancy. This was particularly true for tests of mathematics and science. We conclude that women should be confident that eating fish in pregnancy is beneficial for their unborn child.

1. Introduction

Very high doses of total mercury in pregnancy have a harmful effect on the development of offspring, with increased risks of cerebral palsy and cognitive impairment (Snyder, 1971). Such deleterious exposures have been found, for example, when spillages of pollutants into water have undergone bioaccumulation by fish and shellfish, with subsequent consumption by the population (such as in Minamata in Japan), or when grain treated with mercury was unintentionally put into the human food chain (such as happened in Iraq) (Amin-Zaki et al., 1976). Such adverse events have understandably raised concerns about all levels of exposure to mercury during pregnancy.

There have been several studies measuring maternal prenatal exposure to low levels of mercury and subsequent child development, with results that are sometimes reported erroneously as causing problems to the offspring (e.g. Myers et al., 2015). Such studies necessitate collecting data during pregnancy and then following the offspring into childhood (and beyond). Using a large population cohort in the UK, we have found that early child development and IQ measured at age 8 years were not affected by the mother’s total mercury level if she ate fish (Golding et al., 2016a, 2016b, 2017).

The most important outcome of mercury exposure from the point of view of the future economic success of a country lies in the ability of its workforce, particularly regarding their literacy and numeracy. However, to our knowledge, only two studies appear to have considered these outcomes: the Seychelles Child Development Study (Davidson...
et al., 2010, 2011) and a study in New Zealand (Gearhart et al., 1995).

The New Zealand study is little known; details of the methodology used are scanty, and it is not clear that all the publications arising from it have been peer-reviewed. The study started in the North Island of New Zealand with a birth survey of 10,970 pregnancies. A small group of women with high hair mercury levels who were relatively high fish consumers (> 3 times per week) were identified and each was matched with three controls of differing mercury levels and fish consumption. The offspring of 57 matched sets were followed up at 6 years of age and given a battery of 26 tests which included reading and mathematics. Although the authors did not give the results for each test, they did claim that none showed an association between maternal mercury level and outcome. However, if an outlier of over 50 ppm higher than the rest of the cohort was removed, there were six of the outcomes that were associated at the 10% level, but it is unclear which test results were implicated (Crump et al., 1998).

In comparison, the longitudinal study undertaken in the Seychelles is very well documented and well designed. A study of 643 unselected children in this cohort had results from their national standardised examinations at ages 9 and 17 years linked to their mother's prenatal mercury level (as estimated from maternal hair). The subjects of the examinations undertaken at 9 years of age comprised English, French, Creole, mathematics, science and social studies; at 17 years geography and history were added but Creole and social studies were excluded. None of these outcomes showed any adverse relationship with prenatal mercury exposure, and there was a beneficial association with one of the math tests at 17 years (Davidson et al., 2010, 2011).

The study in the Seychelles was undertaken because the population of the archipelago consumed a large quantity of fish on average and therefore, if there were adverse effects of such a diet, particularly regarding the consequent increased levels of mercury, this study should have sufficient statistical power to reveal it. However, despite a large variety of measures over the years, there have been no significant adverse outcomes attributable to mercury. Indeed comparison of the scholastic abilities of the Seychelles children with other countries in Africa and the Indian Ocean shows them to be among the most advanced in ability (Leste and Davidson, 2004).

Nevertheless, it is important that similar studies be undertaken in areas where less fish is consumed, and where any adverse effects of prenatal mercury exposure may be masked by beneficial effects of fish but revealed in the offspring of women who have not eaten fish. We therefore used the comprehensive data collected on a population of pregnant women in the UK in 1991–2, whose total blood mercury level is available for the first half of pregnancy and whose offspring have been followed throughout childhood and adolescence.

2. Material and methods

2.1. The study design

The Avon Longitudinal Study of Parents and Children (ALSPAC) aimed to study all births to women resident in a geographic area (Avon) in the UK, whose expected date of delivery lay between the 1st April 1991 and 31st December 1992. It recruited 14,541 women who completed at least one questionnaire. Of these initial pregnancies, there was a total of 14,676 fetuses, resulting in 14,062 live births and 13,988 children who were alive at one year of age. The study's stated aims were therefore used the comprehensive data collected on a population of pregnant women in the UK in 1991–2, whose total blood mercury level is available for the first half of pregnancy and whose offspring have been followed throughout childhood and adolescence.

