Is smoking in pregnancy an independent predictor of academic difficulties at 14 years of age? A birth cohort study.

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Abstract

Background: Studies of the effects of maternal smoking during pregnancy have reported inconsistent findings in relation to measures of offspring cognitive functioning. Few studies, however, have examined learning outcomes in adolescents, as opposed to IQ.

Aim: To examine the association between maternal smoking during pregnancy and academic performance among adolescent offspring.

Study Design: Population-based birth cohort study.

Subjects: 7223 mothers and children were enrolled in the Mater-University of Queensland Study of Pregnancy in Brisbane (Australia) from 1981 to 1984. Analyses were restricted to the 4294 mothers and children for whom all information was reported at 14-year follow-up.

Outcome Measures: Reports of academic performance of 14-year-old offspring in English, Science and Mathematics with different patterns of maternal smoking (never smoked, smoked before and/or after pregnancy but not during pregnancy, or smoked during pregnancy).

Results: Low academic achievement was more common only in those whose mothers had smoked during pregnancy. Effect sizes were, however, small. The adjusted mean difference in total learning score for smoking before and/or after pregnancy but not during pregnancy, and for smoking during pregnancy were -0.18 (-0.58, 0.22) and -0.40 (-0.69, -0.12). Similarly, the adjusted odds ratios were 0.9 (0.65, 1.24) and 1.35 (1.07, 1.70).

Conclusion: Maternal smoking during pregnancy is a preventable prenatal risk factor associated with small decrements in offspring academic performance that continue into adolescence.

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Introduction

In reviews of the literature on the effects of maternal smoking during pregnancy, significant deficits on a variety of measures of cognitive functioning have been reported in children whose mothers smoked during pregnancy, in comparison to children of non-smoking mothers, although inconsistent findings have also been found.¹⁻² Effects have been generally evidenced in offspring of mothers who smoked an average of 10 or more cigarettes per day, although low to moderate maternal smoking during pregnancy has also been associated with decreased general cognitive functioning and deficits in learning and memory tasks from infancy to childhood.¹

Several issues require further investigation. Findings in relation to long term effects of prenatal smoking exposure on cognitive development and functioning of offspring are inconsistent, reflecting differences in design and methods used in various longitudinal studies.² Few birth cohort or longitudinal studies of cognitive outcomes of teenage offspring have been reported. Further, conclusions relating to IQ outcomes as distinct from learning outcomes also need to be differentiated. While IQ and learning are related, they should be considered as two separate outcomes since the same factors do not determine both, with IQ explaining from 4% to 25% of the variance in academic achievement.^{3,4}

Longitudinal studies predicting IQ have found that the association between maternal smoking during pregnancy and offspring IQ was confounded by maternal education,⁵⁻⁷ maternal IQ,^{6,7} or social and family factors.⁸ Inconsistent findings have again been reported, however, in studies controlling for maternal education with one

reporting lower cognitive abilities in children whose mothers had smoked during pregnancy in comparison to mothers who smoked only after pregnancy⁹ and the other finding no significant relationship involving prenatal exposure.¹⁰

Although IQ tracks from childhood to adolescence, aspects of learning are not generally apparent until children are in school, with performance being dependent on a variety of factors other than IQ, such as personality^{11,12} and information-processing,¹³ thus resulting in substantial differences between individuals. Influences on learning outcomes in adolescents therefore require separate investigation. It is not clear whether the effects are specific to particular school subjects because of effects on specific cognitive pathways or evidenced across academic areas, nor are we certain of the magnitude of such effects. The extent to which potentially important confounding factors have been controlled also varies between studies, particularly in relation to variables found to be strong predictors of intellectual ability.⁹

