Maternal educational inequalities in measured body mass index trajectories in three European countries

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SYNOPSIS

Study Question

This study examines maternal education differentials in children's body mass trajectories in 4 contemporary child cohorts in 3 European countries (Portugal, Ireland, United Kingdom).

What's already known?

Social inequalities in the prevalence of childhood overweight and obesity are well-established, but less is known about when the social gradient first emerges and how it evolves across childhood and adolescence.

What this study adds?

The social gradient in children's body mass index emerges in early life and widens across childhood and into early adolescence. Children from lower maternal education backgrounds gain body mass more quickly than their tertiary-level counterparts; are more likely to be obese at any age for which International Obesity Task Force cut-offs are available; and more likely to become obese if previously non-overweight reinforcing the need for early intervention.

ABSTRACT

Background

Social inequalities in the prevalence of childhood overweight and obesity are well-established, but less is known about when the social gradient first emerges and how it evolves across childhood and adolescence.

Objective

This study examines maternal education differentials in children's body mass trajectories in infancy, childhood and adolescence using data from four contemporary European child cohorts.

Methods

Prospective data on children's body mass index (BMI) was obtained from four cohort studies – Generation XXI (G21 - Portugal), Growing Up in Ireland (GUI) infant and child cohorts, and the Millennium Cohort Study (MCS - UK) – involving a total sample of 41,399 children and 120,140 observations. Children's BMI trajectories were modelled by maternal education level using mixed-effect models.

Results

Maternal educational inequalities in children's BMI were evident as early as three years of age. Children from lower maternal educational backgrounds were characterised by accelerated BMI growth and the extent of the disparity was such that boys from primary educated backgrounds measured 0.42 kg/m^2 (95% CI 0.24, 0.60) heavier at 7 years of age in G21, 0.90 kg/m^2 (95% CI 0.60, 1.19) heavier at 13 years of age in GUI, and 0.75 kg/m^2 (95% CI 0.52, 0.97) heavier in MCS at 14 years of age. The corresponding figures for girls were

0.71 kg/m^2 (95% CI 0.50, 0.91), 1.31 kg/m^2 (95% CI 1.00, 1.62), and 0.76 kg/m^2 (95% CI 0.53, 1.00) in G21, GUI and MCS respectively.

Conclusions

Maternal education is a strong predictor of BMI across European nations. Socio-economic differentials emerge early and widen across childhood, highlighting the need for early intervention.

Key words: social inequalities; body mass index; growth curves; cohort study; children; overweight; obesity

Word count: 3889

BACKGROUND

The rapid rise in the prevalence of childhood obesity represents a major public health concern[1] and has prompted calls for national Governments to do more to stem the rising tide.[2] According to a recent report, the global prevalence of obesity in the pre-school aged population increased from 4.5% in 1990 to 6.7% (45 million) in 2010, and is projected to rise to 9.1% (60 million) by 2020.[3] These figures are extremely concerning from a population health perspective because obesity tends to track and children who are overweight / obese in childhood are more likely to maintain this status into adolescence and adulthood [4-6] with deleterious downstream consequences for chronic disease risk in later life including increased risk of type 2 non-insulin dependent diabetes mellitus, hypertension, and cardiovascular disease.[7]

Studies have consistently shown that overweight and obesity is more heavily concentrated among children from lower socio-economic position (SEP) households[8-10]. However, the vast majority of studies are cross-sectional and little is known about when these socio-economic differences first emerge and evolve. The few available studies suggest that there is important cross-country variation. In particular, growth curve models suggest that the social gradient in BMI might emerge as early as 9 months in the US[11] but considerably later in European countries including the UK at around 4 years of age[12], between 3-4.5 years of age in the Netherlands[13] and around 7 years of age in Denmark[14]. A recent study involving data for 11 European countries showed substantial differences in overweight prevalence rates in children aged between 4-7 years by maternal education levels[15]. Our study adds to the previous paper in a number of important ways. We use longitudinal data and growth curve methods to examine how these patterns develop from infancy across childhood into early adolescence. Secondly, we look at inequality in the prevalence rates of overweight and obesity at each time-point separately; the previous paper aggregated these two categories and considered the social patterning between 4-7 years of age only. Understanding the age at which these differences first manifest is important because it points towards specific periods in the life course during which time interventions might be most efficacious in each country.

Although rates of childhood overweight and obesity appear to have stabilized in recent years in high income countries[16-18], this trend has not occurred at an equal pace across SEP groups which may have exacerbated socio-economic inequalities[8,19,20]. In a recent paper involving an analysis of four-longitudinal British birth cohorts (1946, 1958, 1970. 2000/1), Bann and colleagues[21] observed that socio-economic inequalities in children's BMI were larger in later born cohorts compared with earlier born cohorts. In response to recent calls for continued monitoring of trends in socio-economic inequalities in overweight/obesity by the Commission on Ending Childhood Obesity[2], this paper uses data from four infant and child cohorts to examine socio-economic differences in longitudinal trajectories of BMI, and overweight and obesity. The cohorts included in this analysis are part of the pan-European LIFEPATH project which examines the social patterning of health over the life course[22]. Although these cohorts comprise only a small number of all cohorts available in Europe, they were chosen for their good combination of measures of socio-economic position, risk factors for disease, and deep biological phenotyping with repeat measurements over time. The cohorts were selected to be reasonably representative of different life-stages allowing us to examine the development of inequalities in health from infancy into late life.

METHODS

Sample

We use data from three European countries and 4 different cohort studies with a combined total of 41,399 participants with repeat physical measurements of children's height and weight. Ethical approval for the G21 study was provided by the University of Porto Medical School/ Hospital S. João Ethics Committee and signed informed consent was required for all participants. Ethical approval for the GUI child cohort was provided by the Health Research Board (HRB) of Ireland's standing Research Ethics committee. Informed consent is obtained from parents, as well as from the children themselves as they grow up. Ethical approval for the GUI infant cohort was provided by a Research Ethics committee convened by the Department of Health and Children. Ethical approval for the MCS study was provided by the NHS Research Ethnics Committee (MREC). Informed consent is obtained from parents, as well as from the children themselves as they grow up.

Generation XXI (G21) comprises a cohort of 8647 newborns recruited in 2005–2006 in the Porto Metropolitan Area, in northern Portugal. Recruitment occurred at the 5 public maternity units, which are responsible for 95% of all births in the region (remaining births occurred at private hospitals)[23]. During the hospital stay, women delivering live births were invited to participate, and 92% of mothers agreed. All who agreed were invited to be re-evaluated at 4 years of age (2009-2011) and then again at 7 years of age (2012-2014). Of the original enrolments, 7459 participants (86.3%) participated at the second wave and 6889 participants remained in the study at wave 3 (80%). Further information concerning the study is available elsewhere[23].

The Growing Up in Ireland Study (GUI) is a longitudinal study of child development that involves two cohorts. The *infant cohort* comprises a nationally representative sample of 11,134 children who were aged 9 months upon recruitment into the study in 2008-2009 and were re-evaluated at 3 years (2010-2011) and 5 years of age (2013). The *child cohort* comprises a nationally representative sample of 8,568 children who were aged 9 years upon recruitment into the survey (2007-2008) and were re-evaluated at 13 years of age (2011-2012). The infant cohort was selected from the Child Benefit Register which has virtually complete coverage of all births in the Republic of Ireland, whilst the child cohort was selected using a two-stage sampling procedure in which schools were randomly sampled from the Department of Education's national database of schools in the first stage and then a random-sample of nine-year old children were selected from within the schools in the second stage. 9793 (88.0%) and 9001 (80.8%) of the original sample of the infant cohort consented to participate at waves 2 and 3 respectively; and 7525 (87.8%) of the child cohort consented to participate in the second wave. Further details concerning the GUI infant[24] and child cohorts[25] is provided elsewhere.

