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Maternal smoking during pregnancy and scholastic achievement in childhood: evidence from the *LIFECOURSE* cohort study

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Background: Research on the impact of maternal smoking during pregnancy (MSDP) on scholastic achievement in the offspring has shown conflicting findings. The objective of this study was to assess the impact of MSDP on scholastic achievement in a birth cohort of children in 4th, 7th and 10th grades. **Methods**: We analysed data from the LIFECOURSE study, a cohort study of risk and protective factors in all children born in Reykjavik, Iceland, in the year 2000 ($N = 1151$, girls = 49.3%). Retrospective registry data for 2014–2015 were merged with prospective survey data that were collected in April 2016. Data on MSDP were assessed during regular antenatal visits at the end of the first trimester. Standardized academic achievement scores were obtained from official school transcripts. Data were analysed using OLS regressions that were entered in three hierarchical blocks. **Results**: Children of mothers who smoked tobacco during the first trimester consistently revealed between 5% and 7% lower scores on standardized academic achievement in 4th, 7th and 10th grade (~6–8 points on a normally distributed 120 point scale) than those of mothers who had not smoked tobacco during this period ($P < 0.05$). These findings held after controlling for several factors associated with the time of birth (e.g. birth weight, maternal age at birth, birth order, parental cohabitation and household income), as well as the year of scholastic assessment (parental cohabitation, household income and parental education). **Conclusions**: Maternal smoking during pregnancy was negatively related to scholastic achievement in the offspring during 4th, 7th and 10th grade.

Introduction

Existing recommendations state that pregnant women should not use tobacco products due to the toxic impact on the fetus,[1] negative influence on birth weight,[2,3] and increased risks for preterm birth.[4] Maternal smoking during pregnancy (MSDP) has also been shown to be associated with elevated risks of poor cognitive and developmental outcomes in the offspring, with study outcomes ranging in time from shortly after birth into adolescence and young adulthood. For example, MSDP has been related to lower intelligence in 9-year-old children,[5] reduced intellectual abilities in 8-year-olds,[6] inferior visual-motor integration and verbal competence in 4–5 year-old children,[7] attentional deficit in children aged 5[8] and 10,[9] lower scholastic achievement in 3–5 year-old children,[5,10] as well as slower physical growth in 10–15 year-old children.[11] MSDP has also been positively related to delinquent behaviours in youth and young adults[9] although findings on delinquency have not been consistent across study sites and age groups.[12]

However, due to conflicting findings in previous research and limited number of studies that reach into adolescence, the long-term impact of MSDP on cognitive developmental factors such as academic achievement in the offspring are not well understood.[13] Longer term studies have both shown negative and null associations between MSDP and intellectual and academic outcomes. For example, an Australian study of almost 4300 mothers and their children found a negative association between MSDP and scores in English, Science and Mathematics at the age of 14.[14] Similar results were reported among 15-year-olds in a Swedish cohort study of over 400 000 individuals born between 1983 and 1987.[15] On the other hand, Gilman et al.[2] found no association between MSDP and academic outcomes in 7-year-olds in the U.S. National Collaborative Perinatal Project, 1959–1974 with over 50 000 participants, and a cohort study based on all births in Sweden between 1983 and 1991 ($N \sim 650\,000$) found full siblings that were differentially exposed to MSDP not to differ in their academic scores and mathematics proficiency at the age of 15.[16] Likewise, a case-control study of French-Canadian children aged 12–18 ($N \sim 500$), reported no differences between cases and controls on the relationship between MSDP and the outcomes on a battery of 33 neuropsychological and intellectual tasks.[17]

Another critical problem in research on the impact of MSDP on cognitive outcomes in the offspring that have been highlighted in previous studies is the inconsistency in the selection of covariates employed in statistical analyses. Some studies control for birth-related outcome variables such as birth weight, head circumference

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or Apgar score (e.g. Lambe et al.[15]) but do not include social and family variables at the time of assessment, and some studies have selected an extensive number of social developmental covariates such as SES-related variables at the time of assessment (e.g. O'Callaghan et al.[14]) but lack birth-related measures. As a result, it has been hypothesized that previous observations regarding the probable impact of MSDP on scholastic outcomes may have been spurious and due to certain missing covariates such as maternal education.[18] Still others have called for a more general improvement and consistency in the selection of covariates in studies of this nature.[13,19]

The objective of this study is to improve our understanding of the impact of MSDP on academic achievement in early to mid-adolescence. We employ data from the LIFECOURSE study, a registry data-based cohort study conducted in Reykjavik, Iceland. We assess the impact of MSDP on standardized scholastic scores in 4th, 7th and 10th grade with real-time data collected before birth, during the neonatal period, as well as during the time of scholastic observation, therefore consistently including many of the covariates that previous studies have commonly lacked and has been called for.