Several studies have reported lower academic performance among children of mothers who smoked during pregnancy.¹⁴⁻¹⁶ In one of these studies,¹⁴ however, the importance of maternal smoking was quite small compared with other sociodemographic and health factors, and it was no more important than paternal smoking, raising the possibility that residual confounding due to environmental and family exposures may explain the reported association. Overall, studies reporting a negative association between maternal smoking during pregnancy and school performance have been unable to disentangle the effects of prenatal and later smoking¹⁶ and have failed to control for important confounders,^{17,18} leading one to conclude that the association may reflect the influence of unmeasured characteristics that distinguish smokers from nonsmokers.¹⁸ Again, however, there is evidence of inconsistent findings.¹⁹

In this paper, we report findings from a large birth cohort study that has examined the effects of maternal smoking during pregnancy (assessed at the time of pregnancy) on offspring followed from birth through to adolescence. We examined whether exposure to prenatal cigarette smoking is an independent predictor of academic difficulties at 14 years, while adjusting for a range of potential confounding social and family factors. Our hypothesis was that maternal smoking during pregnancy would predict poorer academic performance in adolescence.

Methods

Sample

Participants were from the Mater-University of Queensland Study of Pregnancy (MUSP), a prospective study of 7223 mothers and their singleton children. The women attended their first antenatal clinic at the Mater Misericordiae Mothers' Hospital, Brisbane between 1981 and 1984. Full details of the study participants, measurements and attrition rates have been previously reported.²⁰⁻²² Mothers were interviewed at the first clinical visit (FCV) when the women were on average 18-weeks of gestation, then several days after delivery, at 6 months, and at 5 and 14 years when the child was also assessed. The study was approved by the Mater Hospitals and University of Queensland Ethics Committees with written consent being obtained from the mother at each stage of follow-up.

Maternal Smoking

At the FCV and at each follow-up, mothers were asked to record whether they smoked (yes or no). If they smoked, they were asked to report the frequency and quantity of tobacco use in the previous week. In addition, at the FCV women were

asked about whether and how much they smoked before they became pregnant. At 3 to 5 days after delivery, mothers were asked to recall their smoking level over the last trimester.

For in-utero smoking, we combined the two smoking variables from early pregnancy and late pregnancy to define those who were ‘never smokers’ throughout pregnancy and ‘smokers at either stage’. We defined smoking status as: never smoked (responded ‘no’ at all stages of the study), smoked throughout pregnancy (responded ‘yes’ to smoking at FCV and/or ‘yes’ to smoking in the third trimester, and smoked before and/or after pregnancy but not during pregnancy (women who responded ‘no’ to smoking at FCV and third trimester but ‘yes’ either to smoking before pregnancy and/or at any stage of follow-up to the 14 year follow-up). These categories are mutually exclusive.

Offspring Academic Performance

At 14 years, 5139 mothers and adolescents completed learning questionnaires (the mean age of the adolescents was 13.9 ± 0.34 years, range=12.5 to 15.5 years), and 3731 adolescents attended the hospital to complete psychometric assessments. Mothers also rated the child’s overall current academic performance on a five-point scale (1=below average, 2=a bit below average, 3=average, 4=a bit above average, 5=above average). Adolescents separately rated their current academic performance in English, Mathematics and Science as well as their overall academic performance using the same scale. A composite total school performance score was computed by summing these five scales (range=5-25; smoked during pregnancy and at other times: $M=16.61$, $SD=4.2$; $\alpha=0.83$). Complete information was available for 4294 mothers and children. Previous research by Cole and colleagues²³⁻²⁵ has found that in

longitudinal and cross-sectional studies of children's perceived academic and other aspects of self-competence, teacher, parent and peer appraisals corresponded strongly with self-perceived competence.

Ratings of overall academic performance in the final year of school (i.e. Overall Performance scores) were obtained retrospectively at the 21-year follow-up for 1508 youth. They are used to determine entry to tertiary courses (range=1 to 25, with 1 being the highest rank) at completion of secondary school, and in the current study we compared them with maternal- and self-reported academic performance at 14 years in order to provide a more objective indicator of their validity. The correlation between the total school performance score and the tertiary entrance score was 0.53.