The pregnant woman was sent a questionnaire at 32 weeks gestation, which included a food frequency questionnaire. This enquired about the frequency with which she ate white fish and oily fish. We used these two questions to identify women who ate no fish, as previously described (Golding et al., 2016a, 2016b, 2017).

2.3. The outcome measures

A total of 15 different scholastic tests have been used in this paper, covering spelling, reading, phoneme understanding, mathematics and science; 11 of these tests were administered in the ALSPAC clinics in a one-to-one situation, and the three mathematics reasoning and the one scientific reasoning tests were administered in a school setting. Details of the tests used are described in the Supplementary Information.

2.4. The analyses

Ways in which the total blood mercury varies with demographic and lifestyle factors is shown in Appendix Table 1. Because of these and other associations we therefore took account of maternal age at the child's birth, parity of the mother at the birth (no. previous births: 0 v 1+); maternal education level (in five levels of achievement); housing tenure (owner occupied; public housing; other rented); level of household crowding (no. persons in the household divided by the number of living rooms and bedrooms); no. of stressful life events during the first half of pregnancy; whether the mother smoked at mid-pregnancy (yes; no); whether any alcohol was drunk mid-pregnancy (yes; no); whether the infant was breast fed (yes; no); and the family adversity index (a score comprised of a number of adverse features present during pregnancy including presence of maternal depression and anxiety). Because the educational ability of the child depends on the length of time he/she has attended school, we took account of that rather than age when tested.

We mainly employed regression analyses, treating both mercury and the scholastic measures as continuous variables; results for the adjusted and unadjusted outcomes are presented as β coefficients (i.e. the change in value per SD of total mercury). The analyses were repeated according to whether the mother had eaten fish or not prenatally, and whether the child was a boy or girl.

To determine whether the children who had low results on the scholastic tests were at special risk, we used logistic regression to...
Table 1
The basic data for the spelling, reading and phoneme tests for (i) all children; (ii) children whose mothers ate fish in pregnancy, and (iii) children whose mothers ate no fish in pregnancy.

| Outcome Measure | All children | Mother ate fish | Mother ate no fish |
|-----------------|--------------|-----------------|-------------------|
|                 | N | Mean (95% CI) | N | Mean (95% CI) | N | Mean (95% CI) |
| Spelling 7 year | 2192 | 7.7 (7.5, 7.9) | 1815 | 7.9 (7.7, 8.1) | 268 | 7.0 (6.5, 7.6) |
| Spelling 9 year | 2117 | 10.3 (10.1, 10.4) | 1748 | 10.4 (10.2, 10.5) | 253 | 9.4 (9.0, 9.8) |
| Word reading test 7 year | 2224 | 28.2 (27.8, 28.6) | 1842 | 28.5 (28.1, 28.9) | 271 | 27.0 (25.8, 28.2) |
| Word reading test 9 year | 2121 | 7.6 (7.5, 7.7) | 1752 | 7.7 (7.5, 7.8) | 253 | 7.2 (6.9, 7.6) |
| Reading comprehension 9 year | 2079 | 100.8 (100.3, 101.3) | 1724 | 101.3 (100.8, 101.9) | 242 | 99.1 (97.5, 100.7) |
| Reading speed 9 year | 2073 | 105.8 (105.3, 106.3) | 1721 | 106.3 (105.7, 106.8) | 240 | 104.8 (103.2, 106.4) |
| Reading accuracy 9 year | 2079 | 104.7 (104.1, 105.3) | 1724 | 105.2 (104.6, 105.9) | 242 | 102.8 (100.9, 104.7) |
| Reading fluency 13 year | 1574 | 82.7 (82.2, 83.2) | 1313 | 83.0 (82.5, 83.6) | 182 | 81.4 (79.8, 83.1) |
| Phoneme tests 7 year | 2223 | 19.9 (19.5, 20.3) | 1842 | 20.2 (19.8, 20.6) | 271 | 18.6 (17.4, 19.8) |
| Phoneme tests 9 year | 2109 | 5.3 (5.2, 5.4) | 1743 | 5.4 (5.3, 5.5) | 251 | 5.0 (4.7, 5.3) |
| Arithmetic Age 8 | 2067 | 10.6 (10.4, 10.8) | 1732 | 10.6 (10.4, 10.8) | 234 | 10.7 (10.2, 11.2) |
| Mathematics reasoning SY4 | 1212 | 11.0 (10.9, 11.2) | 919 | 11.2 (11.0, 11.4) | 167 | 10.6 (10.1, 11.2) |
| Mathematics reasoning SY6 | 2041 | 19.4 (19.0, 19.7) | 1567 | 19.9 (19.6, 20.3) | 275 | 18.0 (17.2, 18.8) |
| Mathematics reasoning SY8 | 896 | 23.3 (22.9, 23.8) | 778 | 23.9 (23.4, 24.4) | 118 | 21.5 (20.0, 23.0) |
| Scientific reasoning SY6 | 2016 | 6.0 (5.9, 6.1) | 1537 | 6.3 (6.1, 6.4) | 281 | 5.4 (5.1, 5.7) |

