

Trajectories of socioeconomic inequalities in health, behaviours and academic achievement across childhood and adolescence

Online-Only Supplementary Material

Measurement of health outcomes

The child's main caregiver (usually the mother) was asked to assess the child's overall health over the past 12-month period in self-completed questionnaires when the child was aged approximately 30 months (infancy), 81 months (7 years), 103 months (9 years), and 140 months (11 years). The question was phrased as "How would you assess the health of your child [in the past year]?" and had four possible responses: 1) very healthy, no problems, 2) healthy, but a few minor problems, 3) sometimes quite ill, and 4) almost always unwell. Categories 3 and 4 were grouped due to low frequencies.

Birth length (crown-heel) was measured by ALSPAC staff who visited newborns soon after birth (median 1 day, range 1-14 days), using a Harpenden Neonatometer (Holtain Ltd). At ages 7, 9, 11 and 15 years, height was measured at research clinics to the last complete mm using the Harpenden Stadiometer.¹

Total body fat mass was assessed at clinics at ages 9, 11 and 15 years by dual X-ray absorptiometry (DXA) scan using a Lunar prodigy narrow fan beam densitometer with paediatric scanning software (GE Healthcare Bio-Sciences Corp., USA). Bone mineral density (BMD) was also assessed from the DXA scans at ages 9, 11 and 15 years.^{2,3} Bone mineral content (grams) was divided by bone area (cm²) for the total body minus head. The total body less head (TBLH) region was used because bone development in the head is different from the rest of the skeleton and less likely to be influenced by environmental factors. The coefficient of variation for TBLH BMD was 0.84% based on 122 pairs of scans repeated on the same day. For both fat mass and BMD, variables were derived after exclusion of those scans containing artefacts, movement or skeletal irregularities

Blood measures (total cholesterol, high density lipoprotein cholesterol (HDLc), triglycerides, CRP) were measured at clinics at ages 9 from non-fasting blood samples and from the 15-year clinic from fasting samples.^{4,5} Protocols for taking blood and laboratory methods were the same at both clinics. At the 15 year clinic only, participants were asked to fast overnight (for those attending in the morning) or for at least 6 hours for those attending after lunch. Blood samples were immediately spun and frozen at -80°C. Measurements were assayed in batches shortly (3-9 months) after samples were taken with no previous freeze-thaw cycles during this period. Plasma lipids (total cholesterol, triglycerides and HDLc) were performed by modification of the standard Lipid Research Clinics Protocol using enzymatic reagents for lipid determination.

Blood pressure (BP) was measured at clinics at ages 7, 9, 11 and 15 years using a Dinamap 9301 Vital Signs Monitor (Morton Medical, London, UK). Arm circumference was measured prior to blood pressure assessment and used to determine the correct cuff size. Two readings of systolic and diastolic BP (SBP and DBP) were recorded, with the child at rest and their arm supported; the mean of the two measures from each clinic was used in all analyses.

Measurement of behavioural outcomes

The Strengths and Difficulties questionnaire (SDQ) is a 25 item instrument for assessing social, emotional and behavioural functioning that has become a widely used research instrument for the mental health of children^{6,7}. It is also used as a screening tool for identifying cases with psychiatric disorders.⁶ The SDQ questions cover positive and negative attributes and respondents answer each with a response “Not True” (0), “Somewhat True” (1), or “Certainly True” (2). Answers to the 25 questions are grouped into five scales of five items each, so generating scores from 0 to 10 for emotional symptoms, conduct problems, hyperactivity-inattention, peer problems and pro-social behaviour. The latter is not used in most research on child mental health and we follow this practice here, so we use the four dimensions of mental health. Higher scores denote more problems. In addition to using the four separate scores, the four scales were combined into a single total behavioural difficulties score, which has values between 0-40. Total scores were only calculated for individuals with complete data on all relevant questions. These data were collected for children at 81 months (7 years), 103 months (9 years), and 140 months (11 years). Each score was top-coded to group high scores with low frequencies as follows: total SDQ 14-15 grouped and ≥ 16 grouped; hyperactivity ≥ 9 grouped; emotional problems ≥ 6 grouped; conduct problems ≥ 5 grouped; peer problems ≥ 5 grouped. Although these top-coded measures were still right-skewed, log transformation did not improve distribution so untransformed variables were used in analyses.

Measurement of educational outcomes

The UK education system is divided into a number of ‘key stages’. Compulsory national tests mark the end of each key stage. Educational attainment data at key stages are available for ALSPAC participants from linkage with the National Pupil Database. We utilise attainment data from exams taken at the end of key stage 2 (approximate age 11) and key stage 3 (approximate age 14, but referred to as age 15 after this point for comparison with other outcomes in the paper), since comparable measures are available at these stages: scores in English, Mathematics, and Science tests. These scores were generated by summing all test scores in these subjects and converting to a percentage. A summary measure of educational attainment was generated by combining English, Mathematics and Science scores and converting to a percentage.

Analysis model details

The full specification of the random effects linear regression model is:

$$Y_{ij} = (\beta_0 + u_{0j}) + (\beta_1 + u_{1j})(Age_{ij}) + (\beta_2)(Maternal\ education_j) + (\beta_3)(Age_{ij} * Maternal\ education_j) + (\beta_4)(Gender_j) + \beta_5(Exact\ age_j) + e_{ij}$$

Where Y is the outcome, Age is the target age of clinic (0, 7, 9, 11 or 15) centred at the first measurement occasion for a given outcome, Maternal education is a continuous variable representing the proportion of individuals in the full cohort with a lower level of maternal education, Gender is male or female, and Exact age is the exact age in weeks at which outcome Y was measured.

For individual j at measurement occasion i:

- β_0 = average level of outcome at the first age of measurement
- β_1 = average estimate of change in outcome per additional year of age
- β_2 = average estimate of the change in Y comparing Maternal education = 1 (highest maternal education level, with 100% of the cohort having a lower maternal education level) to Maternal education = 0 (lowest maternal education level, with 0% of the cohort having a lower maternal education level) at the first age at which Y was measured. This corresponds to the SII presented in the tables.
- β_3 = average estimate of the change in β_2 for every year increase in Age. This corresponds to the age effects presented in the tables.
- β_4 = average change in Y comparing males to females
- β_5 = average change in Y for each week increase in the exact age at which Y was measured

Details of multiple imputation

We used multivariate multiple imputation to impute missing variables, including all covariables and potential predictors in the imputation equations. We used switching regression in Stata as described by Royston.⁸ We carried out 20 cycles of regression switching and generated 20 imputation datasets. The multiple multivariate imputation approach creates a number of copies of the data (in this case we generated 20 copies) each of which has imputed values for those that are missing, with an appropriate level of randomness, by chained equations.⁸ The main analysis results are obtained by averaging across the results from each of these 20 datasets using Rubin's rules and the procedure takes account of uncertainty in the imputation as well as uncertainty due to random variation.⁸ Imputations were carried out separately by clinic and gender, in order to respect interactions in our main model. We imputed data for all individuals with at least one outcome measure, so the results from this analysis are based on 12,489 individuals.

Table S1: Socioeconomic inequalities, and changes in these over childhood: sensitivity analysis to explore the consequences of missing data