Measurements of confounders and mediators

The following maternal characteristics during pregnancy, reported at FCV, were examined as confounding factors on the basis of their potential association with maternal smoking during pregnancy and offspring academic performance: maternal age (exact age), maternal education (did not complete secondary school, completed secondary school, completed further/higher education), family income (low: <AUS \$10399; medium: AUS \$10400-20799; high: AUS \$26000 or more), marital status, maternal alcohol consumption (abstainer, light, or 1 or more glasses per day; maternal depression (depressed vs. non-depressed), using the Delusions Symptoms States Inventory²⁶ (mothers were classified as depressed if they reported three or more of seven symptoms related to depression); quality of marital relationship (using Spanier's Dyadic Adjustment Scale:²⁷ good relationship vs. not good relationship). Birthweight, number of children in the family at 5-years follow-up, and breast feeding (categorized into three groups: never, <4 months, $\geq$ 4 months, recorded at 6-month

follow-up) were also measured. Child gender was also included as a potential confounder, as well as paternal smoking (yes/no) at 14 years and family communication at 14 years. Family communication was measured by the two subscales of the 20-item Parent-Adolescent Communication Scale:²⁸ problems in mother-child communication and open family communication (good, fair, poor). Finally, we considered child behaviour as a possible mediator and included the externalizing and internalizing scales of the Child Behaviour Checklist²⁹⁻³¹ at 14 years.

Cognitive ability of the 3731 adolescents attending the hospital was assessed by Raven's Standard Progressive Matrices Test.³² This is a widely used test of non-verbal intelligence (mean=100, SD=15) that was re-standardized for Australian norms in 1986.³³ In this paper, we present maternal and child self-reports of academic performance for the principal analyses, as the Raven's was available for substantially fewer children than completed questionnaires. Similarly, infant length was also available for a subsample of children, as well as paternal smoking. A secondary analysis was performed in this subsample to assess the extent to which associations with learning were independent of IQ.

Statistical analysis

The association between pattern of maternal smoking in the three mutually exclusive exposure groups and maternal and adolescent reports of academic performance was examined (1). Chi-square tests were used to examine differences in the frequency distributions in each category (i.e. below average, average etc). The mean score and SD were also calculated for each of the five scales of the composite total learning score scale.

Multiple linear regression was used to investigate the relationship between the three maternal smoking categories and the composite learning score. Multinomial logistic regression was similarly used to examine quintiles of the total learning score and the three maternal smoking categories. The reference categories consisted of those who never smoked and the third quintile, reflecting average academic performance. Higher quintiles indicate stronger academic performance and lower quintiles indicate learning difficulties. Linear and logistic models progressively examined the influence of a range of possible confounders (Tables 2 and 3). These results are for the 4294 adolescents and their mothers with complete data on all variables included in the model.

Mothers of those lost to follow-up were more likely to be teenagers, less educated, single or cohabiting, have three or more children, use tobacco and alcohol during pregnancy and be anxious and depressed at the FCV (all p-values < 0.001). To determine whether this affected the validity of our findings we undertook a weighted analysis using inverse probability (of having missing outcome data) weights.³⁴ The probability weights were computed by using a logistic regression model with the outcome being complete data or not. The influence of all other covariates used in our primary analyses on having complete data or not was assessed in combination in a logistic regression model. The regression coefficients from this model were then used to determine probability weights for the covariates in the main analyses. The results using these inverse weightings did not differ from those presented here. All analyses were undertaken using Stata version 10.0 (Stata Inc., Texas).

RESULTS

Table 1 shows the composite of child- and mother-reported academic performance in English, Mathematics and Science by the three mutually exclusive maternal smoking categories. Average performance based on child self-report and maternal report across all three subjects is also shown. The findings demonstrate a general shift across each category of performance, with more in the below average categories and fewer in the above average categories across subject areas. Though statistically significant, the effect is generally weak with maximal effects being seen in those whose mothers smoked during pregnancy. The difference between mean scores was also statistically significant with smoking in pregnancy having the lowest mean for all measures of school performance, and for the composite indicator mean scores (16.61 (SD=4.20) for smoking during pregnancy and at other times, 17.20 (SD=4.12) for smoking before and/or after pregnancy and 17.53 (SD=4.15) for never smoked).