The Millennium Cohort Study (MCS) is a longitudinal study of child health and development that tracks the progress of a national sample of the UK population born throughout the United Kingdom (England, Scotland, Wales and Northern Ireland) between September 2000 and January 2002. There have been six waves of data collection at ages 9 months, 3 (2003-2004), 5 (2006-2007), 7 (2008-2009), 11 (2012-2013) and 14 years of age (2015/2016). Of the original wave 1 enrolment of 18,551 children, 15,590 (84.0%), 15,246 (82.2%), 13,857 (74.7%), 13,287 (71.6%) and 11,726 (63.2%) remained in the study at waves 2, 3, 4, 5 and 6 respectively. As with GUI, MCS was sampled from the Child Benefit Register with children from disadvantaged wards and from minority populations intentionally oversampled[26].

Children's Anthropometric Measurements

In G21, birthweight and birth length were extracted from clinical records. At ages 4 and 7, the child's height and weight was measured during the clinic visit at the University of Porto Medical School. Participants were measured in underwear in bare feet. Standing height was measured to the nearest 0.1 cm with the use of a SECA wall stadiometer. Weight was measured to the nearest one-tenth of a kilogram with the use of a Tanita digital scale. In GUI, the child's length at 9 months of age was measured using a SECA 210 measuring mat which has a range of 10-99 cm and graduates in 0.5 cm. Height at all other ages was measured using a portable stadiometer. Children were requested to remove their shoes and any head attire prior to measurement and interviewers recorded height to the nearest 0.1cm. In the GUI infant cohort, weight measurements were obtained using a SECA 835 portable electronic scale. It has an upper capacity of 50 kg and graduates in 20g increments when weight is less than 20kg and in 50g increments above 20kg. In the GUI child cohort, weight measurements were recorded to the nearest 0.5 kilogram using a SECA 761 flat mechanical scale that graduated in one kilogram increments and had an upper capacity of 150 kg. Weight was measured without shoes or outdoor clothes. In MCS, height was measured using a portable stadiometer to the nearest 0.1 cm and children were requested to remove their shoes and any head attire prior to measurement. The child's weight was measured using a Tanita HD-305 digital electronic scale with an upper capacity of 150kg and recorded in kilograms to one decimal place. Weight was measured without shoes or outdoor clothes

Outcome variable: Body Mass Index (BMI) and Measurement of Obesity and Overweight

BMI is a widely used epidemiological screening tool for quantifying the extent of overweight and obesity in population samples and is calculated by dividing weight in kilograms by height in metres squared. We use the age and sex-specific cut-offs provided by the International Obesity Task Force (IOTF) to calculate the percentage of children who were overweight and obese by maternal educational status at each time point[27]. They were developed using data for 6 nationally representative cross-sectional growth studies and the growth curves were fitted to pass through the 25kg/m^2 and 30 kg/m^2 cut-points at 18 years of age – which are commonly used to define overweight and obesity in adult populations - and yield age and sex-specific cut-offs for overweight and obesity between the ages of 2-18 years. Because the age in months at which children were measured at each survey wave varied, we binned them in 6 month categories when calculating the IOTF cut-offs. For example, if a child participating in MCS at the 3 year sweep of data collection (i.e. wave 2) was 42 months of age at the time of measurement, then we used the 3.5 year IOTF cut-offs for estimating their risk of overweight/obesity.

Exposure variable: Maternal Educational Level

Highest level of maternal education serves as our measure of SEP.[28] We decided to use maternal education level as our exposure variable because comparative studies in European[29] and OECD countries[30] identifies education as the socio-economic variable most strongly correlated with overweight status, at least in adulthood populations. A second reason for using education is that it captures the knowledge-related assets and health literacy of an individual and likely influences the probability of them engaging in health compromising behaviours that may be deleterious to healthy child development.[31] Maternal education is correlated with total household income and therefore likely determines the material resources (e.g. dietary quality) that are available to promote healthy child growth and development. We chose maternal rather than paternal education because some studies have documented higher correlations of childhood BMI with maternal as opposed to paternal BMI[32-34] and some researchers have suggested that the maternal environment (particularly the intrauterine environment) may play a central role in determining children's BMI trajectories[35].

In each country, the mother of the study child was asked to indicate the highest level of educational qualification they had attained at the time of the first survey sweep. As response categories differed widely across studies, responses to this question were harmonised to create a three-level educational classification within each country where the first level represents those with the minimal level of schooling (i.e. primary/lower secondary), the second level represents those with a higher secondary qualification, and the third level represents those with a degree-level qualification or equivalent. The manner in which maternal education was harmonised across countries to arrive at the 3-level classification is summarised in eTable 1.

Statistical Analysis

We fit latent growth curve models (described in detail in the supplementary appendix) to the data for each cohort. We stratified the analyses by sex because there were significant differences in the BMI growth rate for boys and girls in each cohort, which we tested by fitting a sex*age interaction term in the growth curve models. Eligible children were those who had anthropometric measurements at the baseline sweep of data collection. GUI comprises an infant cohort with measurements taken at 9 months, 3, and 5 years of age, and a childhood cohort with measurements taken at 9 and 13 years of age. Although the cohorts were born approximately 10 years apart, BMI was socially patterned in both cohorts so we fit a pooled model and included a dummy variable (fixed) effect for the cohort indicator. We decided not to pool results across countries given that the measurements of BMI occur at different ages across the cohorts and the cohorts overlap at only three age-points (MCS and GUI overlap at 3 and 5 years of age, MCS and G21 overlap at 7 years of age only, with no overlap between G21 and GUI). We therefore decided to present the results separately for each cohort so as to illustrate any potential differences in associations between countries.

The conditional expectations and the associated 95% confidence intervals for each educational group at the age at which children were measured at each survey wave were derived from the fixed effects parameter estimates. From the fixed-effects parameter estimates, we also estimated differences in expected BMI across maternal educational categories using the highest educated as the reference category. Because the distribution of BMI is skewed, as a sensitivity check we re-ran the models using the natural log of BMI and express the differences for the primary and secondary relative to the tertiary educated in percentage terms.

We estimated the probability of overweight and obesity at each age by maternal educational status using multi-level ordinal logistic regression with IOTF weight status (non-overweight, overweight, obese) at each survey wave representing the 3-level dependent variable. The marginal probabilities and the discrete difference in the probability of overweight and obesity relative to the tertiary-educated reference category were derived from the fitted models. As IOTF cut-offs are only available from the age of 2 years upwards, we only had two measurement occasions - 4 and 7 years of age - for estimating the growth rate in the marginal probability of overweight and obesity by maternal educational status in G21. All analyses were performed using Stata version 15.0 (StataCorp, 2017)[36].

RESULTS

Table 1 describes the number of valid BMI measurements at each wave by cohort stratified by maternal educational status and sex. Tables 2 (boys) and 3 (girls) report the expected BMI and associated 95% confidence intervals (CI) at each age by maternal educational status derived from the fitted models. Figure 1 expresses the expected mean difference in BMI for the primary and secondary educated compared with the tertiary educated at each measurement occasion for each cohort, separately for boys and girls. Across each of the cohorts, there was a significant widening of educational inequalities in BMI as children aged with the primary and secondary educated gaining body mass at a faster rate compared with the tertiary educated.

When does the social gradient in BMI first emerge?

In G21, there were no differences between groups in children's BMI at time of birth, but socio-economic inequalities were apparent by 4 years of age with the difference between extreme maternal educational groups expressed in kg/m^2 amounting to 0.24_{boys} (95% CI 0.13, 0.35) and 0.44_{girls} (95% CI 0.32, 0.57). Similarly in GUI, there were no differences in BMI at 9 months of age, but the pattern was well-established by 3 years of age with the difference in BMI between extreme educational groups equal to 0.23_{boys} (95% CI 0.09, 0.36) and 0.26_{girls} (95% CI 0.12, 0.40). The socio-economic differential in BMI emerged later in MCS as there were no differences in BMI between educational groups at 3 years of age, but by 5 years of age, children from primary educated maternal backgrounds measured 0.10_{boys} (95% CI 0.00, 0.19) and 0.15_{girls} (95% CI 0.05, 0.25) higher on average compared with children from tertiary level backgrounds. In all cohorts, maternal educational inequalities in children's BMI continue to widen over time.