Outcome		Model		Model		Model		Multiple imputation, N=12489
		Individuals with 1+ measure included	N	Individuals with 2+ measures included	N	Individuals with all available measures included	N	
Health measures								
Parent-assessed	SII: Age:	0.066 (-0.004 to 0.137) -0.006 (-0.014 to 0.003)	10663	0.060 (-0.016 to 0.136) -0.005 (-0.014 to 0.003)	8855	0.106 (0.005 to 0.207) -0.007 (-0.018 to 0.003)	4833	-0.050 (-0.342 to 0.243) 0.006 (-0.026 to 0.037)
Height, cm	SII: Age:	0.155 (0.089 to 0.222) 0.012 (0.004 to 0.019)	11463	0.136 (0.058 to 0.213) 0.012 (0.005 to 0.020)	8249	0.053 (-0.067 to 0.173) 0.009 (-0.001 to 0.019)	3171	0.380 (0.253 to 0.507) -0.005 (-0.017 to 0.007)
ln Total fat-mass (m)	SII: Age:	-0.079 (-0.200 to 0.041) 0.001 (-0.016 to 0.018)	3799	-0.104 (-0.238 to 0.030) 0.002 (-0.015 to 0.019)	3050	-0.134 (-0.302 to 0.035) -0.011 (-0.014 to 0.024)	1920	-0.011 (-0.104 to 0.081) -0.024 (-0.047 to -0.001)
ln Total fat-mass (f)	SII: Age:	-0.287 (-0.407 to -0.167) -0.014 (-0.031 to 0.003)	3843	-0.310 (-0.442 to -0.178) -0.013 (-0.031 to 0.004)	3174	-0.342 (-0.507 to -0.178) 0.005 (-0.030 to 0.008)	2093	-0.208 (-0.308 to -0.114) -0.023 (-0.042 to -0.004)
Cholesterol	SII: Age:	-0.124 (-0.229 to -0.019) 0.020 (-0.001 to 0.041)	5560	-0.144 (-0.294 to 0.006) 0.022 (-0.001 to 0.045)	2317	-0.144 (-0.294 to 0.006) 0.022 (-0.001 to 0.045)	2317	-0.123 (-0.237 to -0.010) 0.016 (-0.017 to 0.050)
ln Triglycerides	SII: Age:	0.022 (-0.084 to 0.129) -0.004 (-0.029 to 0.020)	5560	0.048 (-0.101 to 0.197) -0.001 (-0.030 to 0.027)	2317	0.048 (-0.101 to 0.197) -0.001 (-0.030 to 0.027)	2317	0.011 (-0.099 to 0.121) 0.010 (-0.021 to 0.040)
HDL cholesterol (m)	SII: Age:	-0.099 (-0.241 to 0.044) 0.014 (-0.014 to 0.043)	2803	-0.186 (-0.402 to 0.029) 0.021 (-0.011 to 0.052)	1151	-0.186 (-0.402 to 0.029) 0.021 (-0.011 to 0.052)	1151	-0.058 (-0.211 to 0.095) -0.012 (-0.059 to 0.035)
HDL cholesterol (f)	SII: Age:	0.100 (-0.047 to 0.247) 0.024 (-0.004 to 0.051)	2757	0.155 (-0.056 to 0.365) 0.021 (-0.010 to 0.052)	1166	0.155 (-0.056 to 0.365) 0.021 (-0.010 to 0.052)	1166	0.057 (-0.081 to 0.195) 0.034 (-0.001 to 0.169)
ln C-reactive protein (m)	SII: Age:	-0.029 (-0.183 to 0.124) 0.001 (-0.036 to 0.038)	2803	-0.003 (-0.227 to 0.222) -0.011 (-0.056 to 0.034)	1151	-0.003 (-0.227 to 0.222) -0.026 (-0.056 to 0.034)		-0.054 (-0.217 to 0.108) 0.002 (-0.045 to 0.049)
ln C-reactive protein(f)	SII: Age:	-0.238 (-0.394 to -0.082) -0.030 (-0.065 to 0.005)	2757	-0.203 (-0.426 to 0.021) -0.026 (-0.068 to 0.017)	1166	-0.203 (-0.426 to 0.021) -0.011 (-0.068 to 0.017)	1166	-0.199 (-0.334 to -0.063) -0.026 (-0.061 to 0.009)
SBP	SII: Age:	-0.278 (-0.354 to -0.202) 0.025 (0.011 to 0.039)	8488	-0.266 (-0.348 to -0.184) 0.024 (0.010 to 0.039)	6961	-0.224 (-0.336 to -0.113) 0.026 (0.008 to 0.043)	3559	-0.256 (-0.325 to -0.187) 0.030 (0.013 to 0.047)
DBP	SII: Age:	-0.239 (-0.314 to -0.164) 0.020 (0.005 to 0.035)	8487	-0.231 (-0.312 to -0.151) 0.021 (0.005 to 0.036)	6962	-0.153 (-0.263 to -0.044) 0.012 (-0.007 to 0.031)	3557	-0.230 (-0.289 to -0.170) 0.024 (0.009 to 0.040)
Bone mineral density	SII: Age:	0.116 (0.032 to 0.200) -0.013 (-0.025 to -0.002)	7642	0.078 (-0.015 to 0.170) -0.012 (-0.024 to -0.001)	6224	0.079 (-0.039 to 0.196) -0.008 (-0.021 to 0.005)	4013	0.155 (0.077 to 0.233) -0.011 (-0.034 to 0.011)

Outcome		Model		Model		Model		Multiple imputation, N=12489
		Individuals with 1+ measure included	N	Individuals with 2+ measures included	N	Individuals with all available measures included	N	
Behaviour measures:								
Total difficulties	SII: Age:	-0.393 (-0.474 to -0.312) 0.004 (-0.018 to 0.025)	8708	-0.320 (-0.412 to -0.229) 0.000 (-0.023 to 0.022)	6543	-0.238 (-0.350 to -0.126) -0.003 (-0.029 to 0.022)	4040	-0.414 (-0.490 to -0.338) -0.002 (-0.032 to 0.027)
Hyperactivity (m)	SII: Age:	-0.345 (-0.457 to -0.234) 0.003 (-0.026 to 0.032)	4443	-0.391 (-0.513 to -0.270) 0.005 (-0.023 to 0.033)	3685	-0.372 (-0.513 to -0.231) 0.005 (-0.026 to 0.036)	2574	-0.393 (-0.495 to -0.290) 0.001 (-0.035 to 0.036)
Hyperactivity (f)	SII: Age:	-0.505 (-0.621 to -0.390) 0.013 (-0.017 to 0.044)	4265	-0.474 (-0.597 to -0.351) 0.008 (-0.021 to 0.037)	3582	-0.453 (-0.598 to -0.308) 0.005 (-0.028 to 0.037)	2524	-0.503 (-0.613 to -0.313) -0.001 (-0.035 to 0.033)
Conduct problems	SII: Age:	-0.261 (-0.341 to -0.180) -0.012 (-0.036 to 0.011)	8708	-0.250 (-0.334 to -0.165) -0.013 (-0.036 to 0.010)	7326	-0.216 (-0.313 to -0.119) -0.010 (-0.035 to 0.015)	5169	-0.304 (-0.377 to 0.232) -0.003 (-0.033 to 0.027)
Peer problems	SII: Age:	-0.298 (-0.379 to -0.217) 0.031 (0.006 to 0.057)	8708	-0.287 (-0.374 to -0.200) 0.026 (0.001 to 0.051)	7063	-0.242 (-0.342 to -0.142) 0.034 (0.006 to 0.062)	4741	-0.300 (-0.379 to -0.221) 0.024 (-0.009 to 0.056)
Emotional problems	SII: Age:	-0.046 (-0.127 to 0.035) -0.028 (-0.053 to -0.003)	8708	-0.046 (-0.131 to 0.039) -0.030 (-0.054 to -0.006)	7353	0.060 (-0.038 to 0.158) -0.043 (-0.070 to -0.017)	5281	-0.051 (-0.134 to 0.032) -0.036 (-0.069 to -0.003)
Education measures:								
Overall attainment	SII: Age:	1.432 (1.368 to 1.495) -0.094 (-0.107 to -0.082)	10659	1.304 (1.234 to 1.374) -0.089 (-0.102 to -0.076)	8562	1.304 (1.234 to 1.374) -0.089 (-0.102 to -0.076)	8562	1.434 (1.374 to 1.494) 0.004 (-0.012 to 0.020)
English test scores	SII: Age:	1.363 (1.298 to 1.427) 0.036 (0.023 to 0.049)	10735	1.245 (1.175 to 1.316) 0.039 (0.025 to 0.052)	8793	1.245 (1.175 to 1.316) 0.039 (0.025 to 0.052)	8793	1.343 (1.282 to 1.404) 0.036 (0.018 to 0.054)
Mathematics test scores	SII: Age:	1.275 (1.210 to 1.340) -0.048 (-0.065 to -0.030)	10812	1.201 (1.129 to 1.274) -0.047 (-0.065 to -0.029)	8992	1.201 (1.129 to 1.274) -0.047 (-0.065 to -0.029)	8992	1.269 (1.208 to 1.330) -0.039 (-0.059 to -0.019)
Science test scores	SII: Age:	1.344 (1.281 to 1.408) -0.176 (-0.196 to -0.156)	10840	1.296 (1.226 to 1.367) -0.175 (-0.196 to -0.155)	9123	1.296 (1.226 to 1.367) -0.175 (-0.196 to -0.155)	9123	1.340 (1.279 to 1.402) -0.171 (-0.193 to -0.149)