Table 2 is a multiple linear regression showing the multivariable association between the three categories of maternal smoking and the mean change in overall academic performance among adolescents. It shows an effect for average change in performance but only for smoking in pregnancy and not for smoking at other times. The adjustments for a range of potential confounding factors, particularly maternal socio-demographic, lifestyle factors and breastfeeding (i.e. model 2) attenuated the effect although it remained significant. The age and sex adjusted difference in mean total learning score for smoking before and/or after pregnancy but not during pregnancy, and for smoking during pregnancy were -0.44 (95% CI: -0.85, -0.03) and -0.93 (-1.21, -0.66), respectively compared to -0.18 (-0.58, 0.22) and -0.40 (-0.69, -0.12) in the fully adjusted model. Though statistically significant, the effect sizes of

the age and sex adjusted model, or the fully adjusted model are weak, being less than a quarter of the standard deviation of the composite learning scale.

Table 3 shows the results of a multinomial logistic regression in which each of the five quintiles of the composite learning score was predicted by the three categories of maternal smoking status, with the middle quintile as the reference category. For the below average first quintile performance category, the age and sex adjusted odds ratios (OR) for smoking before and/or after pregnancy but not during pregnancy was 1.01 (95% CI: 0.74, 1.38), and for smoking during pregnancy the OR was 1.61 (1.30, 2.00). This reflects a significant shift in these extreme lower scores, showing that smoking during pregnancy predicts below average performance. This association altered only slightly after adjusting for potential confounders, with the adjusted odds ratio for smoking in pregnancy being 1.35 (1.07, 1.70) in the fully adjusted model. For other quintiles of the composite learning scale, including the above average performance category, the age and sex adjusted OR, and fully adjusted OR, were close to the null value and not statistically significant.

In additional analyses, the associations were also examined including the Raven test scores in final model in order to control for adolescent intelligence. Raven's scores were available only for those children attending the hospital for psychometric tests, thus reducing the numbers available for analysis. Infant length was also included, given the reduced numbers available. Addition of the Raven's score, paternal smoking at 14 years, and infant length to the final model led to minimal change in the estimates (results are not shown in the table).

DISCUSSION

In this birth cohort study of mothers and their offspring, we found an overall decline in academic performance across English, mathematics and science among offspring of mothers who smoked during pregnancy, in comparison to those whose mothers had never smoked, or smoked at other times but not during pregnancy. Adolescents exposed to active maternal smoking were more highly represented in the below average performance categories, with fewer in the above average categories. This pattern of declining performance was also reflected in the composite mean score for the three subject areas. Although statistically significant, however, the differences as reflected in the composite indicators were modest. When multivariable associations between mean change in school performance and maternal smoking status were examined and behaviour was added as a mediator, the estimate attenuated and although still significant overall, the magnitude of effect was small. In the final model with all available confounding and mediating factors including family communication, behavioural problems and birth weight taken into account, the effect remained statistically significant, though small (less than a quarter of the standard deviation of the composite learning scale). In the logistic model, the association was restricted to children in the lowest quintile of the composite learning score. These children were at 1.38 times the odds for learning difficulty compared to children in the middle quintile. Overall, these findings provide some evidence for a direct effect of maternal smoking in utero on academic performance among adolescent offspring, though this effect is of limited clinical significance and could also be explained by uncontrolled confounding.

The present results show evidence both of the attenuation of effects of maternal smoking due to confounding, consistent with recent research¹⁸ as well as evidence of a direct effect of maternal smoking on adolescent learning outcomes, consistent with