Maternal educational differences in prevalence of overweight and obesity

Tables 4 (boys) and 5 (girls) summarize the predicted probability of overweight and obesity by maternal educational status at each age across each of the cohorts. Given the large number of comparisons – prevalence of childhood overweight and obesity at each age by maternal educational status, sex and cohort – we discuss only the contrasts between the primary and tertiary educated. Contrasts for the primary and secondary relative to the tertiary educated are depicted graphically in Figures S1A,B (G21), S2A, B (GUI) and S3A,B (MCS).

In G21, we observed widening inequalities in obesity prevalence for the primary educated compared with the tertiary educated between 4 and 7 years of age among both girls and boys. However, children from tertiary educated maternal backgrounds caught up with their peers in relation to overweight between 4 and 7 years of age (Figures S1A,B). In GUI, there was a widening of the educational differential in the prevalence of overweight among boys between 3 and 13 years of age, although prevalence of obesity remained relatively constant over the same span of years (Figure S2A). Girls from primary backgrounds in GUI were characterised by growing inequalities in overweight and obesity (Figure S2B). In MCS, there were no substantial educational differences in the prevalence of overweight or obesity among either boys or girls at 3 years of age. By 5 years of age however, boys from primary backgrounds had higher prevalence of overweight and obesity, which continue to grow over time (Figure S3A). Similar patterns were evident among girls in MCS (Figure S3B).

COMMENT

Principal findings

The evidence from this study involving 41,399 children and 120,140 repeat observations of BMI indicates that the social gradient in BMI emerges early in life and widens across childhood and into early adolescence. Our analysis shows that children from lower SEP backgrounds gain body mass more quickly than their higher SEP counterparts; are more likely to be obese at any age; and are more likely to become obese if previously non-overweight. That the disease burden of obesity is most heavily concentrated among children from lower socio-economic backgrounds is a worrying trend that has implications for the planning, delivery and cost of healthcare both now and into the future. According to a recent meta-analysis involving more than 200,000 children followed into adulthood, around 55% of obese children will become obese adolescents, and 80% of obese adolescents will become obese adults[5]. A recent paper estimated that the incremental lifetime medical costs of a 10-year-old obese child compared with a 10-year old-normal weight child was $19,000, which equates to roughly $14 billion dollars for this age group alone in the US.[37] These findings reinforce the necessity of challenging the childhood obesity epidemic at early ages because our analysis has shown these patterns are difficult to change once they have become entrenched.

The growth curve models provided evidence of widening inequalities in BMI as children aged across all cohorts, but this disguises heterogeneity across cohorts in terms of its impact on prevalence of overweight and obesity. In GUI, we observed a widening in the prevalence of overweight (boys and girls) and obesity (girls only) when comparing the primary with the tertiary educated. In MCS, we observed a widening in the prevalence of overweight and obesity over time for both boys and girls. G21 followed a different pattern as the educational differential in overweight was effectively reversed between 4 and 7 years of age as children from tertiary educated backgrounds caught up with their peers in terms of prevalence. It is not immediately apparent why we observe this pattern of catch up in the prevalence of overweight among the tertiary educated in Portugal and not in Ireland or the UK, although it should be acknowledged that the impact of the Great Recession on the middle classes was particularly crushing in Portugal[38], and led to an large increase in the proportion of middle class families using food banks[39]. According to a recent UNICEF report, families with children lost 10 years, 8 years, and 6 years of income progress in Ireland, Portugal, and the United Kingdom respectively as a consequence of the Great Recession[40]. Future research with these cohorts should be designed to address this hypothesis.

Strengths of the study

Strengths of the study include the use of prospective data with repeat measurements of BMI; extending the scope of the analysis to include data on middle childhood and adolescence, which allows us to examine whether the social gradient in BMI that emerges in early life stabilises, narrows or widens as children age; and the use of data from three contemporary European cohort studies, which shows that overweight and obesity continues to represent a major challenge for public health.

Limitations of the data

Limitations include missing data across survey sweeps (which are mitigated to some extent by the use of growth curve models); the comparability of the three groups of maternal education across countries given differences in the level of precision with which educational attainment was measured; the choice of only three countries in Europe (and the fact that in two of these, the sample is nationally representative, while in Portugal, it is regional). The fact that measurements of height and weight are recorded at widely spaced ages, at different ages across the cohorts, and with little overlap of age-ranges limits our ability to perform between-country comparisons. This is further complicated by the fact that GUI did not include the calendar age (in months) at which children were measured which renders comparisons across countries difficult to interpret. Although we used maternal education as our indicator variable for SEP, a recent study involving data for the MCS cohort between 7 and 14 years of age observed larger social gradients in BMI using father's social class compared with maternal education[21]. Our focus on measurement of inequalities on the relative as opposed to absolute scale may obscure overall moderation/decline in rates of overweight and obesity if the rate of change is not constant across groups.

Interpretation

Childhood obesity represents a major public health problem.[41] Our study has shown that social inequalities in BMI emerge in early childhood and widen as children age. The fact that the social gradient is so pronounced in contemporary European childhood populations reinforces the need for more targeted intervention with these high risk groups. The mechanisms through which SEP may influence body mass are much debated and our study does not have anything to say about the factors contributing to the development of these inequalities. However, a recent systematic review identified a number of risk factors in early life that were consistently associated with childhood obesity[42]. These include, high maternal pre-pregnancy BMI, prenatal tobacco smoke exposure, excessive maternal weight gain during pregnancy, high infant birthweight, and accelerated infant weight gain. Other studies have established that bottle feeding,[43,44] and early transition to solid foods,[43, 45] are also risk factors for childhood obesity. Importantly, almost all of these behaviours are socially patterned and amenable to intervention. Indeed, recent reviews have attempted to establish which interventions are most effective in reducing socio-economic inequalities in obesity[46]. However, Adams and colleagues[47] have sounded a note of caution about the design of obesity interventions noting that initiatives that are highly "agentic" (i.e. rely on an individual's cognitive, material, motivational, or time resources etc.) may be less effective than those which require a lower level of agency, and may even serve to exacerbate social inequalities.

Conclusions

In June 2017, The US Preventive Services Task Force updated their 2010 statement reiterating their call for screening and treatment of obesity in children under the age of 6, where they feel treatment may be most efficacious. If National Governments are serious about checking the rise in obesity and reducing social inequalities in health, then early childhood would seem like the right time to intervene to intercept these riskier developmental trajectories.

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The project has been designed and implemented by the joint ESRI-TCD Growing Up in Ireland Study Team. The GUI datasets are freely available to researchers via the Irish Social Sciences Data Archive (https://www.ucd.ie/issda). The Millennium Cohort Study is conducted by the Centre for Longitudinal Studies (CLS) at the Institute of Education, University of London. Data from the MCS surveys are held and distributed by the UK Data Service (http://ukdataservice.ac.uk), and are freely available to researchers under standard conditions. Neither CLS nor the UK Data Service bear any responsibility for the analysis or interpretation of these data. The authors also gratefully acknowledge the families enrolled in Generation XXI, Growing Up in Ireland, and the Millennium Cohort Study, as well as the members of the respective research teams, hospitals and staff (G21) responsible for the collection and provision of data used in this paper.