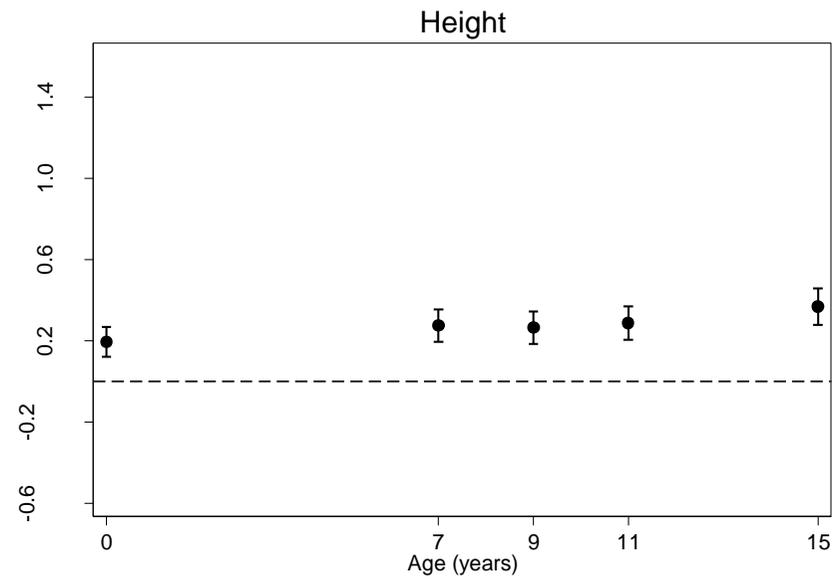
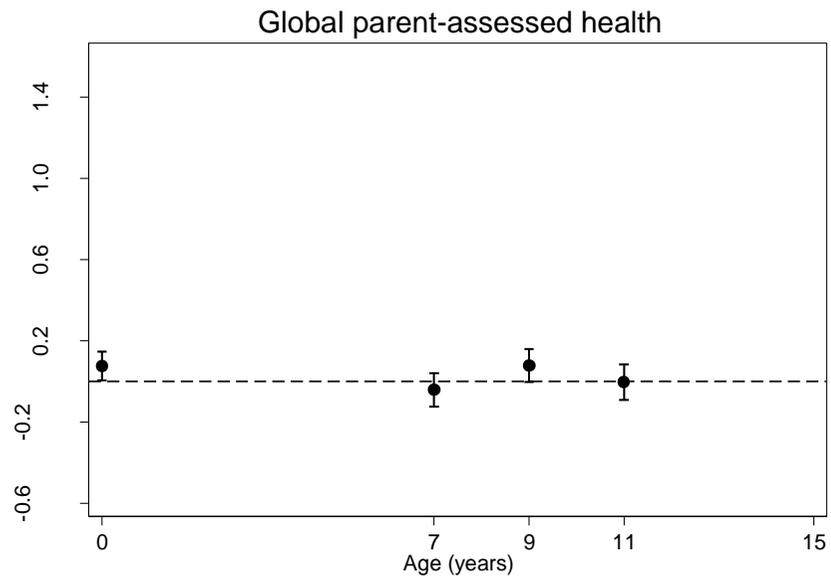
Notes:

SII is the slope index of inequality. It represents the mean difference in standard deviations of the outcome between the individuals with the hypothetical highest and lowest SEP maternal education at baseline (intercept) – i.e. at the first age at which outcomes were assessed. The age coefficient represents the additional change in standard deviations of the outcome between the hypothetical highest and lowest SEP for every one year increase in the child's age. 95% confidence intervals are calculated using robust standard errors. Results are adjusted for the child's exact age in weeks at the time of outcome measurement and the child's gender. Fat-mass is additionally adjusted for height and height squared. SBP is systolic blood pressure. DBP is diastolic blood pressure. N is the sample size for each analysis. Analyses were run 1) including all individuals with at least one measurement for a given outcome, 2) restricting to individuals with at least two measurements for a given outcome, 3) restricting to individuals measured at each possible occasion for a given outcome, and 4) for all individuals with at least one measurement for

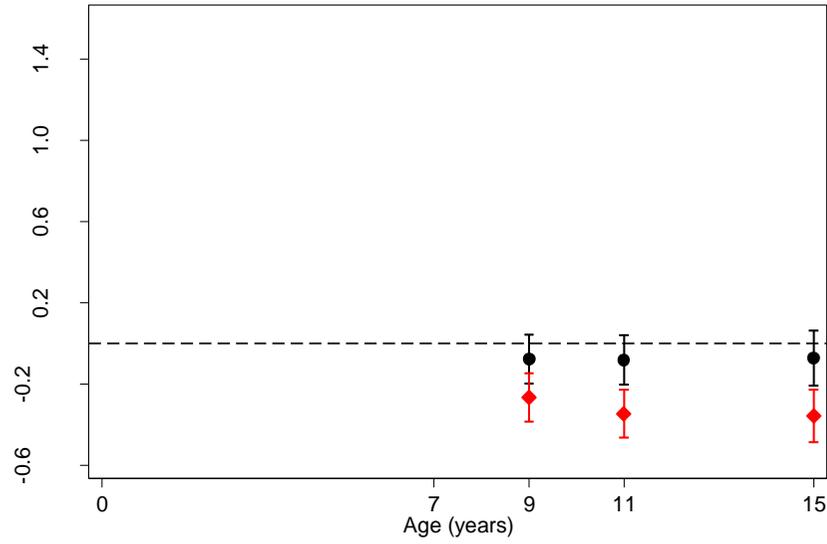
any outcome, using multiple imputation to impute missing values, including all outcomes and several socioeconomic and family characteristics in the imputation model, and combining the results from 20 imputation datasets using Rubin's rules (details in **S4**).

Figure S1: Slope index of inequality (and 95% confidence interval) for health, behavioural and educational outcomes at each time point across childhood and adolescence: examining whether the change in SII is linear across time

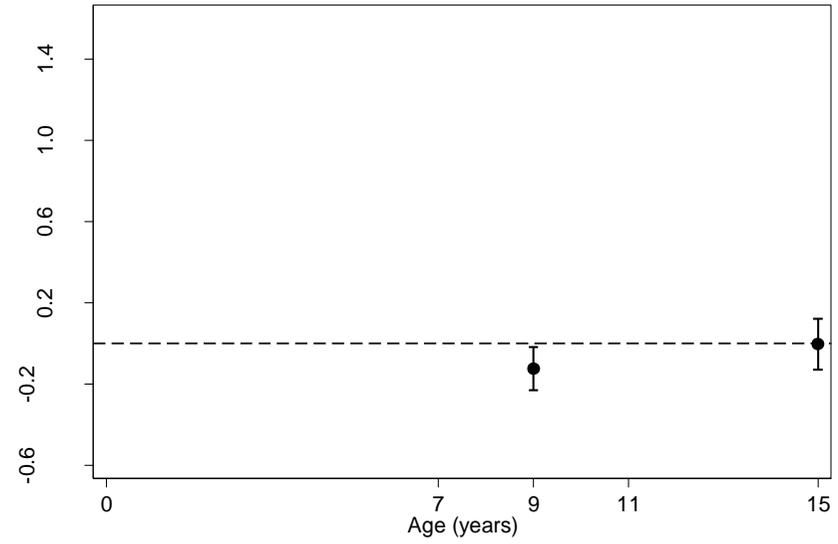
The SII represents the mean difference (in standard deviation units) between the highest and lowest value of maternal education at each age of assessment. The dashed line on each figure illustrates the null value (of 0) and all individual figures have axes that are identically scaled so that comparisons of magnitudes of inequalities for different outcomes across age can be directly compared. For outcomes where there is evidence of gender interactions (total fat-mass, HDLc, CRP and hyperactivity), black circles indicate males and red diamonds indicate females. For all other outcomes, black circles indicate males and females combined, with adjustment for gender. All analyses are adjusted for exact age at outcome measurement.

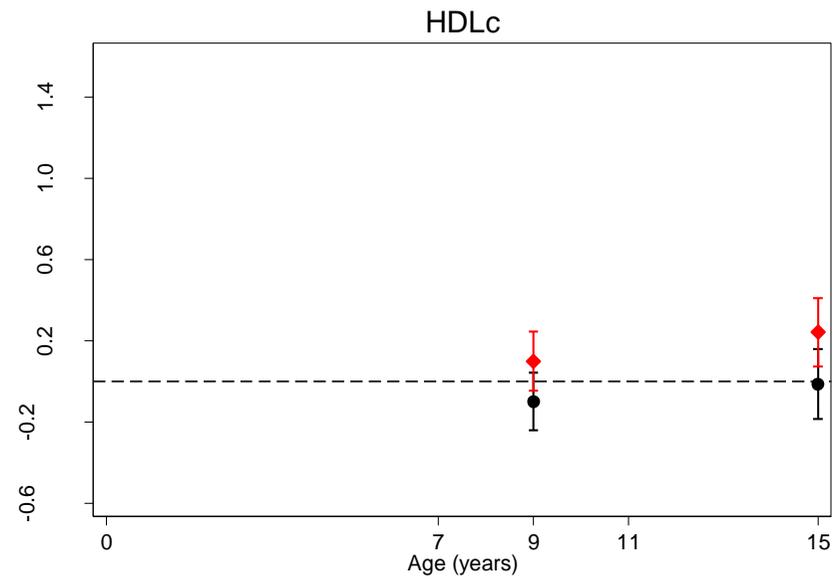
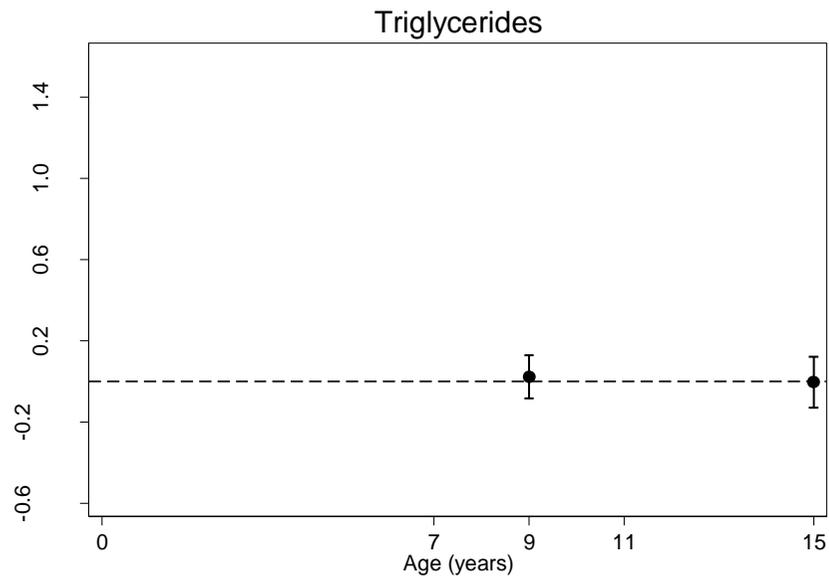