Methods

Sample and participants

This report is based on data from the LIFECOURSE study of risk and protective factors being conducted by the Centre for Social Research and Analysis (ICSRA) at Reykjavik University in Iceland. LIFECOURSE is a developmental cohort study that covers the early lifespan of a birth cohort of children from before birth to the age of 15/16. The theoretical framework for the study has been described elsewhere.[20] The study sampling frame consists of all children born, and residing in, Reykjavik, Iceland, in the year 2000 ($N = 1151$, girls = 49.3%). Study material comprises a combination of official registry data from national data banks and data from a social survey conducted with participants in the spring of 2016 while in 10th grade. For the purpose of this analysis, we used retrospective registry data from the following sources: (i) The National Birth Registry at the Landspitali University Hospital, (ii) Antenatal records from the Primary Health Care Clinics, both overseen by the Icelandic Directorate for Health which oversees the entire health registry system in Iceland, (iii) the Educational Testing Institute overseen by the Ministry of Education, Science, and Culture, (iv) and the Statistical Bureau of Iceland. In addition, (v) prospective data were collected with a social survey of participants. The study was reviewed and approved by the National Bioethics Committee of Iceland (equivalent to a national IRB) and the study has been registered and acknowledged by the Personal Protection Authority.

Procedures

Contact information for the sample was acquired through the Statistical Bureau and sister agencies. A non-traceable research identification number was created for each participant and flash drives with this information delivered to local personnel at each site with the proper authority to handle the sensitive and personal information. The data were then prepared and transferred to files at each site during the years 2014–2016 using the research ID number to identify participants while removing any and all personal information upon delivery of the data files to the research team. Available data for each variable in the registry material ranged from 980 to 1149 or 85.1% to 99.8% of the study sample. A key that links individual names and contact information to research IDs is maintained by a third party at the Primary Health Care Clinics and is not accessible to the research team.

Survey data were collected with participants in their respective schools. Parental informed consent and student assent was required and collected with a combination of take-home paper and email messages that were delivered to parents and students by school nurses on behalf of the Primary Health Care Clinics. The survey data were collected in April 2016 in school classrooms using a protocol that the ICSRA has used in annual surveys for 20 years in collaboration with the Ministry of Education, Science and Culture. The school survey data collection protocol has been published elsewhere.[21] A total of 1103 students were eligible to participate in the survey, or 95.8% of the original sampling frame, of which 497 consented to do so (45.1% of all eligible). Valid survey data were then collected from 464 individuals or (93.4% of consented participants) which are used in the current analyses.

Measures

Dependent variables

From the Educational Testing Institute Scholastic achievement was assessed using official grades in Icelandic and Mathematics in 4th, 7th and 10th grade. These are two of what are referred to as the 'unitary subjects' that all students are required to pass in order to progress to the next year of study. For each subject, scores are standardized to a normally distributed scale ranging from 0 to 60. Scores within years were merged to form a single measure (Alpha = .77/.81/.84).

Independent variable

From the primary health care clinics Maternal smoking during pregnancy was assessed during the first antenatal visit which usually takes place towards the end of the first trimester. Expecting mothers are asked whether they currently smoke tobacco or if they did so before knowing about becoming pregnant. The observed smoking ratio (see table 1) is comparable to national estimates provided by National Directorate for Health in Iceland.[22] Based in this information two dichotomous variables were created for smoking status; one for maternal smoking before pregnancy, another for maternal smoking during pregnancy.

Covariates

From the national birth registry Data on birth weight in grams and maternal age at birth of the child were and coded as is. In addition, since maternal age at birth is slightly curvilinear related to the outcomes it was also inserted as a squared variable in the statistical models.

From the Primary Health Care Clinics Birth order was coded 1 = 'not mother's first child' and 0 = 'first child'. Gender was coded 1 = 'girls' and = 0 'boys'.

From the statistical bureau Parent's cohabitating at birth, in 2010, 2013 and 2016 was coded = 1 'yes' and 0 = 'no'. Total household income at the year of birth, in 2010, and in 2013 was recoded into quintiles with the lowest quintile coded = 1 and the highest quintile coded = 5.