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Table 1: Number of Valid BMI Measurements at Each Wave by Maternal Educational Status, Sex and Cohort

	BOYS				GIRLS			
	Primary	Secondary	Tertiary	Total	Primary	Secondary	Tertiary	Total
G21	n	n	n	n	n	n	n	n
birth	2418	955	988	4361	2409	837	945	4191
4 years	1523	700	763	2986	1547	606	752	2905
7 years	1489	695	798	2982	1441	602	768	2811
GUI infant								
9 months	643	1817	3136	5596	636	1769	2958	5363
3 years	503	1518	2743	4764	509	1517	2619	4645
5 years	455	1398	2593	4446	461	1394	2467	4322
GUI child								
9 years	644	1234	2080	3958	784	1332	2062	4178
13 years	508	1075	1843	3588	614	1132	1801	3547
MCS								
3 years	3692	1048	2201	6941	3711	946	2154	6811
5 years	2999	902	1921	5822	3043	808	1904	5755
7 years	2811	865	1890	5566	2926	802	1876	5604
11 years	2630	811	1787	5228	2736	760	1762	5258
14 years	2213	670	1647	4530	2246	643	1579	4498

Table 2: Expected body mass index (BMI) and associated 95% confidence intervals by maternal educational status at each age by cohort (Boys)

	Primary	Secondary	Tertiary	Difference (Primary vs Tertiary)		Difference (Secondary vs Tertiary)	
G21	*Mean*	*Mean*	*Mean*	Kg/m2	Log BMI (%)	Kg/m2	Log BMI (%)
Birth	13.28 (13.22, 13.34)	13.36 (13.28, 13.43)	13.28 (13.19, 13.36)	0.00 (-0.10, 0.10)	0.00 (-0.8, 0.8)	0.08 (-0.04, 0.19)	0.7 (-0.2, 1.6)
4 years	16.13 (16.05, 16.21)	16.05 (15.95, 16.16)	15.89 (15.81, 15.98)	0.24 (0.13, 0.35)	1.1 (0.4, 1.9)	0.16 (0.03, 0.29)	0.9 (0.1, 1.7)
7 years	17.10 (16.98, 17.22)	16.90 (16.74, 17.06)	16.68 (16.55, 16.81)	0.42 (0.24, 0.60)	2.0 (0.8, 3.1)	0.22 (0.02, 0.43)	1.1 (-0.1, 2.3)
	N = 4361, Observations = 10,233						
GUI pooled	*Mean*	*Mean*	*Mean*	Kg/m2	Log BMI (%)	Kg/m2	Log BMI (%)
9 months	18.90 (18.74, 19.05)	18.91 (18.80, 19.01)	18.82 (18.72, 18.92)	0.08 (-0.09, 0.24)	0.5 (-0.3, 1.4)	0.09 (-0.02, 0.20)	0.7 (0.1, 1.3)
3 years	17.53 (17.40, 17.66)	17.44 (17.36, 17.51)	17.31 (17.24, 17.37)	0.23 (0.09, 0.36)	1.3 (0.5, 2.0)	0.13 (0.05, 0.21)	0.9 (0.4, 1.3)
5 years	16.92 (16.79, 17.04)	16.72 (16.65, 16.79)	16.56 (16.50, 16.61)	0.36 (0.23, 0.49)	1.9 (1.2, 2.6)	0.17 (0.09, 0.25)	1.0 (0.5, 1.4)
9 years	17.37 (17.19, 17.54)	16.98 (16.87, 17.09)	16.74 (16.66, 16.82)	0.63 (0.44, 0.82)	3.2 (2.2, 4.2)	0.24 (0.11, 0.38)	1.2 (0.6, 1.9)
13 years	20.06 (19.78, 20.33)	19.48 (19.29, 19.67)	19.16 (19.04, 19.33)	0.90 (0.60, 1.19)	4.5 (3.0, 5.9)	0.32 (0.10, 0.53)	1.5 (0.4, 2.6)
	N = 9554, Observations = 22,190						
MCS	*Mean*	*Mean*	*Mean*	Kg/m2	Log BMI (%)	Kg/m2	Log BMI (%)
3 years	16.53 (16.47, 16.60)	16.64 (16.52, 16.76)	16.58 (16.50, 16.67)	-0.05 (-0.15, 0.05)	-0.3 (-0.8, 0.3)	0.06 (-0.08, 0.20)	0.3 (-0.4, 1.1)
5 years	16.51 (16.44, 16.57)	16.57 (16.45, 16.68)	16.41 (16.34, 16.48)	0.10 (0.00, 0.19)	0.4 (-0.1, 0.9)	0.16 (0.02, 0.29)	0.8 (0.1, 1.5)
7 years	16.87 (16.79, 16.95)	16.88 (16.75, 17.01)	16.63 (16.55, 16.71)	0.24 (0.13, 0.35)	1.0 (0.4, 1.6)	0.25 (0.10, 0.40)	1.2 (0.4, 2.0)
11 years	18.77 (18.66, 18.89)	18.69 (18.49, 18.88)	18.24 (18.12, 18.36)	0.53 (0.36, 0.70)	2.2 (1.4, 3.0)	0.44 (0.21, 0.67)	2.1 (1.0, 3.2)
14 years	21.23 (21.07, 21.39)	21.07 (20.81, 21.33)	20.48 (20.32, 20.65)	0.75 (0.52, 0.97)	3.2 (2.1, 4.2)	0.59 (0.28, 0.89)	2.8 (1.4, 4.2)
	N = 6941, Observations = 28,036						

Table 3: Expected body mass index (BMI) and associated 95% confidence intervals by maternal educational status at each age by cohort (Girls)

	Primary	Secondary	Tertiary	Difference (Primary vs Tertiary)		Difference (Secondary vs Tertiary)	
G21	Mean	Mean	Mean	Kg/m2	Log BMI (%)	Kg/m2	Log BMI (%)
Birth	13.25 (13.19, 13.31)	13.25 (13.14, 13.35)	13.16 (13.07, 13.25)	0.09 (-0.01, 0.20)	0.7 (-0.1, 1.5)	0.09 (-0.05, 0.22)	0.6 (-0.5, 1.6)
4 years	16.38 (16.29, 16.47)	16.24 (16.12, 16.37)	15.93 (15.83, 16.04)	0.44 (0.32, 0.57)	2.5 (1.7, 3.2)	0.31 (0.16, 0.47)	1.7 (0.8, 2.7)
7 years	17.40 (17.26, 17.53)	17.17 (16.98, 17.37)	16.69 (16.54, 16.84)	0.71 (0.50, 0.91)	3.8 (2.6, 5.0)	0.48 (0.23, 0.73)	2.6 (1.2, 4.1)
	N = 4191, Observations = 9787						
GUI pooled	*Mean*	*Mean*	*Mean*	Kg/m2	Log BMI (%)	Kg/m2	Log BMI (%)
9 months	18.33 (18.16, 18.50)	18.41 (18.28, 18.53)	18.30 (18.21, 18.39)	0.03 (-0.14, 0.20)	0.6 (-0.3, 1.5)	0.11 (-0.02, 0.23)	0.4 (-0.2, 1.1)
3 years	17.23 (17.09, 17.36)	17.11 (17.01, 17.20)	16.96 (16.90, 17.03)	0.26 (0.12, 0.40)	1.6 (0.9, 2.4)	0.14 (0.04, 0.24)	0.7 (0.2, 1.2)
5 years	16.89 (16.76, 17.02)	16.59 (16.51, 16.67)	16.41 (16.36, 16.47)	0.47 (0.34, 0.61)	2.5 (1.8, 3.3)	0.17 (0.08, 0.27)	0.9 (0.4, 1.4)
9 years	18.02 (17.83, 18.21)	17.36 (17.25, 17.48)	17.13 (17.04, 17.21)	0.89 (0.69, 1.10)	4.4 (3.3, 5.4)	0.24 (0.10, 0.38)	1.3 (0.5, 2.0)
13 years	21.56 (21.26, 21.86)	20.55 (20.35, 20.75)	20.25 (20.09, 20.42)	1.31 (1.00, 1.62)	6.2 (4.7, 7.7)	0.30 (0.08, 0.52)	1.6 (0.6, 2.7)
	N = 9541, Observations = 22,055						
MCS	*Mean*	*Mean*	*Mean*	Kg/m2	Log BMI (%)	Kg/m2	Log BMI (%)
3 years	16.27 (16.21, 16.34)	16.17 (16.07, 16.27)	16.26 (16.19, 16.33)	0.01 (-0.08, 0.11)	0.1 (-0.5, 0.6)	-0.09 (-0.21, 0.03)	-0.5 (-1.2, 0.3)
5 years	16.37 (16.30, 16.43)	16.21 (16.11, 16.32)	16.22 (16.15, 16.29)	0.15 (0.05, 0.25)	0.7 (0.1, 1.2)	-0.01 (-0.13, 0.12)	-0.1 (-0.8, 0.7)
7 years	16.92 (16.83, 17.00)	16.71 (16.58, 16.84)	16.63 (16.54, 16.72)	0.29 (0.17, 0.40)	1.3 (0.6, 1.9)	0.08 (-0.08, 0.23)	0.3 (-0.5, 1.2)
11 years	19.37 (19.25, 19.49)	19.06 (18.84, 19.27)	18.81 (18.68, 18.95)	0.56 (0.38, 0.74)	2.4 (1.6, 3.3)	0.24 (-0.01, 0.49)	1.1 (-0.1, 2.3)
14 years	22.40 (22.23, 22.56)	22.00 (21.72, 22.29)	21.63 (21.46, 21.81)	0.76 (0.53, 1.00)	3.3 (2.2, 4.4)	0.37 (0.04, 0.70)	1.7 (0.2, 3.3)
	N = 6811, Observations = 27,839						