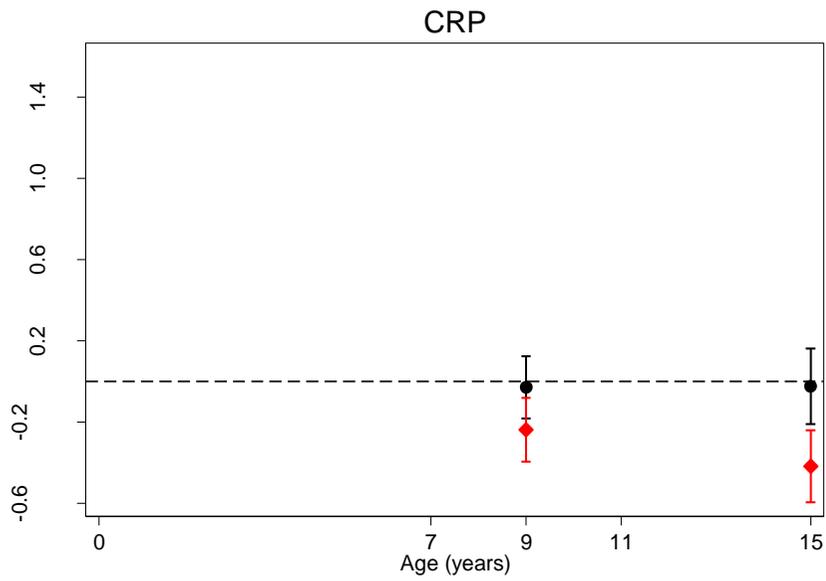
Total Fat Mass

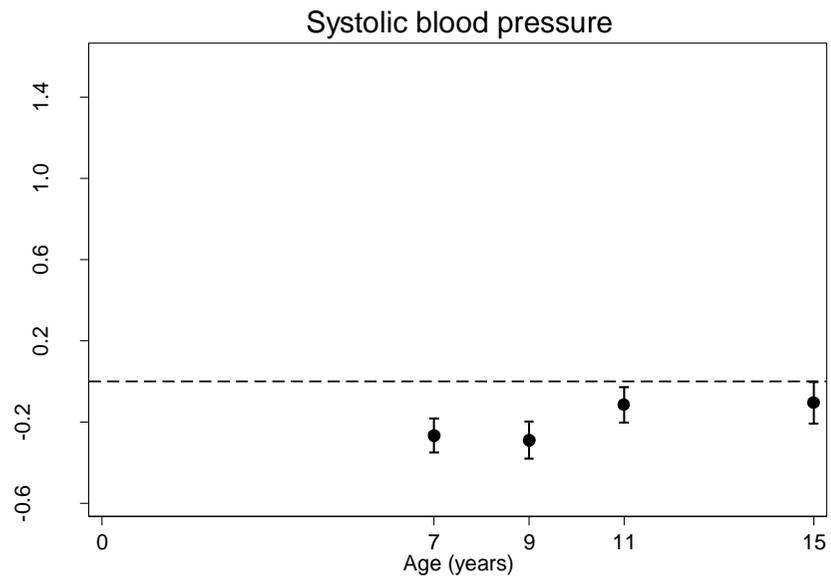


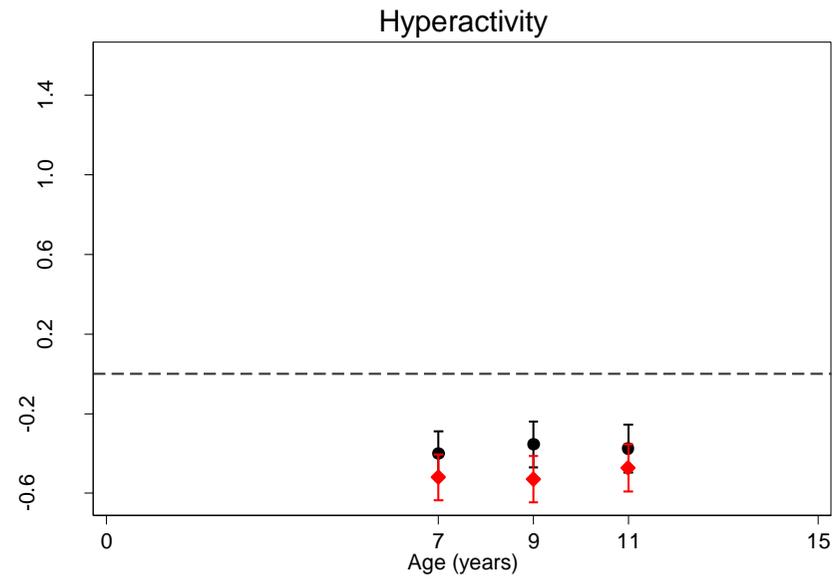
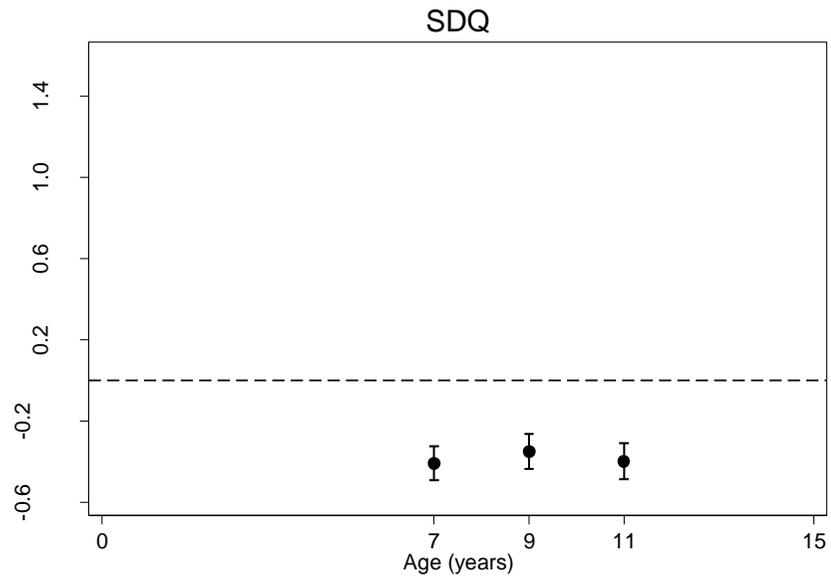
Cholesterol

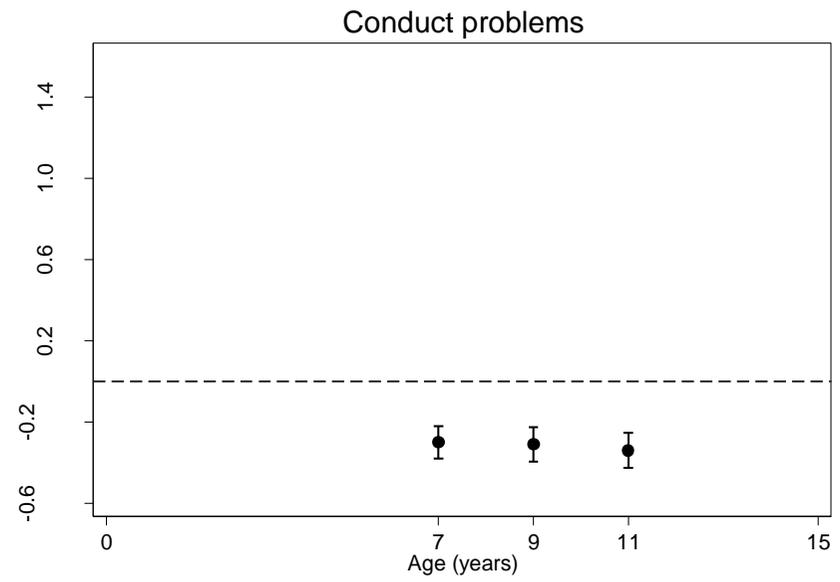
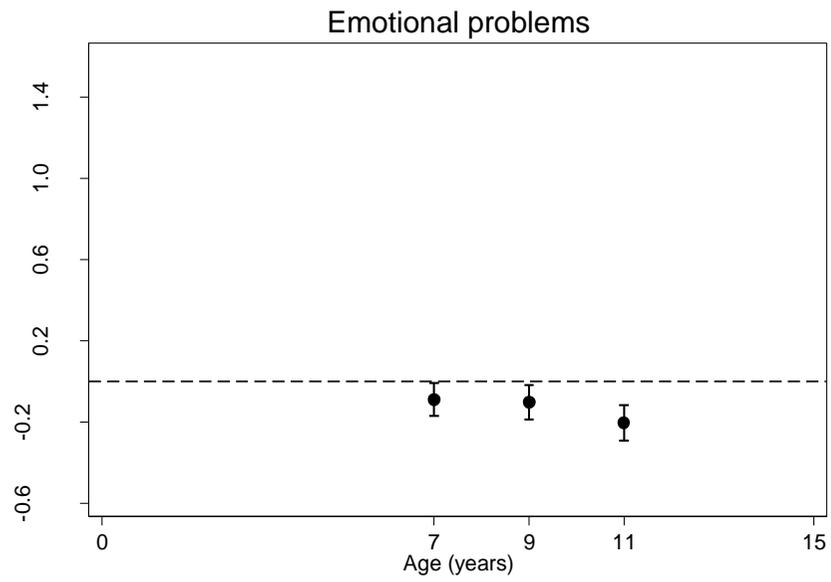