Table 2A
Unadjusted and adjusted* associations of prenatal total blood mercury with measures of scholastic ability using multiple regression.

| Outcome Measure | Unadjusted | Adjusted |
|-----------------|------------|----------|
|                 | N | β (95% CI) | P | N | β (95% CI) | P |
| Spelling 7 years | 2192 | +0.31 (+0.14, +0.47) | < 0.001 | 1863 | +0.02 (−0.16, +0.20) | 0.833 |
| Spelling 9 years | 2117 | +0.21 (+0.08, +0.35) | 0.002 | 1794 | −0.05 (−0.20,0.10) | 0.494 |
| Word reading test 7 years | 2224 | +0.81 (+0.46, +1.15) | < 0.001 | 1888 | +0.09 (−0.30, +0.48) | 0.646 |
| Word reading test 9 years | 2121 | +0.19 (+0.09, +0.29) | < 0.001 | 1797 | −0.01 (−0.11, +0.10) | 0.895 |
| Reading comprehension 9 years | 2079 | +0.71 (+0.41, +1.01) | < 0.001 | 1765 | −0.16 (−1.48, +1.15) | 0.307 |
| Reading speed 9 years | 2073 | +2.65 (+1.62, +3.68) | < 0.0001 | 1761 | +0.31 (−0.80, +1.42) | 0.588 |
| Reading accuracy 9 years | 2079 | +1.54 (+0.75, +2.33) | < 0.0001 | 1765 | −0.28 (−1.13, +0.57) | 0.518 |
| Reading fluency 13 years | 1574 | +0.85 (+0.40, +1.29) | < 0.001 | 1363 | +0.22 (−0.26, +0.71) | 0.362 |
| Phoneme tests 7 years | 2223 | +0.62 (+0.26, +0.97) | 0.001 | 1888 | +0.10 (−0.29, +0.50) | 0.606 |
| Phoneme tests 9 years | 2109 | +0.14 (+0.05, +0.24) | 0.004 | 1788 | −0.00 (−0.11, +0.10) | 0.937 |
| Arithmetic 8 years | 2067 | +0.28 (+0.12, +0.44) | 0.001 | 1762 | +0.03 (−0.15, +0.21) | 0.716 |
| Mathematics reasoning SY4 | 1213 | +0.41 (+0.24, +0.58) | < 0.001 | 943 | +0.09 (−0.11, +0.29) | 0.392 |
| Mathematics reasoning SY6 | 2041 | +0.86 (+0.58, +1.13) | < 0.001 | 1578 | +0.06 (−0.26, +0.38) | 0.721 |
| Mathematics reasoning SY8 | 986 | +1.14 (+0.70, +1.57) | < 0.001 | 779 | +0.29 (−0.17, +0.75) | 0.223 |
| Scientific reasoning SY6 | 2016 | +0.36 (+0.26, +0.47) | < 0.0001 | 1585 | +0.12 (−0.00, +0.27) | 0.054 |

SY = School year.
Regression coefficients of each test represent change in score per standard deviation (SD) of prenatal mercury.

