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Maternal Fiber Intake During Pregnancy and Development of Attention-Deficit/Hyperactivity Disorder Symptoms Across Childhood: The Norwegian Mother, Father, and Child Cohort Study

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ABSTRACT

BACKGROUND: Epidemiological studies suggest that maternal diet quality during pregnancy may influence the risk of neurodevelopmental disorders in offspring. Here, we investigated associations between maternal intake of dietary fiber and attention-deficit/hyperactivity disorder (ADHD) symptoms in early childhood.

METHODS: We used longitudinal data of up to 21,852 mother-father-child trios (49.2% female offspring) from MoBa (the Norwegian Mother, Father, and Child Cohort Study). The relationships between maternal fiber intake during pregnancy and offspring ADHD symptoms at ages 3, 5, and 8 years were examined using 1) multivariate regression (overall levels of ADHD symptoms), 2) latent class analysis (subclasses of ADHD symptoms by sex at each age), and 3) latent growth curves (longitudinal change in offspring ADHD symptoms). Covariates were ADHD polygenic scores in child and parents, total energy intake and energy-adjusted sugar intake, parental ages at birth of the child, and sociodemographic factors.

RESULTS: Higher maternal prenatal fiber intake was associated with lower offspring ADHD symptom scores at all ages (B_{age3} = −0.14 [95% CI, −0.18 to −0.10]; B_{age5} = −0.14 [95% CI, −0.19 to −0.09]; B_{age8} = −0.14 [95% CI, −0.20 to −0.09]). Of the derived low/middle/high subclasses of ADHD symptoms, fiber was associated with lower risk of belonging to the middle subclass for boys and girls and to the high subclass for girls only (middle: odds $ratio_{boys}$ 0.91 [95% CI, 0.86 to 0.97]/odds $ratio_{girls}$ 0.86 [95% CI, 0.81 to 0.91]; high: odds $ratio_{girls}$ 0.82 [95% CI, 0.72 to 0.94]). Maternal fiber intake and rate of change in child ADHD symptoms across ages were not associated.

CONCLUSIONS: Low prenatal maternal fiber intake may increase symptom levels of ADHD in offspring during childhood, independently of genetic predisposition to ADHD, unhealthy dietary exposures, and sociodemographic factors.

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Attention-deficit/hyperactivity disorder (ADHD) is among the most prevalent childhood-onset neurodevelopmental conditions, often persisting throughout life and affecting an individual's development and functioning (1–5). ADHD is associated with significant socioeconomic factors, such as the individual's education (6) and occupation (7), as well as risk of co-occurring somatic (8–10) and psychiatric (11) disorders and premature death (12,13).

ADHD is a categorical construct that is increasingly being understood as a lifelong condition (1), with ADHD symptoms being continuously distributed in the general population and with ADHD diagnosis reflecting an extreme end of that distribution (14,15). Most individuals show a decline in ADHD symptom levels over time during childhood and adolescence (1,16) in addition to different levels and distribution of ADHD symptoms across early to middle childhood (17,18). A previous study has shown that different patterns of ADHD symptoms trajectories derived as latent subclasses may be a useful way to examine ADHD development (19).

Both genetic and environmental factors contribute to the development and persistence of ADHD symptoms (16,20–23), and understanding the role of environmental factors can aid in improving quality of life, as these factors are potentially modifiable. Because intrauterine exposures may play a critical role in offspring brain development (24), evaluating maternal lifestyle during pregnancy is of interest in neurodevelopmental disorders such as ADHD (25). A large body of epidemiological studies has shown that maternal diet quality during pregnancy,

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typically captured by fiber intake (26–30), is associated with offspring ADHD symptoms and diagnosis (31,32). However, how maternal fiber intake during pregnancy may influence levels of ADHD symptoms, patterns of ADHD symptom trajectories, or change in ADHD symptom levels across early childhood has not been studied.