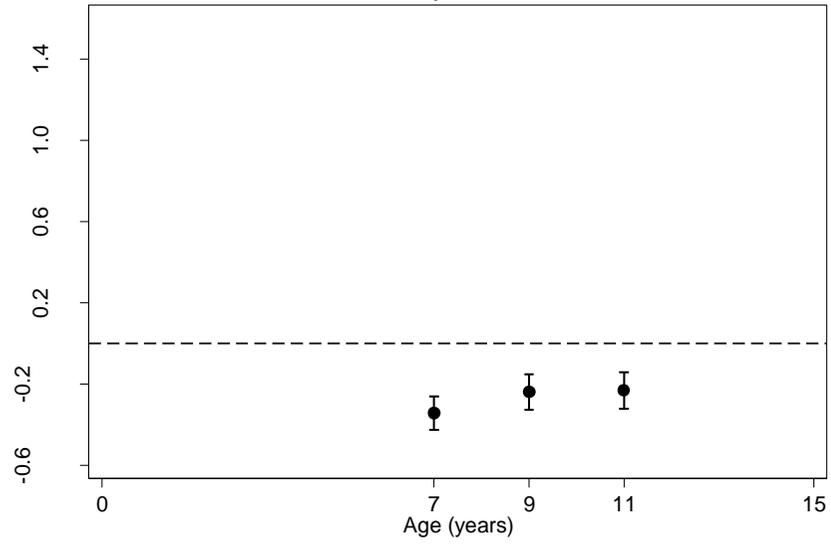




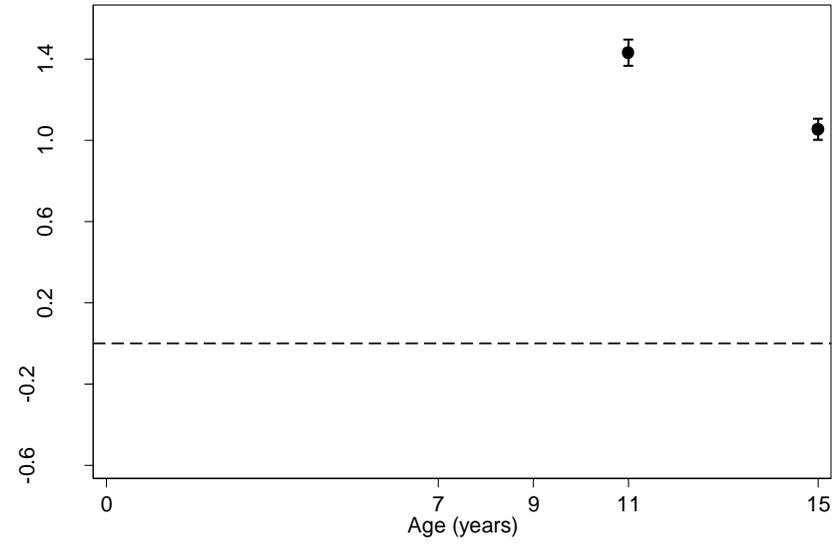




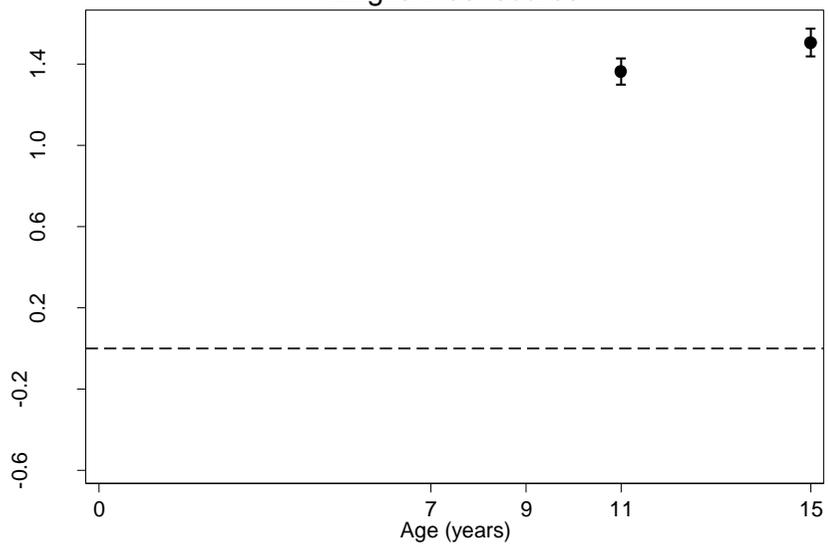
Peer problems



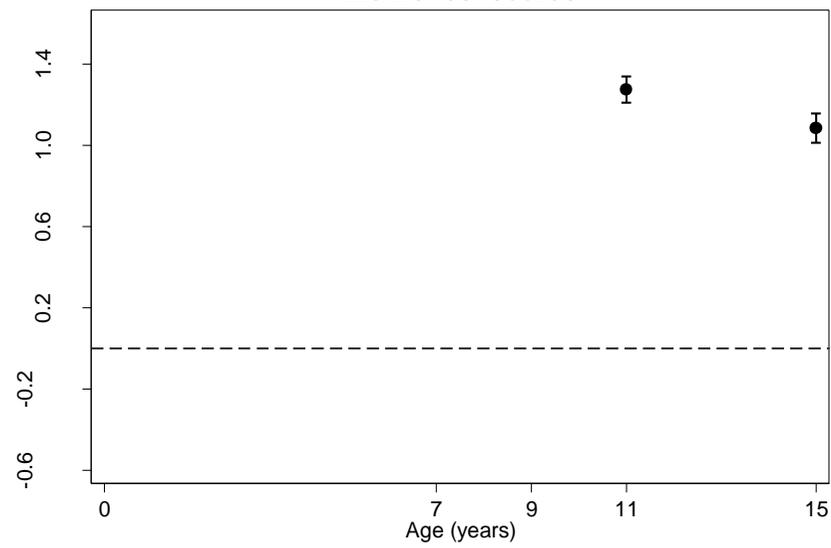
Educational attainment



English test scores



Maths test scores



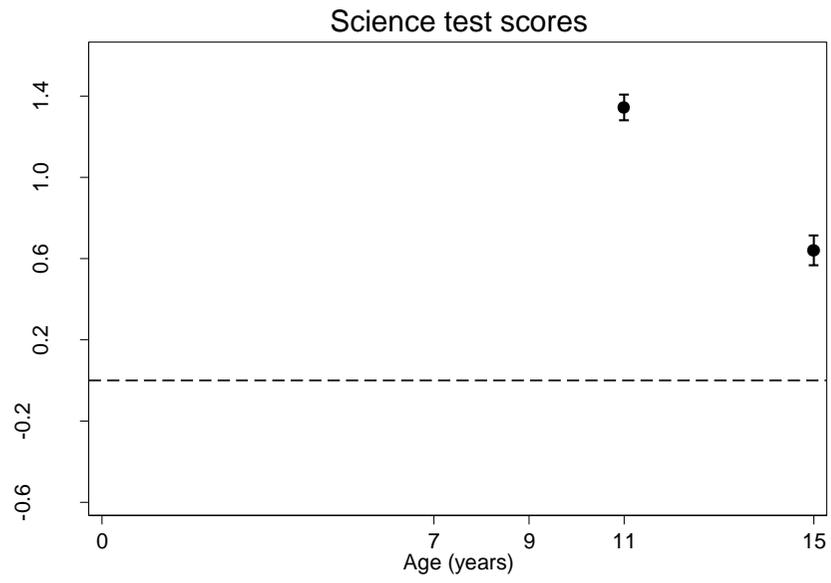
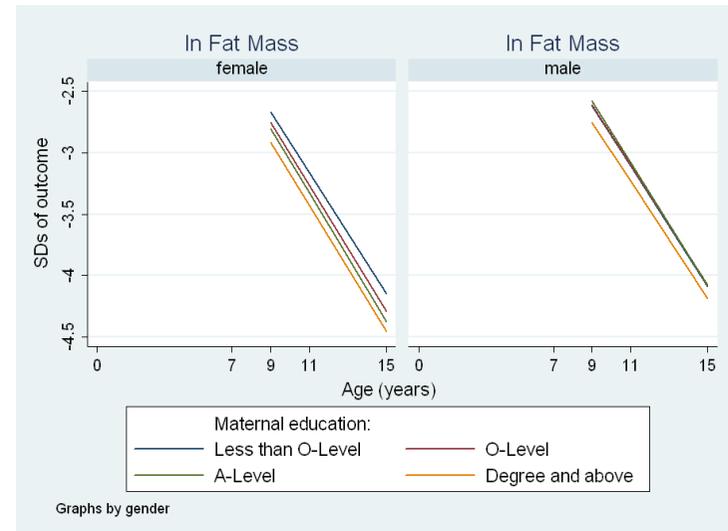
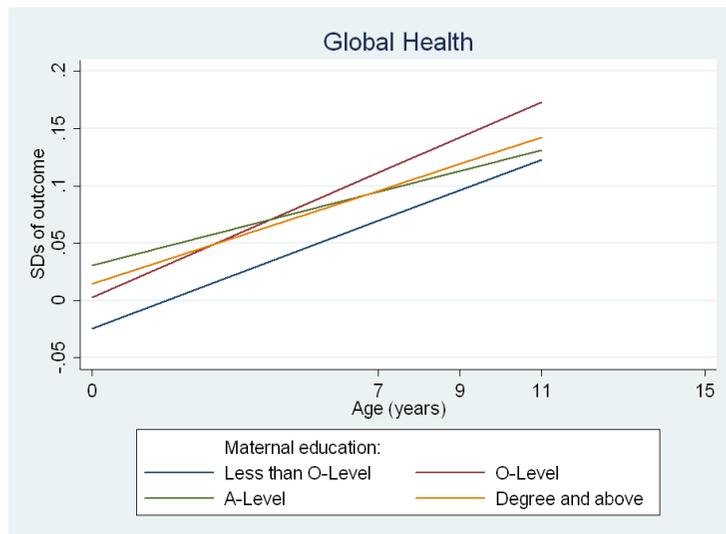