* Adjusted for month of birth relative to school year, sex of child, maternal age, parity, maternal education, family adversity index, housing tenure, household crowding, prenatal life events, prenatal smoking, prenatal alcohol.
assess the variation of total mercury levels with the binary outcome concerning whether the child was in the lowest 15% of the relevant distribution. Both sets of analyses took account of the 11 possible confounders listed above. The analyses were carried out using STATA version 14 (StataCorp LLC). Since we do not consider that the data are likely to be missing at random, we have not included analyses concerning missingness.

The total numbers of children for whom there were both maternal prenatal total mercury levels and an academic outcome vary from 1569 to 2224. Subdividing by whether the mother ate fish in pregnancy resulted in minimum numbers of 120–121 for the non-fish consuming population. Consequently, for the regression analyses the statistical power for these subdivisions ranges from being 80% sure of a statistically significant result from approximately 0.18 SDs for the fish eaters, and 0.27 SDs for the non-fish eaters.

3. Results

The basic statistics for each of the outcome measures are given in Table 1. This table also shows the available data for children whose mothers ate fish in pregnancy and those that did not. These unadjusted data indicate that, except for arithmetic, each test score is higher for children whose mothers ate fish compared with the results for the children whose mothers ate no fish.

3.1. Overall association of prenatal total mercury levels with academic outcomes in the offspring

The unadjusted data of Table 2A provide the regression coefficients of each test per standard deviation (SD) of prenatal mercury. There is a significant positive association for each of the 15 unadjusted educational outcomes with the maternal total mercury level. After adjustment, however, there were no significant associations, although most of the regression coefficients remained positive, and the relationship with scientific understanding was weakly significant ($P = 0.054$). When the children with the poorer 15% of the test results were examined using logistic regression, there were similar findings – there were apparently protective effects with increasing total mercury levels which became non-significant on adjustment (Table 2B).

3.2. Comparison of fish and non-fish eaters

Regressing each of the academic outcomes on maternal total mercury levels after adjustment (Table 3A) demonstrated no significant associations for either the children of the fish eaters or of the non-fish eaters. However, there was evidence of a significant difference between the regression coefficients for the science reasoning in school year 6 and the mathematics comprehension tests in school years 6 and 8 (as illustrated by comparison of the confidence intervals between the associations between mercury and outcome among the fish and non-fish eaters). These showed evidence that the maternal mercury level was associated negatively with the results on these tests if the mother had not eaten fish in pregnancy - in contrast to the children whose mothers had eaten fish for whom there were positive associations with total mercury.

Similarly, when the lowest 15% of each score were considered, after adjustment (Table 3B) there were no significant associations, but there was, again, evidence of an interaction between results contingent upon...
the fish-eating of the mother prenatally. For example, the child of the fish eater was less likely to be in the lowest 15% of mathematics in year 6, and of science reasoning in year 6, whereas the child of the non-fish eater was more at risk of such outcomes.

To determine whether the linear relationships analysed were masking threshold effects, the data were broken down into quintiles for each test and the results were recalculated. The data from this are shown in Table 3A. In all cases, the results were similar to those shown for quintiles 1 and 5.

### 3.3. Sex differences

All analyses were repeated for boys and girls separately, but no differences were statistically significant (data not shown).

### 4. Discussion

This study, which is the largest single population study to date, has emulated the results from the Seychelles (Davidson et al., 2010, 2011) by not being able to demonstrate any adverse scholastic test results with increasing prenatal total mercury levels. However, we have shown different associations between specific tests of mathematical and scientific understanding when the mother eats fish compared with those who do not.

To our knowledge no studies have looked at interactions of prenatal total mercury levels with maternal fish consumption apart from our own study of the child’s IQ (Golding et al., 2017), and a similar study of cognitive function in the INMA study in Spain (Llop et al., 2016). Both showed a similar interaction, with significant differences between the positive association when the mother was a fish eater and a more negative association when she did not consume fish. No other studies have assessed possible interactions with scholastic ability. It is important that our finding of interactions specific to mathematics and scientific understanding be assessed in other studies.

We have concentrated on tests of mathematical and science reasoning designed particularly for the ALSPAC study and administered in schools. The results of these tests were used rather than the national tests as they were specifically designed to test mathematical reasoning. It has been shown that the maths tests, together with knowledge of arithmetic (as assessed in year 4), make independent contributions to children’s achievement in mathematics in the national tests. Consequently, we chose to use both mental arithmetic and the mathematical reasoning tests (Nunes et al., 2009). Similarly, the science reasoning test was shown to be strongly predictive of the national science tests later in the child’s school life (Bryant et al., 2015).