Fiber is a prebiotic involved in modulating the composition and function of gut microbiota, which in turn is implicated in health maintenance (33,34). Previous studies have suggested that the maternal gut microbiome plays an important role in offspring neurodevelopment during pregnancy (35–38). Prenatal maternal fiber intake has been linked to offspring neurocognitive functions via short-chain fatty acids, and the perinatal supplementation of short-chain fatty acids may be used to improve child health (36). There is also an increasing number of studies that suggest an association between the gut microbiome and ADHD, although their results are heterogeneous, with inconsistent conclusions (39–44). Nonetheless, current research marks the prospect of prebiotics having a potentially beneficial effect on neurological and mental health, including ADHD (45–49). Fiber intake may have both short- and long-term effects on gut microbiota, but less is known about the long-term effects of fiber in the maternal prenatal diet on offspring neurodevelopment (50).

Epidemiological studies that have examined associations between gut microbiota and neurodevelopmental outcomes have often used a cross-sectional design (51–54) and do not include genetic data. Therefore, these studies are vulnerable to confounding by gene-environment correlation, especially in its passive form because parents not only pass their genetics on to their offspring but also create the family environment (54). Furthermore, it has been reported that several environmental exposures considered to be risk factors for neurodevelopmental disorders in offspring show correlation with genetics of parents (55). Because of the pervasive effects of genetics on environmental experiences, it is essential to take genetics into account to adequately assess the effects of most environmental factors (54). In addition, it is important to consider the dynamic nature of ADHD symptoms when studying the condition so that attained knowledge can be applied for the development of lifelong solutions. Large-scale longitudinal analyses that control for genetics together with other confounders (such as, for example, socioeconomic status) as well as the dynamic nature of ADHD symptoms are lacking.

Drawing on the data from a prospective population-based pregnancy cohort, we explored the association of maternal fiber intake during pregnancy with the manifestation and course of ADHD symptoms in children ages 3 to 8 years, accounting for sociodemographic factors and participants' genetic propensity for ADHD. We examined the associations of prenatal maternal fiber intake with offspring 1) overall levels of ADHD symptoms, 2) levels of ADHD symptoms differentiated into subclasses, and 3) longitudinal change in ADHD symptoms from ages 3 to 8.

METHODS AND MATERIALS

Sample

These analyses are based on data from MoBa (the Norwegian Mother, Father, and Child Cohort Study) and the Medical Birth Registry of Norway. MoBa is a population-based pregnancy cohort study conducted by the Norwegian Institute of Public Health. Participants were recruited from all over Norway from 1999 to 2008 (56). Women consented to participation in 41% of the pregnancies. The cohort now includes 114,500 children, 95,200 mothers, and 75,200 fathers. This study is based on version 12 of the quality-assured data files released for research in January 2019. Data from MoBa are routinely linked to the Medical Birth Registry of Norway, a national health registry that contains information about all births in Norway since 1967 (57). Blood samples were obtained from both parents during pregnancy and from mothers and children (umbilical cord) at birth (58). The genotypic data were obtained through MoBaPsychGen pipeline version 1 (59). This study was approved by the Regional Committee for Medical Research Ethics (2015/2055), and the STROBE (Strengthening the Reporting of Observational Studies in Epidemiology) criteria were followed (60).

Our study sample consisted of up to 21,852 mother-father-child trios (children born from 2002 to 2009) with information on maternal diet, including fiber intake during pregnancy; behavioral phenotypes when the offspring was 3, 5, and/or 8 years of age; and available genotype data from any member of the mother-father-child trio. We excluded participants if they met one or more of the following criteria: twin/triplet births (4.0%); not participating at 3, 5, and/or 8 years of age (36.7%); unlikely maternal daily energy intake (<0.25 percentile/900 kcal or >99.75 percentile/6000 kcal) (0.2%); total daily fiber intake during pregnancy (<0.25 percentile/8 g or >99.75 percentile/85 g) (0.1%); offspring not born at full term (gestational age <7 or >42 weeks of pregnancy) (2.8%); and no genotype data (36.8%) (Figure 1). All participants were of European ancestry.