From the social survey Family financial status at the time of the social survey (10th grade) was assessed with the question 'How do you rate your family's financial status compared to other families?' Scores ranged from 1 = 'much worse than other families' to 7 = 'much better than other families'. Parental education levels were assessed with two survey questions concerning mothers and fathers headed with: 'What is your mother/father highest level of education?' Responses ranged from 1= 'elementary school or less', to 6 = 'college graduate or higher'. Mother and father education levels were merged to form one variable for parental education. Descriptive statistics for all study variables are displayed in table 1.

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Table 1 Descriptive statistics for all study variables

Continuous variables	*N*	Min	Max	Mean	SD
Dependent variables					
Stand. Grades in 4th	1002	10	119	62.47	18.64
Stand. Grades in 7th	1035	3	114	62.23	18.59
Stand. Grades in 10th	980	7	119	63.78	19.22
Independent variables/covariates					
Birth weight in grams	1149	450	5870	3664	597.63
Maternal age at birth	1149	16	45	29.17	5.56
Maternal age at birth^2	1149	0.03	250.59	30.93	38.09
Household income in 2000 (quintiles)	1079	1	5	2.99	1.42
Household income in 2010 (quintiles)	1079	1	5	2.98	1.42
Household income in 2013 (quintiles)	1079	1	5	3.00	1.42
Family financial status in 2016	460	1	7	4.70	1.02
Parental education in 2016	441	2	12	8.61	2.23
Categorical variables/covariates	***N***	**% (*n*)**			
Maternal smoking before pregnancy	1103	6.3(69)			
Maternal smoking during pregnancy	1103	19.0(210)			
Girls	1149	49.3(567)			
Birth order (multiparous)	1149	60.9(700)			
Parents cohabitating at birth	1149	83.2(956)			
Parents cohabitating in 2010	1079	69.3748			
Parents cohabitating in 2013	1079	67.9(733)			
Parents cohabitating in 2016	458	65.3(299)			

Table 2 Linear regression of maternal smoking during pregnancy on standardized grades in 4th grade

	Model 1: smoking		Model 2: + birth year var		Model 3: + year of outcome var	
	B	***SE***	**B**	***SE***	**B**	***SE***
Maternal smoking before pregnancy	−4.26	3.81	−4.18	3.73	−4.59	3.75
Maternal smoking during pregnancy	−6.30**	2.53	−6.28**	2.53	−5.79*	2.58
Birth weight (gr)			0.002	0.002	0.003	0.002
Parents cohabitating at birth			−2.80	2.91	−3.83	3.03
Household income in 2000 (quintiles)			1.95**	0.68	1.60*	0.72
Maternal age at birth			0.57*	0.23	0.56*	0.23
Maternal age at birth^2			0.07*	0.03	0.07*	0.03
Girls			2.85	1.80	2.76	1.80
Birth order (multiparous)			−9.48**	2.22	−10.15**	2.26
Parents cohabitating in 2010					1.24	2.70
Household income in 2010 (quintiles)					1.27	0.91
Parental education in 2016					−0.20	0.43
R^2	0.02		0.11		0.12	
ΔR^2	F (2, 374) = 3.47*		F (7, 367) = 5.08***		F (3, 364) = 1.50	

*: $P < 0.05$.
**: $P < 0.01$.
***: $P < 0.001$.

Analyses

In order to understand how maternal smoking during pregnancy may affect scholastic achievement, we use a series of OLS regression models run in three hierarchical model blocks. Model 1 includes an analysis of the two smoking variables and the outcomes, scholastic achievement in 4th, 7th and 10th grade, respectively. Model 2 adds covariates associated with the birth period (birth weight, maternal age at birth, participant sex, not the first child, household income during year of birth, parental cohabitation at birth). In model 3, we then add covariates that concern the year of assessment of each dependent variable, respectively (household income and/or family financial status and parental cohabitation in 2010/2013/2016). Data were analysed using SPSS 24 (IBM Corporation, Armonk, New York 2015). The results are shown in tables 2–4.

Given that three covariates in the analyses were from the survey responses in 10th grade (i.e. family structure, parental education and family financial status in 10th grade, which by means of list-wise deletion reduces the number of eligible data by roughly half), we also conducted a sensitivity analysis. We analysed the data for participants while in 4th and 7th grade (tables 2 and 3) both with and without the missing participants on these three variables. This analysis yielded no markedly different results from the original models. Additionally, during model development we ran all statistical models by including gestational length as a covariate[23] but it did not add explanatory power ($P > 0.05$) to any models over birth weight, and was therefore excluded in the final models.