If there are differences between the children of fish and non-fish eaters, the key question concerns the possible causes of such an interaction. There are several possibilities. One concerns interactions with other features of the diet. We have shown elsewhere (Golding et al., 2013) that some dietary factors appear to be negative predictors of total blood mercury in our study population, including white bread, whole milk, sugar, French fries, baked beans, and meat pies/pasties. Consistent with these findings, Bates et al. (2007) reported negative associations between total blood mercury and white bread, whole milk, sugar, and French fries in a study of 1216 British adults 19–64 years of age.
Table 3B

| Outcome Measure | Mother ate fish (N OR (95% CI)) | P | Mother ate no fish (N OR (95% CI)) | P |
|-----------------|---------------------------------|---|-----------------------------------|---|
| Spelling 7 year | 1651 0.96 (0.83, 1.11) 0.569 229 0.89 (0.52, 1.50) 0.652 |
| Word reading test 7 year | 1675 0.98 (0.85, 1.14) 0.819 241 1.12 (0.68, 1.83) 0.654 |
| Reading comprehension 9 year | 1583 1.05 (0.90, 1.22) 0.550 210 1.06 (0.61, 1.85) 0.838 |
| Reading speed 9 year | 1580 0.98 (0.84, 1.13) 0.746 209 1.17 (0.69, 2.01) 0.559 |
| Reading accuracy 9 year | 1583 1.02 (0.88, 1.17) 0.834 210 0.81 (0.46, 1.43) 0.471 |
| Reading fluency 13 year | 1218 1.04 (0.90, 1.21) 0.574 161 0.81 (0.47, 1.41) 0.459 |
| Phoneme tests 7 year | 1675 0.98 (0.86, 1.13) 0.790 241 1.18 (0.76, 1.85) 0.461 |
| Arithmetic 8 years | 1578 1.01 (0.87, 1.17) 0.877 208 0.81 (0.40, 1.65) 0.558 |
| Mathematics reasoning SY4 | 804 0.81 (0.62, 1.07) 0.139 136 1.38 (0.60, 3.13) 0.447 |
| SY6 | 1377 0.97 (0.82, 1.15) 0.720 223 1.59 (0.96, 2.62) 0.071 |
| SY8 | 686 0.87 (0.66, 1.15) 0.528 102 0.79 (0.44, 1.44) 0.450 |
| Scientific reasoning SY6 | 1348 0.91 (0.73, 1.12) 0.362 229 1.55 (0.95, 2.53) 0.079 |

SY = School year.

Odds ratios for each test represent odds of being in the lowest 15% of the test score.

* Significant difference between children of mothers who ate fish and those whose mothers did not.

* Adjusted for month of birth relative to school year, sex of child, maternal age, parity, maternal education, family adversity index, housing tenure, household crowding, prenatal life events, prenatal smoking, prenatal alcohol.

Age. Other possible explanations relate to the various beneficial components of fish including iodine, omega-3 fatty acids, choline and vitamin D, all of which have been shown to be associated with improved cognitive abilities (Darling et al., 2017).

4.1. Strengths and weaknesses

Mercury levels were obtained from blood collected from the mother in the first trimester of pregnancy. This is more appropriate than mercury exposure based on the assumptions from intake of diet alone (e.g. the Norwegian Mother and Child Cohort Study: Vejrup et al., 2014). Nevertheless, it should be noted that the measures may not be representative of those found later in pregnancy, e.g. those obtained from maternal hair, cord blood or placenta.

All scholastic test results were obtained without knowledge of the level of exposure of the fetus to mercury or of whether the mother ate fish or not. Many of the tests were designed specifically to test different aspects of the child’s ability.

The seafood eaten in the study area does not include sea mammals. This is likely to be important as sea mammals, such as whale, have far fewer beneficial nutrients than found in fish, and more pollutants such as PCBs; consequently studies including sea mammals such as that from the Faroes (Weihe et al., 1996) may be less likely to show any beneficial associations of mercury from seafood consumption.