Maternal Prenatal Diet

Maternal diet was assessed using a Food Frequency Questionnaire filled out by pregnant women around week 22 of their pregnancy. The questionnaire covered habitual diet during the first half of the pregnancy (61). The MoBa Food Frequency Questionnaire has been found to provide valid estimates and rank pregnant women according to dietary intake of foods and nutrients (61,62). The total fiber intake has been reported to reflect the quality of the overall diet (26–29,31), and we adopted it as a diet quality measure in this study. The maternal total fiber intake was calculated using FoodCalc (62,63) based on the self-reported intake of food containing fiber (e.g., bread, cereals, fruits, vegetables, legumes) and is reported in grams per day (62,63).

ADHD Symptom Scores

We constructed an ADHD symptom score for offspring at 3 years (ADHD3), 5 years (ADHD5), and 8 years (ADHD8) of age, using maternally reported behavioral measures across the MoBa questionnaires (Supplemental Methods; Table S1; Figure S1). At ages 3 and 5, items from the Child Behavior Checklist (64), Child Behavior and Manner questionnaire (65), and Conners' Parent Rating Scale-Revised, Short Form, were used (66). At 8 years, the ADHD score was based on DSM-IV items from the Parent/Teacher Rating Scale for Disruptive Behaviour Disorders (67). Information on ADHD symptoms was

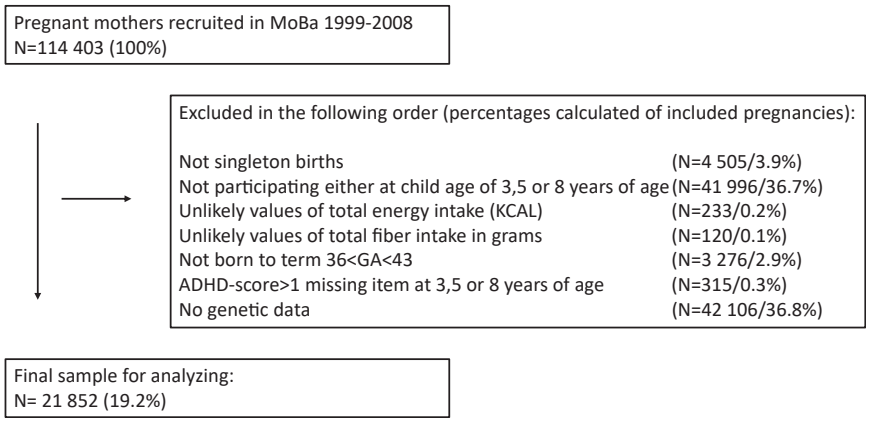

Figure 1. Flowchart of the study sample. ADHD, attention-deficit/hyperactivity disorder; GA, gestational age in weeks; MoBa, the Norwegian Mother, Father, and Child Cohort Study.

available for 18,472 children (84.5%) at the age of 3, 13,563 children (62.1%) at the age of 5, and 13,849 children (63.4%) at the age of 8. Of these children, 10,759 (49.2%) were girls (Table 1). Total scores were constructed by summing the Likert ratings, so that a higher score reflected more ADHD symptoms.

Covariates

In this sample, intake of fiber was positively correlated with total energy intake (Spearman's rho of 0.73, $p < .001$). Thus, we included total energy intake (kcal) in all of the models to have a better estimate of the contribution of fiber itself. In addition, we added "energy-adjusted sugar" intake as a proxy for unhealthy food/processed food. Because each gram of sugar is 4 kcal, we calculated energy-adjusted sugar as the percentage of sugar intake of the total energy intake. By adding energy-adjusted sugar to the model, the variation in sugar due to energy intake is partly removed. The covariate energy-adjusted sugar was negatively correlated with fiber intake (Spearman's rho of −0.11, $p < .001$). Both total energy intake and sugar intake were calculated based on the self-reported intake of food using FoodCalc (62,63).

In addition to the covariates related to the diet (total energy and energy-adjusted sugar), we included the following covariates in all of our models: child, maternal, and paternal ADHD polygenic score (PGS_{ADHD}) (Supplemental Methods); maternal highest attained education level; and maternal and paternal ages at the birth of the child (68,69) because ADHD is associated with fathers or mothers being young at the time of birth (70). Parental ages were treated as continuous variables. Maternal education served as a proxy for socioeconomic status and was specified as a categorical variable with 3 categories: low (less than high school), middle (high school), or high (college/university).