previous research highlighting the vulnerability of adolescent offspring of cigarette smokers.^{14,15} We are therefore able to provide a more complete picture of the relationship between these factors, given that we were able to distinguish in utero exposure from smoking exposure at other times, using a large sample, focusing on specific academic areas and taking into account a wide range of confounding factors. Fogelman¹⁵ found that reading performance was about one-eighth of the total population standard deviation and mathematics performance was about one-fifth of a standard deviation, findings similar to this study. The effect seems to reflect a specific association with smoking in pregnancy although if the effect were truly biological, it could be argued that the relationship should be influential across all categories (i.e. with significant reductions in above average performance levels as well). Smoking in pregnancy, however, in conjunction with other environmental or genetic factors specific to this group, may constitute a causal pathway affecting learning. An alternative explanation of the effects is that they could be the result of uncontrolled confounding, possibly in relation to maternal IQ, which may itself be part of a causal web of social disadvantage. A concern with previous research has been the failure to adjust for maternal education and/or IQ, thereby potentially biasing the influence of maternal smoking during pregnancy on offspring cognitive ability.⁶ Previous research shows that in explaining the inverse association between maternal smoking and offspring IQ, “the attenuating effect for maternal education was stronger than that for maternal IQ”.⁶ In an attempt to disentangle the effects of adolescent IQ, we conducted a separate analysis including Raven scores in the final model. The effect, however, did not change, suggesting that the significant associations reported here are due to learning difficulties and do not merely reflect the effects of IQ,

intelligence being only one of several factors affecting academic achievement in children.¹¹⁻¹³

In order to understand the mechanisms by which maternal smoking during pregnancy may influence cognitive performance in adolescence, it is necessary to consider the effects of exposure not only to nicotine, but to large amounts of other toxic substances including carbon monoxide and components of tar that can directly affect development of the fetal brain and nervous system. Other factors include reduced uterine blood flow resulting in the fetus being deprived of nutrients and oxygen; and alterations in the fetal hypothalamic-pituitary-adrenal axis that may be involved in a general vulnerability for developmental psychopathology and substance use.¹ Social and environmental factors characteristic of women who smoke during pregnancy, as well as genetic factors, must also be considered.⁶

A limitation of the research is that academic performance was based on subjective measures obtained from mothers and adolescents and may therefore be subject to bias. Previous research provides evidence that teacher, parent and peer appraisals of children's academic competence corresponded strongly with children's self-perceived competence.²³⁻²⁵ Moreover, mothers' ratings of their sons' academic performance correlate with final grades as well as, or better than, teachers' ratings with the strength of this relationship increasing with years of schooling.³⁵ In our study, given that there was a moderately high correlation between adolescents' combined school performance scores and later measures of their ranking among all high school students in their final year of school, as well as with the individual five items, this provides further support for the validity of the self- and mother-reported school performance scores. Loss to follow-up also limits the conclusions that can be drawn, and would bias the results if the associations between maternal smoking and academic

performance were non-existent or in the opposite direction among those with incomplete data. Consideration of possible selection effects in the regression models, however, produced similar results to those presented here. Other potentially important exposures during pregnancy that could influence offspring cognitive functioning, such as ingestion of methylmercury in fish, organochlorines and lead, and other environmental exposures were not measured. Such exposures could also be associated with maternal smoking pattern, thus residual confounding may have been present.

In conclusion, maternal smoking during pregnancy is a preventable prenatal risk factor associated with small decrements in offspring academic performance that continue into adolescence.

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Conflict of interest statement

The authors declare that they have no conflicts of interest.