Table 4: Predicted prevalence (%) and associated 95% confidence intervals of overweight and obesity at each age according to the international obesity task force cut-offs by maternal educational level and cohort (Boys)

	OVERWEIGHT				OBESITY			
G21*	*Primary*	*Secondary*	*Tertiary*	*Total*	*Primary*	*Secondary*	*Tertiary*	Total
4 years	15.6 (12.9, 18.2)	12.3 (8.5, 16.1)	8.9 (5.6, 12.3)	13.4 (11.1, 15.8)	3.9 (3.4, 4.4)	3.5 (3.2, 3.9)	3.3 (3.0, 3.5)	3.7 (3.3, 4.0)
7 years	17.6 (16.0, 19.3)	18.0 (16.5, 19.4)	18.7 (17.5, 19.9)	17.9 (16.6, 19.3)	8.7 (6.7, 10.6)	8.1 (6.3, 9.8)	5.9 (4.9, 6.9)	7.9 (6.4, 9.5)
	N = 3361, Observations = 5908							
GUI pooled*	*Primary*	*Secondary*	*Tertiary*	*Total*	*Primary*	*Secondary*	*Tertiary*	Total
3 years	21.6 (20.0, 23.1)	20.2 (19.1, 21.4)	19.5 (18.5, 20.6)	20.2 (19.2, 21.3)	8.4 (6.4, 10.3)	6.9 (5.7, 8.1)	6.3 (5.2, 7.3)	7.0 (5.8, 8.1)
5 years	19.5 (18.5, 20.6)	18.0 (17.2, 18.7)	16.7 (16.0, 17.4)	17.7 (17.1, 18.3)	6.3 (5.3, 7.2)	5.2 (4.6, 5.7)	4.5 (4.1, 5.0)	5.2 (4.6, 5.7)
9 years	17.1 (15.7, 18.5)	15.2 (13.9, 16.4)	12.9 (11.8, 13.9)	14.6 (13.6, 15.6)	4.7 (4.0, 5.4)	3.9 (3.4, 4.3)	3.1 (2.7, 3.5)	3.7 (3.3, 4.1)
13 years	17.8 (15.7, 19.9)	15.9 (14.2, 17.5)	12.7 (11.1, 14.2)	14.9 (13.5, 16.3)	5.1 (3.9, 6.2)	4.1 (3.5, 4.8)	3.0 (2.6, 3.5)	3.9 (3.4, 4.4)
	N = 8978, Observations = 16,594							
MCS	*Primary*	*Secondary*	*Tertiary*	Total	*Primary*	*Secondary*	*Tertiary*	Total
3 years	13.5 (12.6, 14.4)	15.1 (13.7, 16.4)	12.6 (11.6, 13.7)	13.5 (12.8, 14.2)	4.0 (3.6, 4.4)	4.7 (4.0, 5.4)	3.7 (3.2, 4.1)	4.0 (3.6, 4.3)
5 years	15.4 (14.7, 16.1)	16.1 (15.0, 17.2)	13.7 (12.8, 14.5)	15.0 (14.4, 15.5)	4.8 (4.4, 5.3)	5.2 (4.5, 5.8)	4.1 (3.7, 4.5)	4.6 (4.3, 5.0)
7 years	17.0 (16.4, 17.7)	16.9 (15.9, 17.9)	14.5 (13.7, 15.3)	16.2 (15.7, 16.8)	5.8 (5.3, 6.3)	5.7 (5.0, 6.4)	4.4 (4.0, 4.8)	5.4 (4.9, 5.8)
11 years	19.5 (18.8, 20.2)	18.0 (17.0, 19.1)	15.8 (14.9, 16.7)	18.1 (17.5, 18.7)	8.0 (7.3, 8.7)	6.6 (5.7, 7.4)	5.1 (4.5, 5.6)	6.8 (6.3, 7.4)
14 years	20.8 (20.0, 21.7)	18.6 (17.2, 19.9)	16.4 (15.3, 17.4)	19.1 (18.4, 19.8)	9.8 (8.8, 10.7)	7.0 (5.8, 8.2)	5.4 (4.7, 6.0)	8.0 (7.3, 8.6)
	N = 6941, Observations = 28,036							

* Observations for G21 at birth and GUI at 9 months of age are omitted from this analysis because IOTF cut-offs are only available for age 2-18 years.

Table 5: Predicted prevalence (%) and associated 95% confidence intervals of overweight and obesity at each age according to the international obesity task force cut-offs by maternal educational level and cohort (Girls)

	OVERWEIGHT				OBESITY			
G21*	*Primary*	*Secondary*	*Tertiary*	*Total*	*Primary*	*Secondary*	*Tertiary*	Total
4 years	19.0 (17.9, 20.2)	19.3 (18.3 20.3)	16.1 (13.3, 18.9)	18.4 (17.5, 19.4)	7.3 (5.7, 8.9)	5.5 (4.4, 6.7)	3.8 (3.4, 4.3)	6.2 (5.0, 7.3)
7 years	16.0 (12.6, 19.5)	17.5 (15.1, 19.9)	19.3 (18.5, 20.1)	17.1 (14.5, 19.6)	12.7 (10.1, 15.4)	10.2 (7.9, 12.4)	6.3 (5.2, 7.3)	10.8 (8.8, 12.9)
	N = 3188, Observations = 5621							
GUI pooled*	*Primary*	*Secondary*	*Tertiary*	*Total*	*Primary*	*Secondary*	*Tertiary*	Total
3 years	22.4 (20.8, 24.1)	21.8 (20.6, 23.1)	20.5 (19.3, 21.6)	*21.4 (20.3, 22.5)*	7.5 (5.8, 9.1)	6.9 (5.7, 8.1)	5.8 (4.9, 6.7)	6.6 (5.6, 7.6)
5 years	22.4 (21.2, 23.6)	20.9 (20.1, 21.8)	19.5 (18.8, 20.3)	*20.7 (20.0, 21.4)*	7.4 (6.3, 8.5)	6.1 (5.5, 6.8)	5.2 (4.7, 5.7)	6.1 (5.5, 6.7)
9 years	22.6 (21.4, 23.8)	19.3 (18.2, 20.5)	17.9 (16.9, 19.0)	*19.5 (18.6, 20.5)*	7.6 (6.6, 8.7)	5.1 (4.5, 5.7)	4.4 (4.0, 4.9)	5.5 (4.9, 6.0)
13 years	23.3 (21.6, 25.0)	18.2 (16.5, 19.9)	16.8 (15.3, 18.4)	*18.8 (17.5, 20.1)*	8.4 (6.6, 10.2)	4.5 (3.8, 5.3)	4.0 (3.4, 4.5)	5.3 (4.6, 6.0)
	N = 9044, Observations = 16,692							
MCS	*Primary*	*Secondary*	*Tertiary*	*Total*	*Primary*	*Secondary*	*Tertiary*	Total
3 years	15.7 (14.8, 16.6)	14.5 (12.9, 16.0)	14.6 (13.6, 15.7)	*15.2 (14.5, 15.9)*	4.1 (3.7, 4.5)	3.7 (3.1, 4.2)	3.7 (3.3, 4.2)	3.9 (3.6, 4.3)
5 years	18.3 (17.6, 19.0)	17.1 (15.9, 18.3)	16.7 (15.9, 17.5)	*17.6 (17.1, 18.2)*	5.4 (4.9, 5.9)	4.8 (4.2, 5.4)	4.6 (4.1, 5.0)	5.1 (4.7, 5.4)
7 years	20.1 (19.5, 20.8)	19.0 (18.0, 19.9)	18.1 (17.4, 18.9)	*19.4 (18.8, 19.9)*	6.8 (6.2, 7.4)	5.9 (5.2, 6.5)	5.3 (4.8, 5.8)	6.2 (5.7, 6.7)
11 years	22.3 (21.4, 23.1)	21.1 (20.1, 22.1)	19.5 (18.7, 20.3)	*21.2 (20.5, 21.9)*	9.3 (8.4, 10.1)	7.7 (6.7, 8.7)	6.2 (5.6, 6.8)	8.1 (7.5, 8.7)
14 years	22.9 (21.9, 23.8)	21.6 (20.3, 22.8)	19.4 (18.4, 20.3)	*21.6 (20.8, 22.4)*	10.2 (9.1, 11.2)	8.3 (7.0, 9.7)	6.2 (5.4, 6.9)	8.7 (7.9, 9.4)
	N = 6811, Observations = 27,839							