In comparison with other studies, the sample we utilised was large. Nevertheless, as with all longitudinal studies, there was notable attrition among those where attendance at a clinic was necessary to obtain the results. We have shown elsewhere that this causes bias, with excess drop-out from young parents, smokers, those of lower educational achievement, and those living in rented accommodation (Gregg et al., 2005). However, for the tests undertaken in schools (maths, spelling and science), all children in a class were included, and the biases were more concerned with whether the child’s family had left the study area and/or the attitude of the teacher. The fact that the results were broadly similar regardless of type of test adds validity to the findings of no adverse effects of maternal total mercury levels. The major disadvantage of the study design lies in the relatively small numbers of children in the study whose mothers did not eat fish during pregnancy.

5. Conclusion

The data analysed in this study have given no indication that there were any adverse effects of prenatal maternal total mercury levels on the scholastic abilities of the offspring. However, there was a suggestion that children whose mothers denied eating fish were less likely to do well in mathematics and scientific reasoning with increasing exposure to mercury than the child whose mother had eaten fish in pregnancy. Replication in other cohorts is needed, but meanwhile the recommendation to eat at least two portions of fish per week should be supported.

Acknowledgements

We are extremely grateful to all the families who took part in this study, the midwives for their help in recruiting them, and the whole ALSPAC team, which includes interviewers, computer and laboratory technicians, clerical workers, research scientists, volunteers, managers, receptionists and nurses.

Funding statement

The UK Medical Research Council and the Wellcome Trust (Grant ref.: 102215/2/13/2) and the University of Bristol currently provide core support for ALSPAC. The assays of the maternal blood samples were carried out at the Centers for Disease Control and Prevention (CDC) with funding from the National Oceanic & Atmospheric Administration (NOAA). The statistical analyses were carried out in Bristol with support from the Intramural Research Program of the National Institute of Alcohol Abuse & Alcoholism (NIAAA) of the National Institutes of Health. CMT was supported by a Wellcome Trust Career Re-Entry Fellowship (Grant ref.: 104077/Z/14/Z). The funders were not involved in the study design nor in the collection, analysis and interpretation of the data and the researchers worked independently from the funders. The findings and conclusions in this report are those of the authors and do not necessarily represent the views of the CDC or the NIH.

Competing financial interests

The authors have no competing interests.
Appendix A

Appendix Table 1
Mean and median total blood mercury (pg/l) in pregnancy for demographic variables

| Maternal age (years) | N   | Median | Mean (SD) | R² (%) |
|----------------------|-----|--------|-----------|--------|
| < 20                 | 239 | 1.34   | 1.50 (0.74) |        |
| 20-24                | 813 | 1.57   | 1.79 (1.00) |        |
| 25-29                | 1531| 1.90   | 2.11 (1.11) |        |
| 30-34                | 1019| 2.12   | 2.29 (1.07) |        |
| 35+                  | 311 | 2.18   | 2.44 (1.21) | 4.87   |

| Parity (n)           | N   | Median | Mean (SD) | R² (%) |
|----------------------|-----|--------|-----------|--------|
| 0                    | 1622| 1.97   | 2.22 (1.24) |        |
| 1                    | 1249| 1.86   | 2.02 (0.95) |        |
| 2                    | 540 | 1.86   | 2.02 (0.90) |        |
| 3+                   | 239 | 1.68   | 1.86 (0.95) | 0.96   |

| Maternal education   | N   | Median | Mean (SD) | R² (%) |
|----------------------|-----|--------|-----------|--------|
| A (lowest)           | 673 | 1.54   | 1.75 (0.95) |        |
| B                    | 335 | 1.73   | 1.89 (1.01) |        |
| C                    | 1155| 1.88   | 2.03 (1.03) |        |
| D                    | 802 | 2.05   | 2.29 (1.16) |        |
| E (highest)          | 547 | 2.40   | 2.60 (1.18) | 5.98   |

| Smoked mid-pregnancy | N   | Median | Mean (SD) | R² (%) |
|----------------------|-----|--------|-----------|--------|
| Yes                  | 752 | 1.61   | 1.83 (0.97) |        |
| No                   | 2968| 1.96   | 2.16 (1.11) | 1.50   |