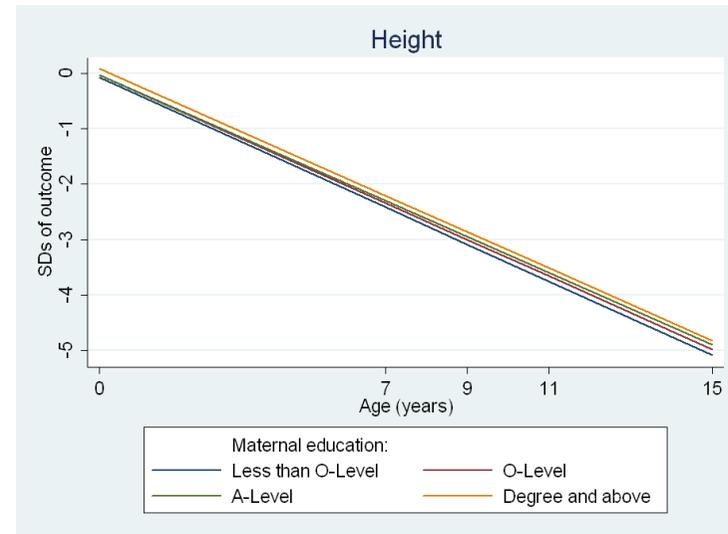
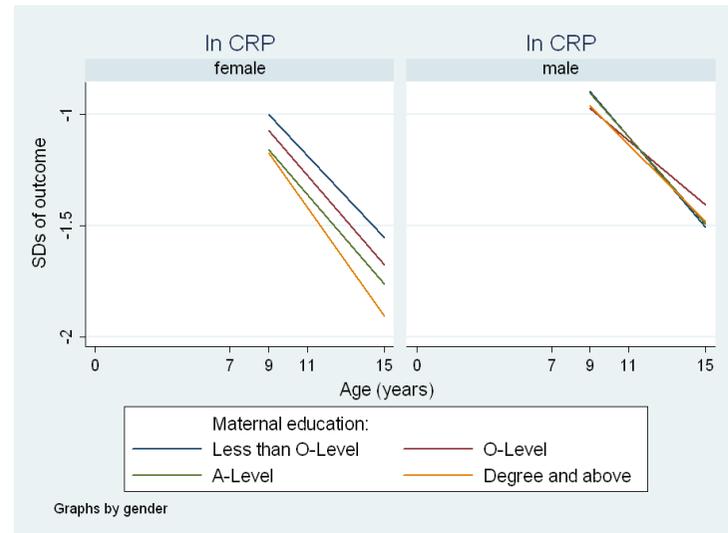
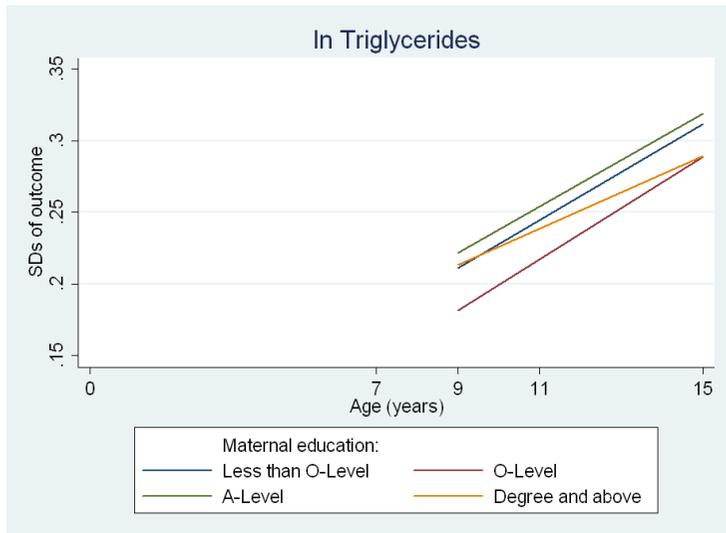
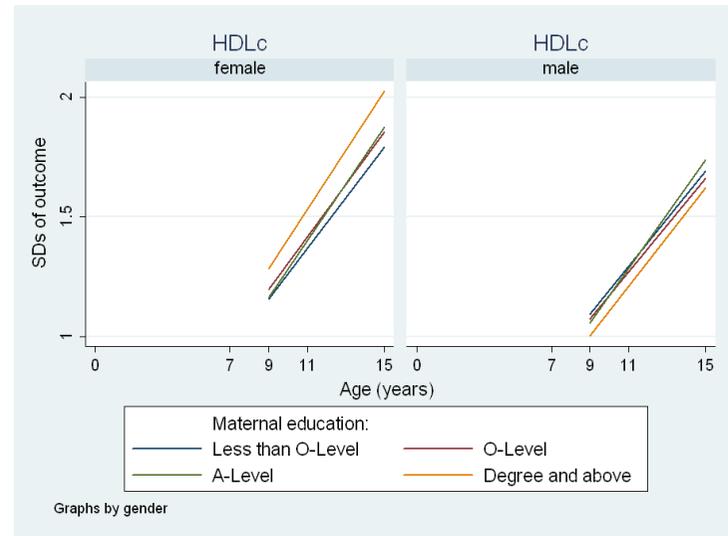
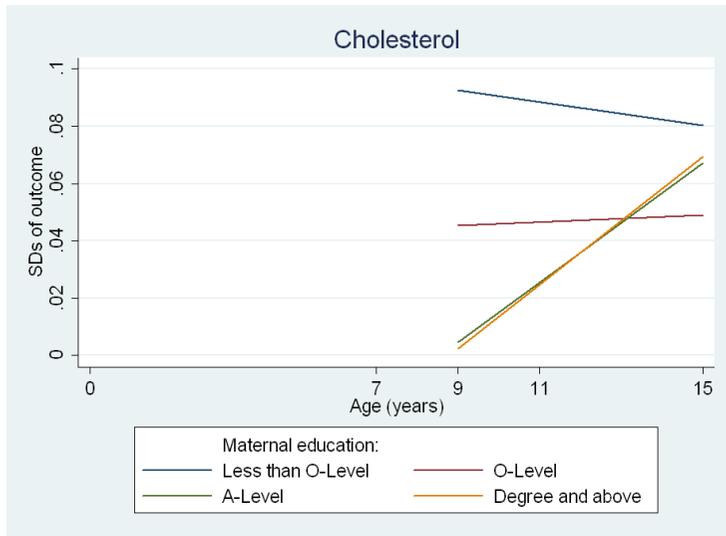
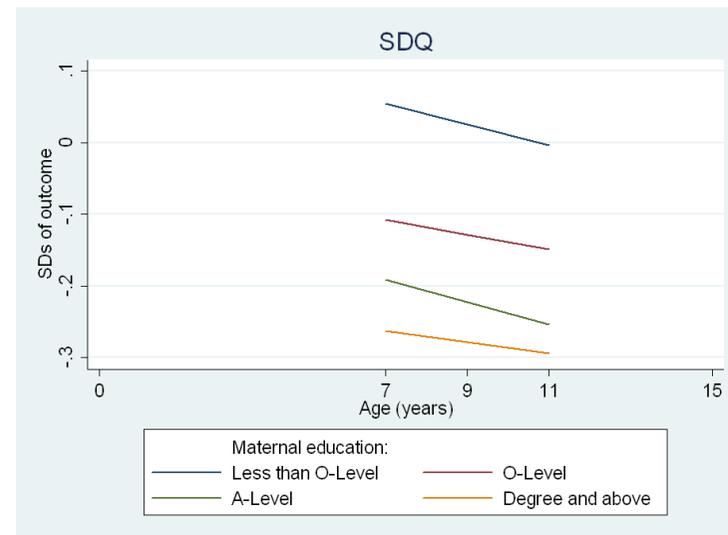
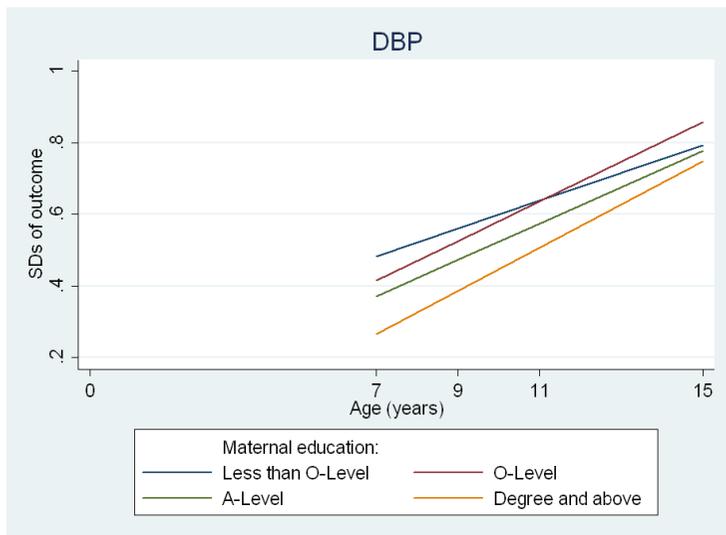
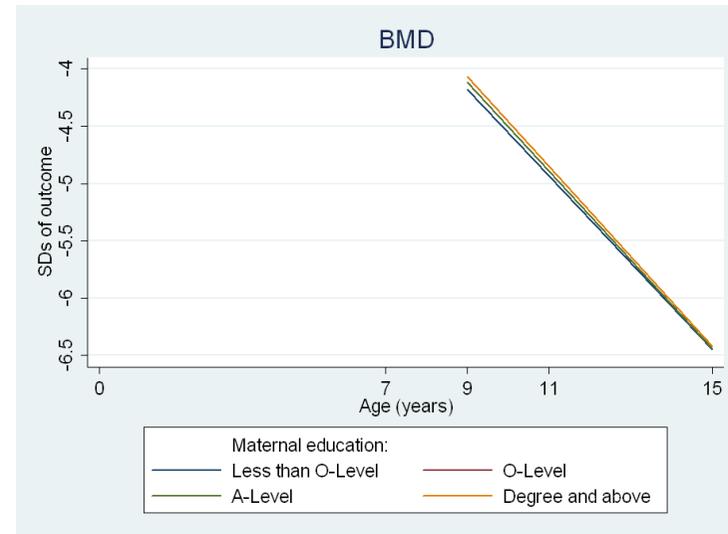
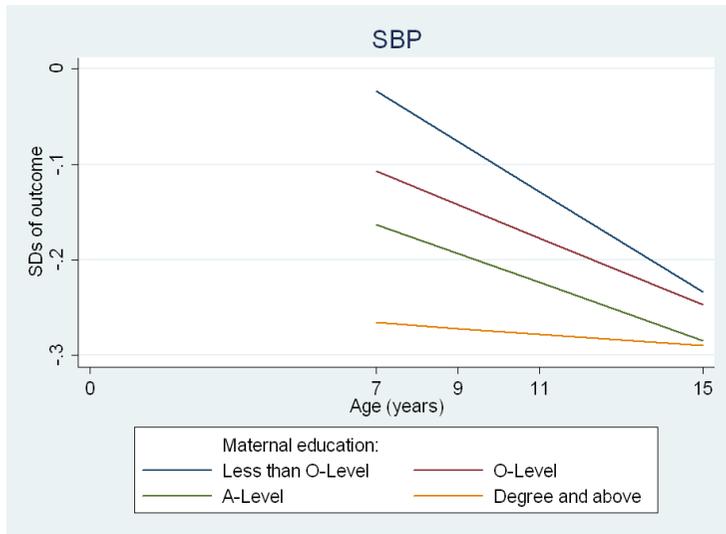