Table 1. Characteristics of the Study Sample at Offspring Ages 3, 5, and 8 (*N* = 21,852)

	Offspring Age		
Characteristic	3 Years	5 Years	8 Years
Offspring With Phenotypic Data	18,472 (84.5%)	13,563 (62.1%)	13,849 (63.4%)
Offspring Sex			
Female	9091 (49.2%)	6683 (49.3%)	6799 (49.1%)
Male	9381 (50.8%)	6880 (50.7%)	7050 (50.9%)
Maternal Education at Pregnancy			
Less than high school	274 (1.5%)	175 (1.3%)	178 (1.3%)
High school	5112 (27.7%)	3393 (25.0%)	3555 (25.7%)
College/university	12,631 (68.4%)	9655 (71.2%)	9773 (70.6%)
Missing maternal education	455 (2.5%)	340 (2.5%)	343 (2.5%)
Maternal Age at Birth, Years	30.3 (4.3)	30.6 (4.3)	30.6 (4.2)
Paternal Age at Birth, Years	32.7 (5.02)	32.9 (5.01)	32.9 (5.04)
Child ADHD PGS	11,549 (62.5%)	8622 (63.6%)	8769 (63.3%)
Mother ADHD PGS	14,721 (79.7%)	10,876 (80.2%)	11,025 (79.6%)
Father ADHD PGS	13,343 (72.2%)	10,075 (74.3%)	10,149 (73.3%)
Total Fiber Intake, g	30.7 (10.2)	30.9 (10.2)	30.8 (10.2)
Missing fiber information	1004 (4.6%)	313 (1.4%)	268 (1.2%)

Values are presented as *n* (%) or mean (SD).
ADHD, attention-deficit/hyperactivity disorder; PGS, polygenic score.

Statistical Analyses

We explored the associations between maternal prenatal fiber intake and ADHD symptoms in offspring using structural equation modeling by constructing 3 models with the following outcomes: (model I) overall ADHD symptoms in offspring at 3 time points (3, 5 and 8 years), (model II) derived latent subclasses of ADHD symptoms at the aforementioned 3 time points, and (model III) the longitudinal change in ADHD symptoms from ages 3 to 8.

In model I, we explored the associations between maternal fiber intake during pregnancy and overall ADHD symptoms in offspring at each examined time point. We first analyzed a crude multivariate model I, adjusted for sex of the offspring, total energy intake, and energy-adjusted sugar intake, and then analyzed a crude model I to which we added child PGS_{ADHD}. Finally, we analyzed a full model I, adjusting for child and parental PGS_{ADHD}s and the sociodemographic variables (Figure S2).

Heterogeneity in ADHD symptoms in the groups of children may be represented as different levels and distribution of ADHD symptoms in different unobserved groups (forming latent subclasses) (19,22). Thus, we explored their relationship with maternal prenatal fiber intake (model II). Based on the ADHD symptoms, we analyzed mixture population models, and we explored latent subclasses to decide the number of separable classes with the best empirical support. First, we derived the subclasses representing different levels of ADHD symptoms without including covariates at each age (ADHD3, ADHD5, and ADHD8) in latent class analyses (LCAs) (71). Model fit measures for the LCA were based on the Akaike information criterion, Bayesian information criterion, sample size–adjusted Bayesian information criterion, and goodness-of-fit with an entropy of >0.80. After identifying the number of subclasses, we used multinomial regression to examine whether prenatal maternal intake of fiber could differentiate between subclasses of offspring with different levels of ADHD symptoms at the studied time points measured as odds ratio (OR) with the subclass of low levels of ADHD symptoms as the reference.