| Alcohol consumption (units) mid pregnancy | N   | Median | Mean (SD) | R² (%) |
|-------------------------------------------|-----|--------|-----------|--------|
| Not at all                                 | 1789| 1.76   | 1.96 (1.05) |        |
| < 1/week                                   | 1228| 1.95   | 2.17 (1.07) |        |
| 1-6 / week                                 | 550 | 2.09   | 2.28 (1.06) |        |
| 1+ / day                                   | 65  | 1.94   | 2.39 (1.56) | 1.44   |

| Housing tenure                           | N   | Median | Mean (SD) | R² (%) |
|-------------------------------------------|-----|--------|-----------|--------|
| Owned/mortgaged                          | 2695| 2.00   | 2.20 (1.10) |        |
| Council rented (public housing) Other    | 570 | 1.52   | 1.71 (0.96) |        |
|                                           | 444 | 1.79   | 2.02 (1.18) | 2.61   |

Appendix Table 2
Mean (SE) maths and science test scores according to prenatal total mercury levels divided at the 20th, 40th, 60th, 80th, and 90th centiles

| Prenatal total blood mercury (g/l) | N   | Math SY6 | Science SY6 |
|------------------------------------|-----|----------|-------------|
| All children                       |     |          |             |
| < 1.28                             | 388 | 18.04 (0.35) | 21.64 (0.59) | 5.43 (0.12) |
| 1.28-1.68                          | 432 | 18.82 (0.35) | 22.19 (0.55) | 5.80 (0.13) |
| 1.69-2.10                          | 393 | 19.52 (0.36) | 22.68 (0.52) | 5.99 (0.14) |
| 2.11-2.74                          | 409 | 19.53 (0.36) | 24.50 (0.47) | 6.28 (0.13) |
| 2.75-3.39                          | 217 | 20.16 (0.47) | 25.25 (0.68) | 6.21 (0.17) |
| > 3.39                             | 202 | 21.49 (0.49) | 25.80 (0.62) | 6.91 (0.18) |
| P for trend                         | < 0.0001 |          | < 0.0001   | < 0.0001 |

Children whose mothers ate fish

| Prenatal total blood mercury (g/l) | N   | Math SY6 | Science SY6 |
|------------------------------------|-----|----------|-------------|
| < 1.28                             | 206 | 18.17 (0.49) | 22.57 (0.75) | 5.71 (0.17) |
| 1.28-1.68                          | 309 | 19.45 (0.40) | 23.08 (0.60) | 6.07 (0.14) |
| 1.69-2.10                          | 329 | 20.04 (0.38) | 22.88 (0.58) | 6.13 (0.15) |
| 2.11-2.74                          | 358 | 19.94 (0.38) | 24.41 (0.51) | 6.42 (0.14) |
| 2.75-3.39                          | 188 | 20.51 (0.48) | 25.59 (0.68) | 6.29 (0.18) |
| > 3.39                             | 177 | 21.86 (0.52) | 25.89 (0.64) | 7.11 (0.19) |
| P for trend                         | < 0.0001 |          | < 0.0001   | < 0.0001 |

(continued on next page)
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Appendix Table 2 (continued)

| Prenatal total blood mercury (μg/l) | N | Test score (mean (SE)) |
|-----------------------------------|---|------------------------|
|                                   |   | Maths SY6 | Maths SY8 | Science SY6 |
| < 1.28                            | 128 | 18.42 (0.61) | 21.19 (1.18) | 5.30 (0.20) |
| 1.28-1.68                         | 69  | 18.57 (0.87) | 19.52 (1.65) | 5.79 (0.34) |
| 1.69-2.10                         | 34  | 16.47 (1.26) | 22.71 (1.53) | 5.06 (0.52) |
| 2.11-2.74                         | 24  | 17.25 (1.13) | 23.42 (1.84) | 5.45 (0.50) |
| 2.75-3.39                         | 10  | 16.80 (2.73) | 26.25 (1.03) | 4.73 (0.92) |
| > 3.39                            | 10  | 16.90 (2.42) | 29.00 (3.00) | 5.30 (0.87) |
| P for trend                        |    | 0.646      | 0.308     | 0.677     |

SY, school year.

Appendix B. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.envint.2018.03.024.

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