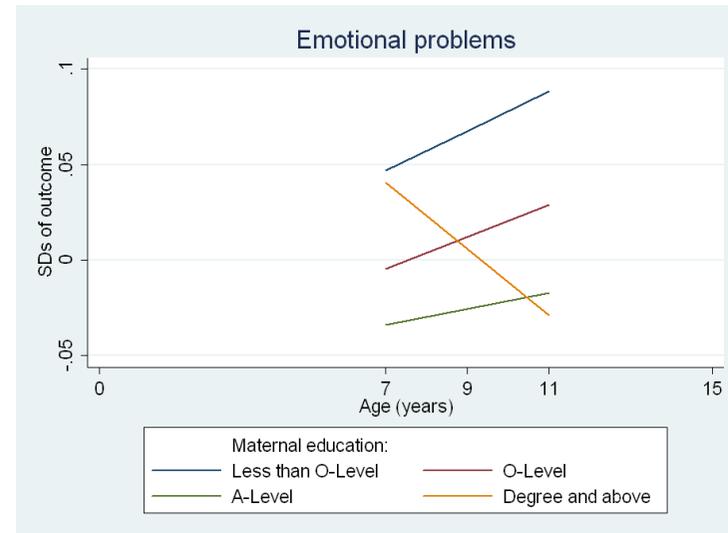
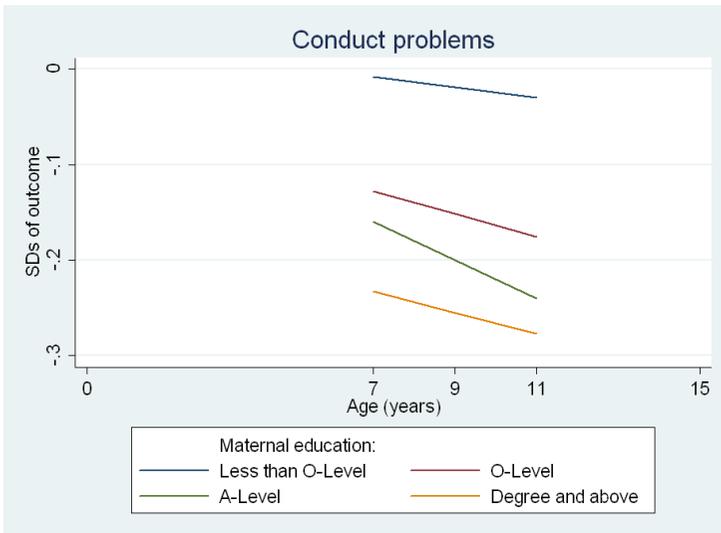
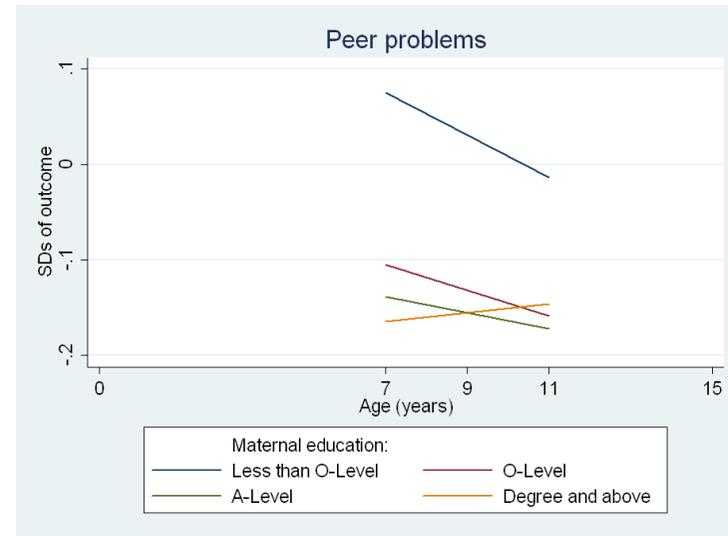
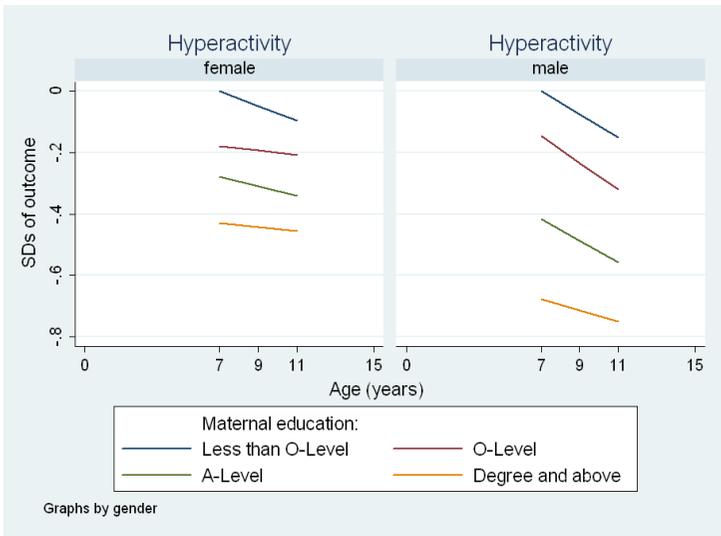
Figure S2: Graphs to examine whether the associations between maternal education and outcomes are linear across categories of maternal education