Because ADHD symptoms in children can change from early to later childhood (16), we also examined the association between prenatal maternal fiber intake and changes in levels of ADHD symptoms over time (model III). To do so, we used latent growth curve models, which, like mixed-effects models, give insight into the ADHD symptom levels and their change at mean and individual levels. To allow for nonlinear change, represented as changes in the 2 intervals (3–5 and 5–8 years), 2 slope factors were estimated. It was not possible to estimate this model without fixing some parameters. Therefore, we constrained the covariances of intercepts with slopes to 0 (Supplemental Methods; Figure S3).

To minimize the effect of missing data, the full information maximization likelihood method was used (72,73). Statistical significance was established by 95% confidence intervals. Because these were exploratory analyses, no correction for multiple testing was applied. To account for relatedness between offspring siblings, we clustered the analyses on maternal identity, identifying relatedness based on the Medical Birth Registry of Norway and genetic information. Analyses took place between April and November 2022 using STATA version 16.1 (74) and Mplus version 8 (75).

RESULTS

Demographic characteristics of the study sample at offspring ages 3, 5, and 8 are presented in Table 1. The mean daily maternal fiber intake during pregnancy was ~30.8 g (SD = 10.2). The mean ADHD symptom scores at 3, 5, and 8 years of age were 3.6 (SD = 2.1), 2.5 (SD = 2.2), and 3.3 (SD = 2.5), respectively, and there were significant sex differences wherein girls were reported to have lower ADHD symptoms at all three ages than boys ($p < .001$).

The results from the crude model examining the overall ADHD symptom levels (model I) suggested that higher maternal intake of fiber (per 1 g of fiber per day) during pregnancy was associated with a lower level of ADHD symptoms at all ages (unstandardized regression coefficient [β] (β_{age3} = −0.17 [95% CI, −0.21 to −0.13]; β_{age5} = −0.18 [95% CI, −0.23 to −0.13]; β_{age8} = −0.17 [95% CI, −0.23 to −0.12]). These associations were attenuated, but still significant, when PGS_{ADHD} and sociodemographic variables were added to the full model (β_{age3} = −0.14 [95% CI, −0.18 to −0.10]; β_{age5} = −0.14 [95% CI, −0.19 to −0.09]; β_{age8} = −0.14 [95% CI, −0.20 to −0.09]) (Table S2). The associations were similar at all three ages; for each gram increase of prenatal fiber intake by the mother per day, the offspring ADHD score was reduced by 0.14 at all three ages (Figure 2). Overall, the model explained 2.1% to 4.7% (R^2) of the total variance in ADHD symptoms, with the highest R^2 observed at age 8 in the full model (Table S3).

The LCA of symptom scores and no covariates in the total sample resulted in poor separation between subclasses (entropy = 0.60). Subsequently, we performed LCA by sex with 1 and up to 5 subclasses, which gave us the best fit indices with entropy (0.81) for 3 subclasses for both girls and boys (Table S4). Therefore, we decided to use the LCA with 3 subclasses (low, medium, and high levels of ADHD symptoms) in each sex. The subclass with the highest ADHD symptom level had the smallest sample size among the 3 subclasses, 492 (2.3%) girls and 572 (2.6%) boys (Table S4). The score patterns for low, middle, and high levels of ADHD symptoms were slightly different for boys and girls; however, no significant sex differences were found (Figure 3).

In model II, maternal fiber intake during pregnancy was associated with a lower risk of belonging to the middle subclass for both boys and girls (middle: OR_{boys} 0.91 [95% CI, 0.86 to 0.97]/OR_{girls} 0.86 [95% CI, 0.81 to 0.91]) and with a lower risk of belonging to the high subclass for girls (high: OR_{girls} 0.82 [95% CI, 0.72 to 0.94]) (Table S5).

In model III, we found no significant associations between maternal fiber intake during pregnancy and change in ADHD symptom levels between ages 3 and 5 or ages 5 and 8 in offspring (Table S7). Consistent with the findings from model I, the estimated baseline ADHD symptom level was significantly associated with maternal fiber intake during pregnancy in this model ($\beta_{ADHDbaseline}$ = −0.14 [95% CI, −0.18 to −0.10]). The model was also analyzed separately by sex, and no significant sex differences were found related to the exposure (Table S8A, B).