Results

Table 2 includes the linear regression models for maternal smoking during pregnancy on standardized academic achievement in 4th grade. Model 1 shows that children of mothers who smoked tobacco during pregnancy scored an average of 6.30 points less

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Table 3 Linear regression of maternal smoking during pregnancy on standardized grades in 7th grade

	Model 1: smoking		Model 2: + birth year var		Model 3: + year of outcome var	
	B	***SE***	**B**	***SE***	**B**	***SE***
Maternal smoking before pregnancy	−5.06	3.69	−5.51	3.61	−5.52	3.59
Maternal smoking during pregnancy	−7.14**	2.45	−6.76**	2.44	−5.98**	2.46
Birth weight (gr)			0.002	0.001	0.003	0.001
Parents cohabitating at birth			0.003	2.81	−1.87	2.90
Household income in 2000 (quintiles)			1.20	0.64	0.80	0.66
Maternal age at birth			0.55*	0.22	0.55*	0.22
Maternal age at birth^2			0.08**	0.03	0.07*	0.03
Girls			3.79*	1.71	3.74*	1.70
Birth order (multiparous)			−10.25***	2.13	−10.83***	2.14
Parents cohabitating in 2013					−0.85	2.55
Household income in 2013 (quintiles)					2.41	0.86
Parental education in 2016					−0.40	0.41
R^2	0.03		0.12		0.14	
ΔR^2	F (2, 384) = 4.83**		F (7, 377) = 5.68***		F (3, 374) = 3.62*	

*: $P<0.05$.
**: $P<0.01$.
***: $P<0.001$.

Table 4 Linear regression of maternal smoking during pregnancy on standardized grades in 10th grade

	Model 1: smoking		Model 2: + birth year var		Model 3: + year of outcome var	
	B	***SE***	**B**	***SE***	**B**	***SE***
Maternal smoking before pregnancy	−2.55	3.98	−2.06	3.88	−1.77	3.90
Maternal smoking during pregnancy	−8.30**	2.70	−6.76*	2.68	−6.22*	2.73
Birth weight (gr)			0.003	0.002	0.003	0.002
Parents cohabitating at birth			−0.74	3.17	−0.45	3.27
Household income in 2000 (quintiles)			1.98**	0.70	1.87**	0.72
Maternal age at birth			0.61**	0.24	0.58*	0.24
Maternal age at birth^2			0.07*	0.03	0.07*	0.03
Girls			6.34***	1.87	6.19***	1.88
Birth order (multiparous)			−9.37***	2.32	−9.14***	2.36
Parents cohabitating in 2016					1.45	2.13
Family financial status in 2016					−0.53	0.97
Parental education in 2016					0.40	0.44
R^2	0.03		0.12		0.13	
ΔR^2	F (2, 374) = 4.78**		F (7, 367) = 5.96***		F (3, 364) = 0.48	

*: $P<0.05$.
**: $P<0.01$.
***: $P<0.001$.

than children of mothers who did not smoke during pregnancy ($P=0.01$) but maternal smoking before pregnancy was not related to scholastic achievement. Model 2 includes the covariates that are associated with the time of birth, both biological (e.g. birth weight, maternal age and not first child), and social factors (e.g. household income and parental cohabitation). In short, the explanatory power improves significantly between the two models [F (7, 367) = 5.08, $P=0.000$] but the impact of MSDP remains mostly unchanged. Model 3 adds the covariates associated with the year of student assessment (2010) to model 2; however, the addition of these covariates do not add a significant explanation to the model [F (3, 364) = 1.50, $P=0.215$] and neither do they change the impact of MSDP on academic achievement in 4th grade, which is 5.79 points less for children of mothers who smoked tobacco during pregnancy compared with children of mothers that did not ($P=0.025$).

Tables 3 and 4 include the linear regression models for MSDP on standardized scholastic achievement in 7th and 10th grade, respectively. In short, both models paint a very similar picture as the models displayed in table 2. In 7th grade, the impact of MSDP on grades is −7.14 points in model 1 and drops to −5.98 points in the 3rd and final model while including all covariates. Explained variance increased significantly between models 1 and 2 [F (7, 377) = 5.68, $P=0.000$] as well as models 2 and 3 [F (3, 374) = 3.62, $P=0.013$]. In 10th grade, the impact of MSDP on grades is −8.30 points in model 1 and drops to −6.22 points in the 3rd and final model while including all covariates. Explained variance increases significantly between models 1 and 2 [F (7, 367) = 5.96, $P=0.000$] but not between models 2 and 3 [F (3, 364) = 0.48, $P=0.697$].