REFERENCES

1. Huizink AC, Mulder EJJ. Maternal smoking, drinking or cannabis use during pregnancy and neurobehavioural and cognitive functioning in human offspring. *Neurosci Biobehav Rev.* 2006;30:24-41
2. Lassen K, Oei TPS. Effects of maternal cigarette smoking during pregnancy on long-term physical and cognitive parameters of child development. *Addict Behav.* 1998;23:635-653
3. Neisser U, Boodoo G, Bouchard TJ, Boykin AW, Brody N, Ceci SJ, Halpern DF, Leohlin JC, Perloff R, Sternberg RJ, Urbina S. Intelligence: Knowns and unknowns. *Am Psychol.* 1996;51:77-101.
4. Sternberg R. Successful intelligence: How practical and creative intelligence determines success in life. New York: Simon and Schuster; 1996.
5. Lawlor DA, Najman JM, Batty GD, O'Callaghan MJ, Williams G, Bor W. Early life predictors of childhood intelligence: findings from the Mater-University study of pregnancy and its outcomes *Paediatr Perinat Epidemiol.* 2006;20:148-162
6. Batty GD, Der G, Deary IJ. Effect of maternal smoking during pregnancy on offspring's cognitive ability: empirical evidence for complete confounding in the US National Longitudinal Survey of Youth. *Pediatrics.* 2006;118:943-950
7. Breslau N, Paneth N, Lucia VC, Paneth-Pollak R. Maternal smoking during pregnancy and offspring IQ. *Int J Epidemiol.* 2005;34:1047-1053.
8. Fergusson DM, Lloyd M. Smoking during pregnancy and its effects on child cognitive ability from the ages of 8 to 12 years. *Paediatr Perinat Epidemiol.* 1991;5:189-200

9. Julvez J, Ribas-Fito N, Torrent M, Forns M, Carcia-Esteban R, Sunyer J. Maternal smoking habits and cognitive development of children at age 4 years in a population-based birth cohort *Int J Epidemiol.* 2007;36:825-832.
10. Bauman KE, Flewelling RL. Parental cigarette smoking and cognitive performance of children. *Health Psychol.* 1991;10:282-288
11. Duckworth AL, Seligman MEP. Self-discipline outdoes IQ in predicting academic performance of adolescents. *Psychol Sci.* 2005;16:939-944
12. Furnham A, Chamorro-Premuzic T. Personality predicts academic performance: Evidence from two longitudinal university samples. *J Res Pers.* 2003;37:319-338.
13. Colom R, Escorial S, Shih PC, Privado J. Fluid intelligence, memory span, and temperament difficulties predict academic performance of young adolescents. *Pers Individ Dif.* 2007;42:1503-1514.
14. Rantakallio P. A follow-up study to the age of 14 of children whose mothers smoked during pregnancy. *Acta Paediatr Scand.* 1983;72:747-753
15. Fogelman K. Smoking in pregnancy and subsequent development of the child. *Child Care Health Dev.* 1980;6:223-249
16. Batstra L, Hadders-Algra M, Neeleman J. Effect of antenatal exposure to maternal smoking on behavioural problems and academic achievement in childhood: prospective evidence from a Dutch birth cohort. *Early Hum Dev.* 2003;75:21-33.
17. Martin RP, Dombrowski SC, Mullis C, Wisenbaker J, Huttunen MO. Smoking during pregnancy: association with childhood temperament, behaviour, and academic performance. *J Pediatr Psychol.* 2006;31:490-500
18. Lambe M, Hultman C, Torrang A, MacCabe J, Cnattingius S. Maternal smoking during pregnancy and school performance at age 15. *Epidemiol.* 2006;17:524-530

19. Fried PA, Watkinson B, Gray R. Differential effects on cognitive functioning in 13- to 16-year-olds prenatally exposed to cigarettes and marihuana. *Neurotoxicol Teratol.* 2003;25:427-436
20. Najman JM, Bor W, O'Callaghan M, Williams, G.M., Aird, R., Shuttlewood, G. Cohort profile: the Mater-University of Queensland Study of Pregnancy (MUSP). *Int J Epidemiol* 2005;34:992-997
21. Lawlor D, Najman JM, Sterne J, Williams GM, Ebrahim S, Davey Smith G. Associations of parental, birth and early life characteristics with systolic blood pressure at age 5: Findings from the Mater-University study of pregnancy and its outcomes. *Circulation.* 2004;110(16): 2417-2423
22. Keeping JD, Najman JM, Morrison J, Western JS, Andersen MJ, Williams GM. A prospective longitudinal study of social, psychological and obstetric factors in pregnancy: response rates and demographic characteristics of the 8556 respondents. *Br J Obstet Gynaecol.* 1989;96:289-297
23. Cole DA. Change in self-perceived competence as a function of peer and teacher evaluation. *Dev Psychol.* 1991;27:682-688
24. Cole DA, Martin JM, Powers B. A competency-based model of child depression: A longitudinal study of peer, parent, teacher, and self-evaluations. *J Child Psychol Psychiatry.* 1997;38:505-514
25. Cole DA, Jacquez FM, Maschman TL. Social origins of depressive cognitions: A longitudinal study of self-perceived competence in children. *Cognitive Ther Res.* 2001;25:377-395
26. Bedford A, Foulds GA. *Delusions-Symptoms-States Inventory of Anxiety and Depression.* Windsor, UK: National Foundation for Educational Research; 1978