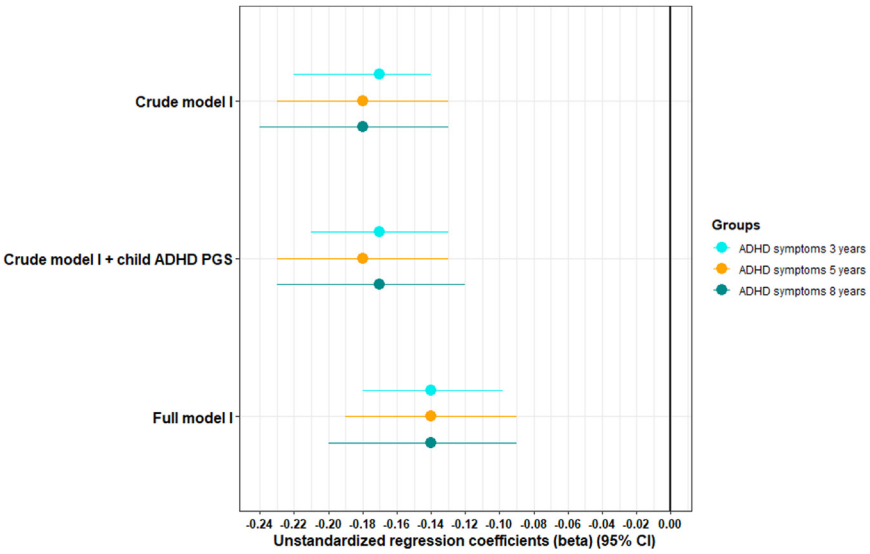

Figure 2. Unstandardized regression coefficients (β) for the associations between maternal intake of fiber during pregnancy and attention-deficit/hyperactivity disorder (ADHD) symptoms at 3, 5, and 8 years of age (model I). All estimates with p values $< .001$. Estimates in unstandardized regression coefficients and 95% CI; crude model I includes only sex of child; crude model I + child ADHD polygenic score (PGS); full model I includes crude model I + child PGS_{ADHD}/parental PGS_{ADHD} + socioeconomic status (parental age when becoming parents, attained maternal education).

DISCUSSION

In this large prospective population study, we examined the association of prenatal maternal fiber intake with 3 models of ADHD characteristics from ages 3 to 8: overall ADHD symptom levels (model I), different subclasses of ADHD symptoms (model II), and ADHD symptom change (model III). Overall, we observed a significant inverse association between maternal prenatal fiber intake and ADHD symptom levels as well as with the latent subclasses, including after controlling for parental and offspring ADHD PGSs, other relevant unhealthy dietary exposures, and sociodemographic factors.

Our results from model I indicate a significant and stable association of maternal fiber intake during pregnancy with childhood ADHD symptoms up to age 8 years, suggesting that maternal prenatal fiber intake may play an important role in offspring neurodevelopment. This is consistent with a previous study that investigated whether a prenatal or postnatal period represents a critical time for associations between the gut microbiome and neurodevelopment and showed that the maternal prenatal microbiome is more pertinent to offspring neurodevelopment than the child's own microbiome during the first year of life (76). The literature also offers reasons other than the gut microbiome to understand the association between diet and neurodevelopment. A theory of prenatal programming proposes that a fetus may be particularly sensitive to environmental influences, like maternal diet, that affect child development through epigenetic mechanisms (77). Furthermore, poor prenatal diet quality has been associated with