* Observations for G21 at birth and GUI at 9 months of age are omitted from this analysis because IOTF cut-offs are only available for age 2-18 years.

Figure 1: Expected Difference in Body Mass Index of the Primary and Secondary Educated compared with the Tertiary Educated by Age, Sex and Cohort

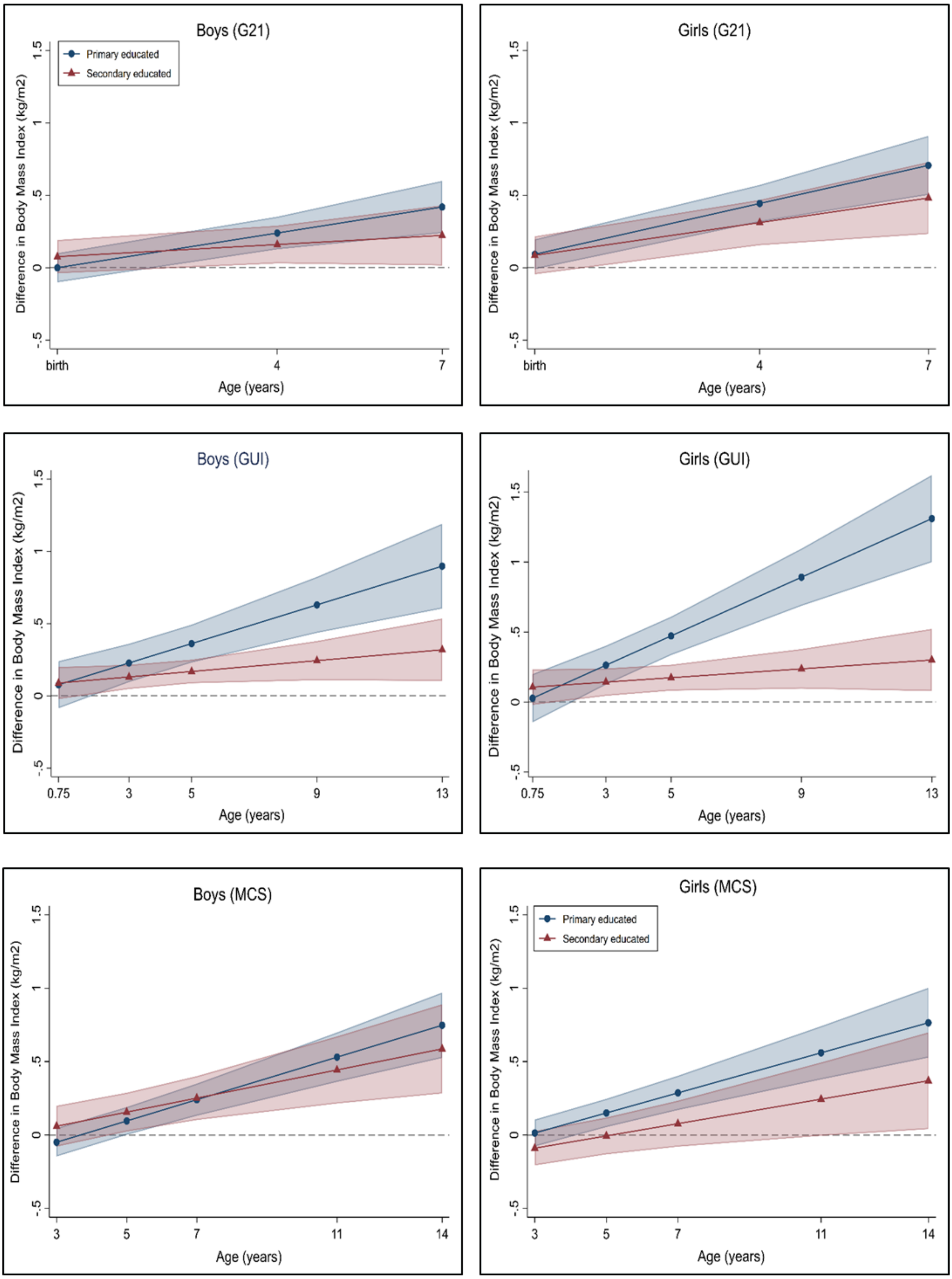


Figure 1 Legend:

Horizontal y-line represents the reference category for children from tertiary educated maternal backgrounds

95% confidence intervals for the primary and secondary educated are shown in blue and pink respectively

Supplementary Appendix – Description of Growth Curve Model

Latent growth curve models were fit to the data separately for boys and girls because of significant differences in the BMI growth rate by sex. Because the child's calendar age at time of measurement varied from child to child, analysis must adjust for this whilst estimating the differential in BMI by maternal educational level. Each child can contribute multiple observations so mixed hierarchical models with fixed and random components are used to adjust for the correlation between observations. We fit the following model (Equation 1) to the data:

$$bmi_{ij} = \beta_0 + \beta_1 Age_{ij} + \beta_2 Age_{ij}^2 + \ \beta_3 Primary_i + \beta_4 Secondary_i + \beta_5 Age_{ij} Primary_i + \beta_6 Age_{ij} Secondary + u_{0i} + u_{1i} Age_{ij} + e_{ij} \qquad \textbf{\textit{Eq1.}}$$

where $j = 1, \ldots, m_i$ (number of observations for individual i), $i = 1, \ldots, n$ (number of individuals), Age_{ij} is the age of individual i at time j, Age_{ij}^2 is the corresponding squared age term allowing for non-linearity in growth, and bmi_{ij} represents BMI at Age_{ij}. $\beta_3 Primary_i$ and $\beta_4 Secondary_i$ represent dummy variables for the primary and secondary educated relative to the tertiary educated reference category. $\beta_5 Age_{ij} Primary_i$, and $\beta_6 Age_{ij} Secondary_i$ represent linear age*education interaction terms allowing for linear acceleration / deceleration in the BMI growth rate over time by maternal educational level. The terms u_i and e_{ij} are residuals representing an unobserved individual effect and an error term for person i at time j, sampled from normal distributions with variances τ^2 and σ^2 respectively. We include a random slope for age where $(u_{0i}, u_{1i}) \sim MVN(0, \Sigma)$ are the random intercept and random coefficient terms respectively distributed according to a multivariate normal distribution, $u_{0i} \perp e_{ij}$ and $u_{1i} \perp e_{ij}$. Growth curve models use data from all eligible children under a missing at random assumption, allow for the change in scale and variance of BMI over time and take account of the actual age at which children were measured, with the exception of the GUI cohorts which provided age in years rather than months. We estimated separate models for each cohort. As GUI comprised both an infant cohort with measurements taken at 9 months, 3 years and 5 years of age, and a childhood cohort with measurements taken at 9 years and 13 years of age, we fit a pooled model and included a dummy variable (fixed effect) for the cohort indicator.