27. Spanier GB. Measuring dyadic adjustment: new scales for assessing the quality of marriage and similar dyads. *J Marriage Fam.* 1976;38:15-28
28. Barnes HL, Olson DH. 1985. Parent-adolescent communication and the Circumplex model. *Child Dev.* 56: 438-447
29. Achenbach TM, Edelbrock C. Manual for the Child Behaviour Check List and Revised Child Behaviour Profile. Burlington, USA: University of Vermont Department of Psychiatry; 1983
30. Achenbach TM, Edelbrock C. Behavioural problems and competencies reported by parents of normal and disturbed children aged four through sixteen. *Monogr Soc Res Child Dev.* 1981;46:1-82
31. Najman JM, Behrens BC, Andersen M, Bor W, O'Callaghan M, Williams GM. Impact of family type and family quality on child behaviour problems: a longitudinal study. *J Am Acad Child Adolesc Psychiatry.* 1997;36:1357-65
32. Raven JC. *Progressive Matrices: A Perceptual Test of Intelligence.* London, UK: HK Lewis & Co.;1938
33. De Lemos MM. *Standard Progressive Matrices: Australian Manual.* Melbourne, VIC: Australian Council for Educational Research, 1986
34. Hogan JW, Roy J, Korkontzelou C. Handling drop-out in longitudinal studies. *Stat Med.* 2004;23:1455-1497
35. Maguin E, Loeber R. How well do ratings of academic performance by mothers and their sons correspond to grades, achievement test scores, and teachers' ratings? *J Beh Educ.* 1996;6: 405-425

TABLE 1 School Performance at 14 years According to Maternal Smoking Category
(before &/or after pregnancy, during pregnancy or never smoked)

		Maternal Smoking Category			
School performance	N	Never smoked (n=2182) %	Smoked before and /or after pregnancy but NOT during pregnancy (n=524) %	Smoked during pregnancy and at other times (n=1594) %	p-value
English					
Below average	190	3.94	3.82	5.27	
A bit below average	390	8.48	9.54	9.72	
Average	1779	39.83	39.50	44.10	
A bit above average	1231	30.16	29.39	26.29	
Above average	710	17.60	17.75	14.62	<0.007
Mathematics					
Below average	314	5.78	6.30	9.72	
A bit below average	615	13.02	13.36	16.37	
Average	1483	34.07	33.97	35.26	
A bit above average	1027	25.03	25.76	21.71	
Above average	860	22.10	20.61	16.94	<0.001
Science					
Below average	250	5.09	5.54	6.91	

A bit below average	511	10.96	11.28	13.38	
Average	1632	36.15	41.49	39.38	
A bit above average	1142	28.81	25.62	23.87	
Above average	745	18.85	15.30	15.95	<0.001
Self-average: composite indicator					
Below average	96	1.79	1.53	3.07	
A bit below average	267	5.09	6.87	7.53	
Average	1838	40.83	42.56	45.42	
A bit above average	1419	34.33	34.92	30.55	
Above average	680	17.97	14.12	13.43	<0.001
Mother-average: composite indicator					
Below average	260	5.50	7.06	6.46	
A bit below average	510	9.99	11.26	14.62	
Average	1578	35.79	36.83	37.89	
A bit above average	1038	25.02	24.05	22.96	
Above average	914	23.69	20.80	18.07	<0.001
Statistical test = chi squared					