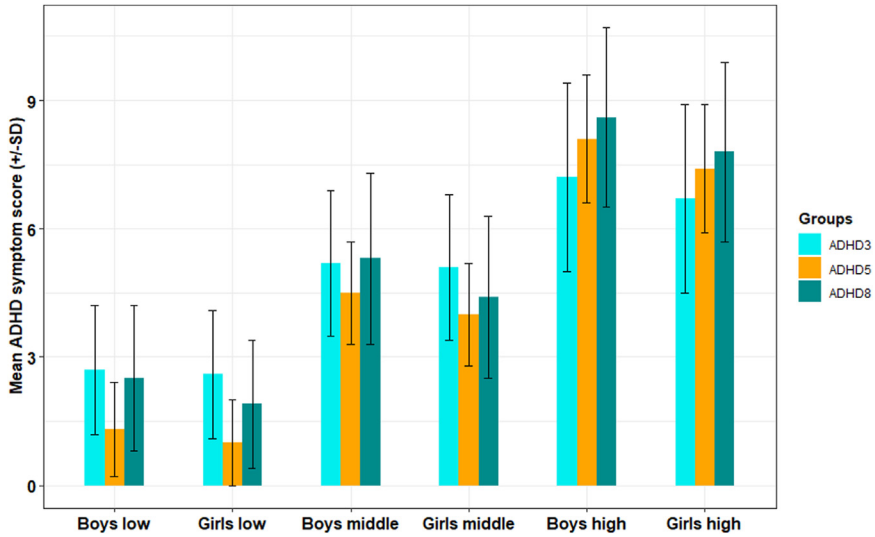

Figure 3. Subclassification by level of attention-deficit/hyperactivity disorder (ADHD) symptom scores (by latent class analyses) in offspring at 3, 5, and 8 years of age (ADHD3, ADHD5, and ADHD8, respectively), by sex (N = 21,852 children; boys n = 11,093; girls n = 10,759). Low ADHD symptoms: boys n = 7175 (64.7%); girls n = 7249 (67.4%). Middle ADHD symptoms: boys n = 3346 (30.2%); girls n = 3018 (28.1%). High ADHD symptoms: boys n = 572 (5.2%); girls n = 492 (4.6%).

inflammation and suboptimal levels of such important nutrients as zinc, iron, magnesium, vitamin D, iodine, and alcohol, all of which have been linked to neurodevelopmental aberrations (78–82).

Maternal prenatal fiber intake was also significantly associated with the longitudinal development of ADHD symptoms in offspring during childhood (model II); the more fiber the mother consumed during pregnancy, the less likely it was that the offspring would develop moderate (middle class in the model, both boys and girls) or high (high class in the model, girls only) levels of ADHD symptoms. A recent review on the role of nutrition in ADHD (83) indicated that a diet high in vegetables is associated with lower levels of ADHD symptoms (84,85). These previous reports support the notion that a good-quality diet that is rich in vegetables, and consequently fiber, may be helpful for ADHD management.

Despite significant associations between maternal prenatal fiber intake and ADHD symptom trajectories, we did not observe a significant effect of fiber on change in levels of ADHD symptoms from 3 to 8 years (model III). Nonetheless, the findings may be of importance to families with children who are at high risk of developing ADHD because they indicate that increasing maternal fiber intake during pregnancy could reduce the baseline or average level of ADHD symptoms in offspring over time.

While performing LCAs (model II), we noted that splitting the sample by sex gave better fit indices, so we carried out the analyses stratified by sex. We also examined the effect of maternal fiber consumption on change in ADHD symptom levels (model III) split by sex. However, the sex differences that we found in mother-reported ADHD symptom scores at all three ages are consistent with findings from other studies with parent-reported symptom information (86,87). This may be the reason why the LCA-derived subclasses in model II gave better fit indices when split by sex, even though we did not find significant sex differences between levels of ADHD symptoms in either of the models.

The effect sizes of the inverse associations between prenatal maternal fiber intake and offspring ADHD symptoms observed in our study are small. Overall, MoBa represents healthy individuals of high socioeconomic status who have a good diet quality. The average daily fiber intake during pregnancy estimated in this study was ~30 g, consistent with established recommendations for healthy nutrition for adults (88). High fiber intake may also be seen as a marker of a healthy lifestyle in this sample (30). It has been postulated that large effect sizes of nutrition cannot be observed in such a healthy, well-fed population (89). Nonetheless, small effect sizes can be of great impact when nutritional changes affect entire populations (32), particularly in countries with malnourished groups within those populations. Additional studies with diverse populations can elucidate to what extent the associations observed in this healthy sample may influence neurodevelopmental outcomes in other populations.