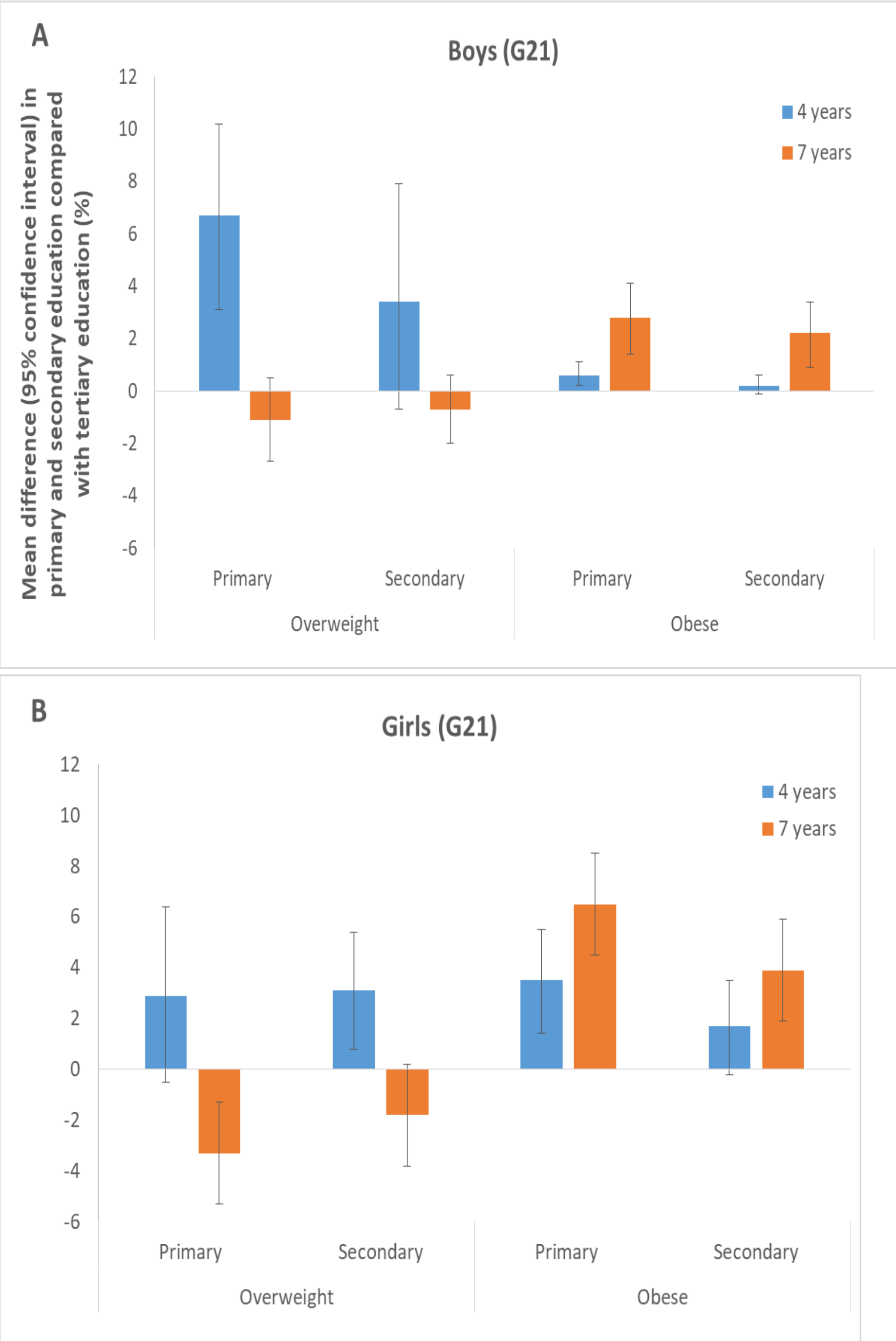
The conditional expectations and the associated 95% confidence intervals for each educational group at the age at which children were supposed to be measured at each survey wave were derived from the fitted model. From the fixed-effects parameter estimates, we also estimated differences in expected BMI across maternal educational categories using the highest educated as the reference category. Because the distribution of BMI is skewed, as a sensitivity check we re-ran the models using the natural log of BMI and express the differences for the primary and secondary relative to the tertiary educated in percentage terms.

We estimated the probability of overweight and obesity at each age by maternal educational status using multi-level ordinal logistic regression with IOTF weight status (non-overweight, overweight, obese) at each survey wave representing the 3-level dependent variable The marginal probabilities and the discrete difference in the probability of overweight and obesity relative to the tertiary educated reference category were derived from the fitted models. As nationally representative cohort studies, GUI and MCS provided survey weights at each wave of data collection, which incorporate both a design weight to take account of over/undersampling of particular subpopulations and an attrition weight to take account of non-response at the unit level at subsequent waves. G21 did not provide survey or attrition weights so we calculated inverse probability weights to take account of attrition across waves[36]. The survey weights were utilised in fitting the growth curves and in estimating the prevalence of overweight and obesity in all three cohorts. All analyses were performed using Stata version 15.0 (StataCorp, 2017).

eTable 1: Coding Schema Used to Derive the 3-Level Maternal Educational Variable within Each Cohort and Country and Percentage of the Sample within each Educational Grouping