Discussion

The results of this study show a consistent negative relationship between MSDP and standardized scholastic achievement in the offspring at the time of 4th, 7th and 10th grades. In the smoking only analyses (models 1), the differences in scholastic achievement ranged from 5.3% (6.30/120 points in 4th grade students) to 6.9% (8.30 points in 10th grade students) and from 4.8% (5.79 points in 4th grade students) to 5.2% (6.22 points in 10th grade students) in the full models including all control variables and covariates.

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Interestingly, smoking before pregnancy was unrelated to scholastic achievement in all models. The consistency of these findings are particularly noteworthy given the large range of covariates that was selected for the analysis and are both associated with the physical birth (e.g. birth weight, maternal age at birth and sex), the social environment into which the baby is born (e.g. birth order, parental cohabitation status and total family income during the year of birth), as well as SES related variables at the year of scholastic assessment (e.g. parental cohabitation status, total family income and parental education). The findings differ from the review results by Clifford et al.[13] where many reviewed studies showed little or no impact of MSDP on cognitive performance and observed relationships were often masked out by other factors. In addition, the homogenous nature of the Icelandic population should ideally serve to deter the observed differences in scholastic achievement as it operates as a natural environmental control measure. Iceland has been described as being universally middle-class where the lifestyle, values and beliefs tend to be alike across the population.[24] Iceland's relative lack of social hierarchy therefore serves as evidence of a greater likelihood for a biological link between MSDP and scholastic outcomes in the offspring given that we were able to control for the little variation that exists. Also, the fact that smoking before pregnancy was consistently unrelated to the outcome measures lends further support to the potential biological link between MSDP and scholastic achievement in the offspring.

There are several potential biological explanations for these findings. First, cigarette smoking includes carbon monoxide which creates carboxyhemoglobin that in turn serves to decrease the oxygen carrying capacity of maternal and fetal blood and may in some cases lead to fetal hypoxia.[25–28] Also, nicotine causes vasoconstriction, which decreases placental blood flow.[26,27] Decreased oxygen flow and blood stream have been linked to low birth weights and smaller head circumference.[26,29] Low birth weights have been associated with significant neurologic consequences such as the risk for behaviour problems,[30,31] decreased intellectual capacity, hyperactivity and learning disabilities,[2,6,32,33] as well reduced brain growth *in utero*.[25,34] Other plausible impacts are more distal in nature but authors have also speculated that a combination of factors and compound exposure may explain the longer term impact of MSDP on cognitive outcomes in the offspring.[13]

Strengths

Our study has notable strengths. First, we selected and included in our analyses more extensive control variables than most studies have to date. Second, scholastic achievement was assessed at three time points, which enabled us to assess a consistent pattern of probable impact from 4th grade through 10th grade across developmental stages. Third, the registry-based data add robustness to the study because such data substantially decrease the prospects of systematic bias due to sampling variation.

Limitations

Four study limitations are worth noting. First, we did not control for post-partum smoking exposure. This represents a particular challenge in studies of this nature as comprehensive measures of smoking exposure are difficult in a life-course study without collecting real-time data during the course of an individual participant's lifetime. Second, our measure of MSDP is conducted at the end of the first trimester and does not differentiate among differing levels of maternal smoking nor smoking following the first trimester. Third, although we do control for several variables highlighted as important in previous research we cannot rule out that the observed relationships between MSDP and scholastic achievement is due to residual confounding or other missing variables. Finally, although the data from the LIFECOURSE study is longitudinal in nature, our analyses for this current study are conducted by treating the data as cross-sectional. Based on these findings it appears that children exposed to MSDP have lower baseline academic achievement and then fail to catch up over the life course.

Conclusions

We believe the results of this study provide convincing evidence of the negative impact of MSDP on academic achievement in the offspring in 4th, 7th and 10th grade. A large number of control variables and covariates were included in statistical models and which only minimally decreased the observed bivariate relationship between MSDP and scholastic achievement. Future studies should strive to control for both post-partum smoking exposure as well as the amount of maternal smoking during pregnancy.

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Conflicts of interest: None declared.

Key points

- Life course data were analysed to assess potential impact of maternal smoking during pregnancy on scholastic achievement in the offspring in 4th, 7th and 10th grade.
- Across all grades, children of mothers who smoked tobacco during the first trimester consistently had 5–7% lower standardized scholastic scores than children of non-smoking mothers.
- Early detection and prevention of maternal smoking during pregnancy should be a policy priority.

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