Strengths and Limitations

Our study has several strengths, including a large sample size from a prospective study of mothers, fathers, and their offspring, with both phenotypic and genetic data. Genetic confounding is essential to consider in the examination of environmental factors in psychiatry because of the likely effects of gene-environment correlation. In this study, by including genetics of both offspring and parents, we were able to partially account for such correlation, inclusive of its passive form (when genetics of parents influence the environment that they create for their children), which is considered to be of most importance in early childhood. The trio data of MoBa permitted incorporation of fathers' PGSs (together with maternal and offspring PGSs), further strengthening our analyses because research conducted only on mother-child dyads remains vulnerable to confounding from unmeasured paternal effects. This study also benefited from the detailed, repeated phenotypic records that allowed 1) the modeling of latent subclasses and an evaluation of symptom changes over time and 2) the incorporation of crucial confounders (such as total energy intake or socioeconomic status) as covariates in our models.

In the current study, we constructed ADHD scores from several different instruments, which may have resulted in a heterogeneous phenotype. Nonetheless, the data showed acceptable factor loadings, and the PGS_{ADHD} showed a significant association with our ADHD scores at all three examined ages, accounting for an amount of variance that is consistent with previous publications (23,90,91). Furthermore, because practices of ADHD diagnosis have been reported to vary across counties in Norway (92,93), the use of maternally reported symptoms may avoid such regional differences.

While we did include parental and offspring PGS_{ADHD} in our models to account for potential genetic confounding in the association between prenatal maternal fiber intake and offspring ADHD, it is important to note that a PGS can only capture what an ADHD genome-wide association study can detect, explaining a small proportion of the ADHD phenotype with OR < 2 for ADHD diagnosis and variance explained in dimensional assessments of ADHD traits of around 1 to 3% (94). It is also important to note that accounting for gene-environment correlation does not always eliminate the effect of all possible confounders because other environmental factors not included in this study may also act as confounders.

Because all the dietary variables used in this study are from the same Food Frequency Questionnaire, there is a risk of potential under- or overreporting of foods consumed and their portions. In addition, we did not have information on all the nutrients that may be important in the development of ADHD. We adjusted our analyses for both total energy intake and a variable that represents unhealthy food consumption, energy-adjusted sugar. Furthermore, because the socioeconomic status of MoBa participants was reported to be higher than the average of the Norwegian population at the time of MoBa recruitment (56,94,95) and the average fiber consumption in our sample was consistent with the recommended amount for a healthy diet during pregnancy (88), it is likely that the participants led healthy life styles and did not lack nutrients.

In the current study, we did not have information on ADHD diagnosis or fiber intake in children that could potentially have affected our results. However, in a previous study in the MoBa population, no clear associations were observed between children's own diet quality at age 3 and ADHD symptoms at age 8 (32).

The MoBa cohort, like all cohorts that are based on voluntary participation, is subject to some selection bias (96), with relative underrepresentation of young parents and parents with less education, which may have hindered the detection of some effects, and generalizability to populations not represented in the MoBa should not be assumed (95,97).

Implications

An increasing number of studies have indicated that diet may have beneficial effects on ADHD symptomatology and management. Our findings add to this notion and may inform the development of strategies to manage and/or prevent ADHD and the design of studies on dietary effects on ADHD. Our study strengthens the focus toward the effect of environmental factors in ADHD that could be applicable to the majority of individuals with the condition, whether the purpose is to prevent, manage, or promote psychiatric health.

Conclusions

In this large, prospective pregnancy cohort with a longitudinal design and genetic information available, we showed that higher maternal intake of fiber during pregnancy is associated with development of fewer ADHD symptoms in offspring in early childhood (up to 8 years of age). Our findings suggest that fiber intake during pregnancy may influence the development of ADHD traits in offspring, although the observed effect sizes were small. More studies conducted with diverse populations and with robust longitudinal designs are needed to disentangle this relationship and improve our understanding of the effect that pre- and/or postnatal nutrition may have on neurodevelopment and to identify developmental windows when children are most sensitive to changes in diet quality for the timely intervention and promotion of child health.

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