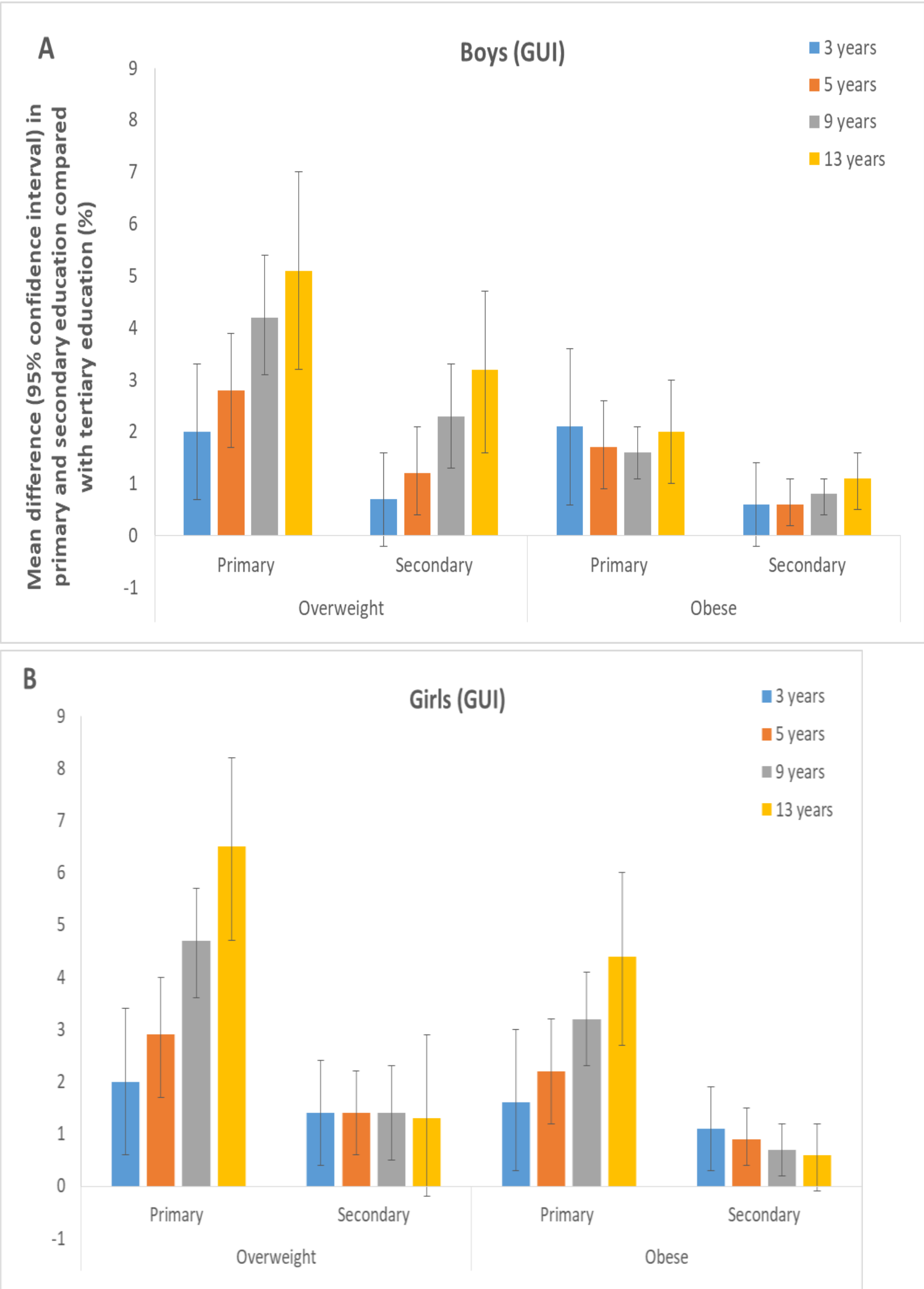
Question Wording	Primary	Secondary	Tertiary
G21 "What is the highest educational level that you completed?" [translation]	(1) First cycle of basic education (4th year) (2) Second cycle of basic education (6th year) (3) Third cycle of basic education (9th year) (56.4%)	(4) Secondary school (12th grade) (21.0%)	(5) Bachelor degree (6) Degree (7) Masters degree (8) Doctorate (22.6%)
GUI infant cohort "What is the highest level of education (full-time or part-time) which you have completed to date?"	(1) No formal education (2) Primary (3) Lower secondary (11.7%)	(4) Upper secondary (5) Technical or vocational qualification (6) Both upper secondary and technical/vocational qualification (32.7%)	(7) Non-degree (8) Degree (9) Professional qualification (10) Degree and professional qualification (11) Postgraduate diploma (12) Postgraduate Masters degree (13) Doctorate (55.6%)
GUI child cohort "What is the highest level of education you have completed to date?"	(1) Primary or less (2) Lower secondary (17.6%)	(3) Upper secondary (31.5%)	(4) Diploma / Certificate (5) Primary degree (6) Postgraduate / Higher degree (50.9%)
MCS "Please tell me whether you have any of the qualifications on this card"	(1) GCSE grades D-G (2) O level / GCSE grades A-C (53.8%)	(3) A / AS / S levels (14.5%)	(5) Diplomas in higher education (6) First degree (7) Higher degree (31.7%)

Figures S1A,B: Discrete difference in the prevalence of overweight and obesity at each survey sweep comparing the primary and secondary educated with the tertiary educated reference category by sex (Generation XXI)



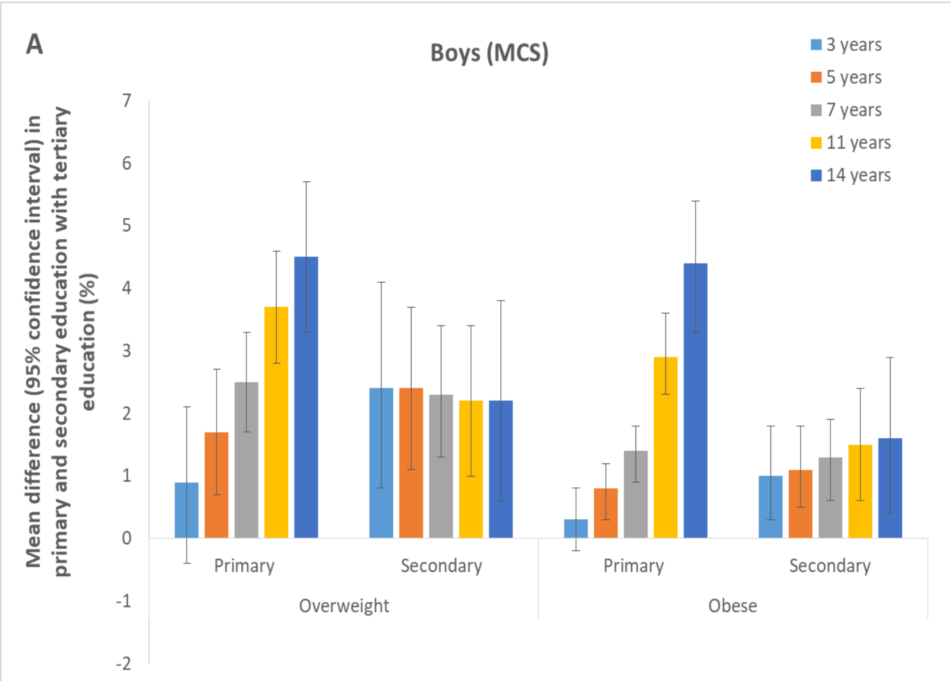
Error bars represent 95% confidence intervals

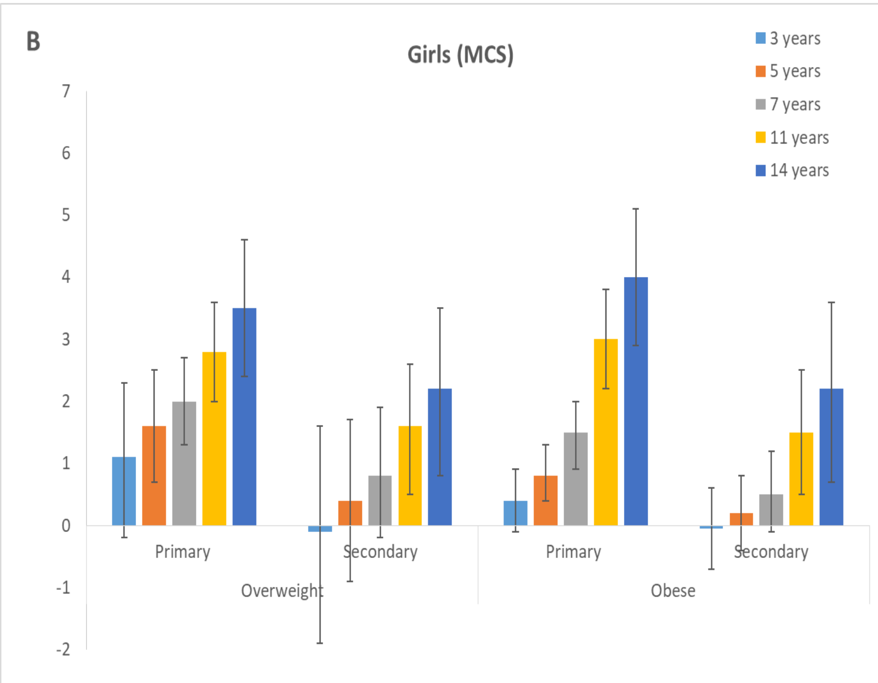
Figures S2A,B: Discrete difference in the prevalence of overweight and obesity at each survey sweep comparing the primary and secondary educated with the tertiary educated reference category by sex (Growing Up in Ireland)



Error bars represent 95% confidence intervals

Figures S3A,B: Discrete difference in the prevalence of overweight and Obesity at each Survey Sweep comparing the Primary and Secondary Educated with the Tertiary Educated Reference Category (Millennium Cohort Study)





Error bars represent 95% confidence intervals