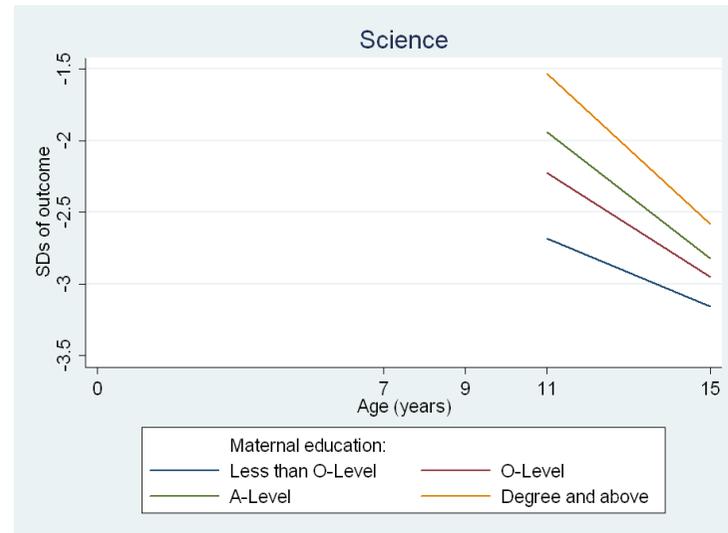
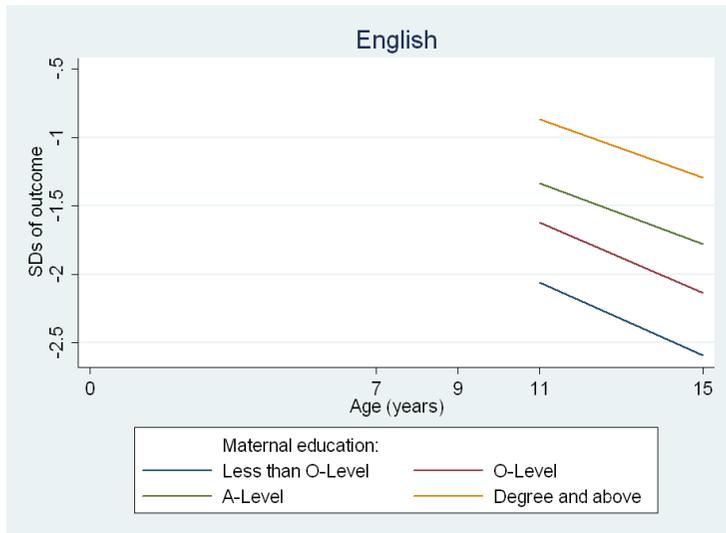
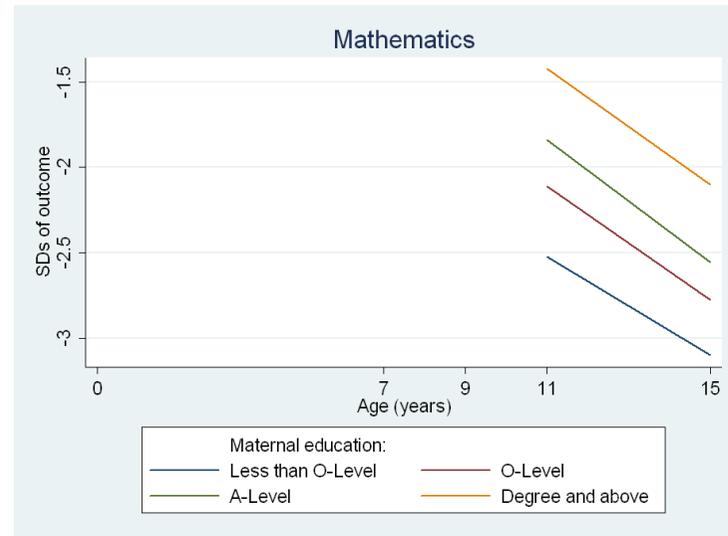
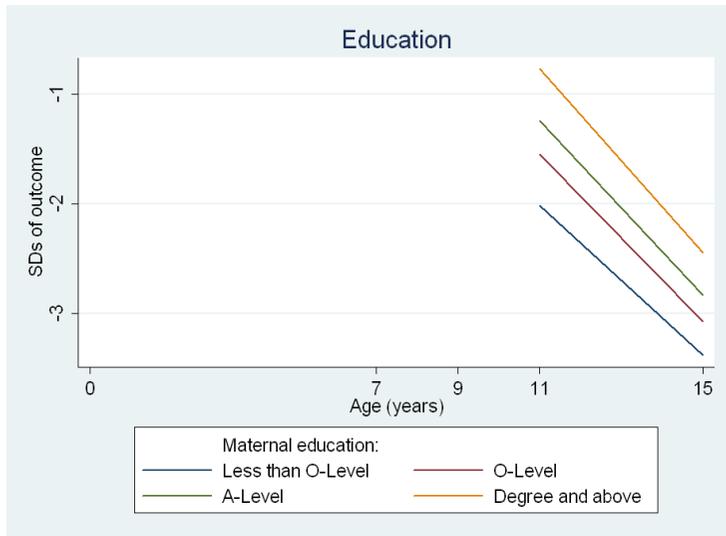
SDQ is a measure of total behavioural difficulties, and Education is a summary measure of attainment in English, mathematics and science tests. BMD is total body less head bone mineral density. SBP and DBP are systolic and diastolic blood pressure.











Supplementary material Reference List

1. Howe LD, Tilling K, Galobardes B, Davey Smith G, Gunnell D, Lawlor DA. Socioeconomic differences in childhood growth trajectories: at what age do height inequalities emerge? *Journal of Epidemiology & Community Health*. 2010; ePub ahead of print. doi:10.1136/jech.2010.113068.
2. Macdonald-Wallis C, Tobias JH, Davey Smith G, Lawlor DA. Parental smoking during pregnancy and offspring bone mass at age 10 years: findings from a prospective birth cohort. *Osteoporos Int*. 2010.
3. Macdonald-Wallis C, Tobias JH, Davey Smith G, Lawlor DA. Relation of maternal prepregnancy body mass index with offspring bone mass in childhood: is there evidence for an intrauterine effect? *Am J Clin Nutr*. 2010;92:872-880.
4. Howe LD, Tilling K, Benfield L, Logue J, Sattar N, Ness AR, et al. Changes in ponderal index and body mass index across childhood and their associations with fat mass and cardiovascular risk factors at age 15. *PLoS One*. 2010;5:e15186.
5. Lawlor DA, Benfield L, Logue J, Tilling K, Howe LD, Fraser A, et al. Association between general and central adiposity in childhood, and change in these, with cardiovascular risk factors in adolescence: prospective cohort study. *BMJ: British Medical Journal*. 2010;341:c6224.
6. Goodman R, Ford T, Simmons H, Gatward R, Meltzer H. Using the Strengths and Difficulties Questionnaire (SDQ) to screen for child psychiatric disorders in a community sample. *The British Journal of Psychiatry*. 2000;177:534-539.
7. Chittleborough CR, Lawlor DA, Lynch JW. Young Maternal Age and Poor Child Development: Predictive Validity From a Birth Cohort. *Pediatrics*. 2011; ePub ahead of print.
8. Royston P. Multiple imputation of missing values. *Stata Journal*. 2004;4:227-241.