TABLE 2 Multivariable Linear Regression Models showing Mean Difference in School Performance by Maternal Smoking Category, Adjusting for Potential Confounders and Mediators (N=3963)

Model Number	Maternal Smoking Category		
	Never smoked* (n=2042)	Smoked before and /or after pregnancy but NOT during pregnancy (n=476)	Smoked during pregnancy (n=1455)
1	0	-0.44 (-0.85,-0.03)	-0.93 (-1.21,-0.66)
2	0	-0.25 (-0.66, 0.16)	-0.51 (-0.80,-0.21)
3	0	-0.42 (-0.83,-0.02)	-0.85 (-1.12,-0.57)
4	0	-0.29 (-0.69, 0.11)	-0.75 (-1.03,-0.48)
5	0	-0.18 (-0.58, 0.22)	-0.40 (-0.69,-0.12)

Multivariable linear regression models adjusted by

1. exact age at 14 and sex
2. factors in model 1 plus maternal age, education, income, marital status, depression, alcohol consumption at FCV, birth weight and breastfeeding reported at 6 month follow-up
3. factors in model 1 plus family communication at 14 years
4. factors in model 1 plus behavioural problems (CBCL externalizing and internalizing) at 14 years
5. all covariates

* Reference category

TABLE 3 Multinomial logistic regression models showing Odds Ratios and 95% Confidence Intervals for Quintiles of Total Learning Score by Maternal Smoking Categories, Adjusting for Potential Confounders and Mediators (N=3963)

Model number	Quintiles of composite indicator (3 rd quintile as reference)	Maternal Smoking Category		
		Never smoked* (n=2042)	Smoked before and /or after pregnancy but NOT during pregnancy (n=476)	Smoked during pregnancy (n=1455)
1	Q1	1	1.01 (0.74,1.38)	1.61 (1.30,2.00)
	Q2	1	0.99 (0.72,1.36)	1.27 (1.01,1.58)
	Q3	1	1	1
	Q4	1	0.91 (0.66,1.26)	1.10 (0.88,1.38)
	Q5	1	0.77 (0.55,1.08)	0.81 (0.64,1.03)
2	Q1	1	0.94 (0.68,1.29)	1.40 (1.11,1.76)
	Q2	1	0.92 (0.66,1.27)	1.18 (0.93,1.49)
	Q3	1	1	1
	Q4	1	0.90 (0.65,1.25)	1.14 (0.89,1.45)
	Q5	1	0.80 (0.57,1.13)	0.93 (0.72,1.20)
3	Q1	1	1.01 (1.27,1.96)	1.58 (1.27,1.96)
	Q2	1	0.99 (0.72,1.36)	1.26 (1.00,1.57)
	Q3	1	1	1
	Q4	1	0.91 (0.66,1.26)	1.11 (0.89,1.39)

	Q5	1	0.77 (0.55,1.08)	0.82 (0.65,1.05)
4	Q1	1	0.95 (0.69,1.30)	1.51 (1.21,1.87)
	Q2	1	0.98 (0.72,1.35)	1.25 (1.00,1.56)
	Q3	1	1	1
	Q4	1	0.93 (0.67,1.28)	1.11 (0.89,1.39)
	Q5	1	0.78 (0.56,1.10)	0.83 (0.65,1.06)
5	Q1	1	0.90 (0.65,1.24)	1.35 (1.07,1.70)
	Q2	1	0.91 (0.66,1.26)	1.16 (0.91,1.47)
	Q3	1	1	1
	Q4	1	0.91 (0.66,1.26)	1.14 (0.90,1.45)
	Q5	1	0.81 (0.57,1.14)	0.95 (0.73,1.23)

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1. adjusted by exact age at 14 and sex
 2. adjusted by factors in Model 1 plus maternal age, education, income, marital status, depression and alcohol consumption at FCV, birth weight and breastfeeding reported at 6 month follow-up
 3. adjusted by factors in Model 1 plus family communication at 14 years
 4. adjusted by factors in Model 1 plus behavioural problems (CBCL externalizing and internalizing) at 14 years
 5. all covariates

* Reference category