Childhood overweight: socio-economic inequalities and consequences for later cardiovascular health

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Abstract

The last few decades have seen a dramatic rise in the prevalence of overweight/obesity in children and adolescents. Being overweight or obese as a child poses considerable long-term risks, particularly for cardiovascular health. Historically, obesity was a disease of affluence. Today, both adults and children from lower socio-economic backgrounds tend to be more overweight in high-income settings. In this paper, I present analysis of three research questions using data from the Avon Longitudinal Study of Parents and Children (ALSPAC), a cohort of children born in the south west of England in 1991/2. Firstly, I review two previously published papers examining i) the age at which socio-economic inequalities in adiposity emerge and ii) socio-economic inequalities in cardiovascular risk factors when the participants were age 10 years. And finally, I present new findings on the tracking of overweight/obesity across childhood and adolescence, and whether this differs across socio-economic groups. The findings show that socio-economic differences in adiposity and cardiovascular risk factors emerge at a much earlier age than in older generations. If children are overweight/obese at age 7, there is a low probability that they will return to a healthy weight by age 15, and this probability is lower in low socio-economic groups. Together, these findings suggest an urgent need to prevent obesity at an early age, particularly amongst disadvantaged groups, in order to prevent wide socio-economic differences in cardiovascular health in later life.

Key words: socio-economic factors, obesity, cardiovascular diseases, cardiovascular system, child, adolescent, ALSPAC

1. Introduction

The last few decades have seen a dramatic rise in the prevalence of overweight and obesity in children and adolescents. Being overweight or obese as a child poses considerable long-term risks, particularly for cardiovascular health (Owen et al., 2009). Historically, obesity was a disease of affluence, with a high-calorie diet and sedentary lifestyle being the preserve of the rich. This pattern has reversed across high-income countries. Today, both adults (McClaren, 2007) and children (Shrewsbury & Wardle, 2008) from lower socio-economic backgrounds tend to be more overweight in high-income settings. In low- and middle-income countries, the social patterning of obesity is beginning to change, with the burden of excess adiposity moving towards lower socio-economic groups in many countries, particularly amongst women (Monteiro, Moura, Conde, & Popkin, 2004). Whereas a gradient of higher levels of adult obesity with decreasing socio-economic position (SEP) has long been established in high income countries (McClaren, 2007) a similar socio-economic gradient in childhood adiposity is a relatively recent phenomenon (Batty & Leon, 2002). The emerging socio-economic inequalities in obesity amongst today's children may result in larger inequalities in cardiovascular disease and other adult outcomes than those already seen in today's adults.

In the UK and internationally, a multitude of interventions are being introduced in order to reduce childhood overweight and obesity prevalence and socio-economic inequalities in overweight/obesity and the resultant cardiovascular consequences. To design and target interventions effectively, it is crucial to have a full understanding of how childhood obesity develops, and how socio-economic inequalities emerge and change over childhood. This requires high-quality longitudinal studies and appropriate analysis of longitudinal data. In this paper, I synthesise two previously published manuscripts on this topic from the Avon Longitudinal Study of Parents and Children (ALSPAC), a cohort of children born in the south west of England in 1991-1992, as well as presenting new results on the socio-economic patterning of tracking of overweight across childhood, with the aim of discussing how these three related analyses link together to shed light on the picture of socio-economic inequalities in childhood overweight/obesity. The research questions addressed in this paper are i) at what age do socio-economic inequalities in adiposity emerge, ii) are there socio-economic inequalities in cardiovascular risk factors in childhood, and iii) are there socio-economic differences in the tracking of overweight/obesity across childhood/adolescence.

The remainder of this paper is structured as follows: section 2 details the data and methodology, section 3 provides a brief description of the background and existing literature on each research question (although space prohibits an exhaustive literature review of each question) and describes the findings from the analysis of ALSPAC data, and section 4 discusses and brings the three questions together.

2. Data and methods

Sample

The data are taken from a cohort of children born in the UK in the early 1990s, the Avon Longitudinal Study of Parents and Children (ALSPAC). http://www.bristol.ac.uk/alspac/ ALSPAC is a prospective cohort study investigating the health and development of children (Boyd et al., 2012; Fraser et al., 2012). Pregnant women resident in one of three Bristol-based health districts with an expected date of delivery between 1 April 1991 and 31 December 1992 were invited to take part in the study. Of these women, 14,541 were recruited. From these pregnancies, there were 14,062 live-born children, 13,988 of whom were alive at one year. Follow-up has included parent- and child-completed questionnaires, links to routine data, and clinic attendance. Ethical approval was obtained from the ALSPAC Law and Ethics Committee and the Local Research Ethics Committees.

Measurements

For all analyses, maternal education was used as the measure of SEP; this was self-reported by mothers at approximately 32 weeks gestation and is categorised as below O-Level (Ordinary Level; exams taken in different subjects usually at age 15-16 at the completion of legally-required school attendance, equivalent to today's UK General Certificate of Secondary Education; 30% of study mothers), O-Level only (35% of study mothers), A-Level (Advanced-Level; exams taken in different subjects usually at age 18, 22% of study mothers), or university degree or above (13% of study mothers). All analyses were repeated using family income and highest occupational social class for the mother and father, but results for these SEP measures were similar to those for maternal education so will not be presented or discussed further.

Anthropometric measurements for ALSPAC participants are available from birth records, health visitor measurements that form part of routine clinical care, parent-reports from questionnaires, and research clinics. The exact measurement schedule and number of measures per person has been described in detail elsewhere (Howe et al., 2010). Body mass index (BMI) was calculated from weight in kilograms divided by height in metres squared for each available measurement, and ponderal index was calculated as weight in kilograms divided by height in metres cubed. Where relevant, BMI status (underweight, normal, overweight or obese) was defined by age and sex-specific z-scores for BMI according to International Obesity Task Force cut-offs (Cole, Bellizzi, Flegal, & Dietz, 2000).

Cardiovascular risk factors (cholesterol, triglycerides, high density lipoprotein cholesterol [HDLc], apolipoprotein A1 and B, adiponectin, systolic and diastolic blood pressure, c-reactive protein [CRP], leptin and interleukin 6 [IL]) were measured at a research clinic held when the children were approximately 10 years old, using standard protocols that have been described in detail elsewhere (Howe et al., 2010b).

Statistical Analysis

For objective 1 (*At what age do socio-economic inequalities in adiposity emerge?*), trajectories of ponderal index from birth to two years, and BMI from two to ten years were estimated using linear spline multilevel models. These models identify periods of age during which the average change in ponderal index or BMI is approximately linear. Individual-level intercepts (ponderal index at birth or BMI at age two) and slopes (linear change in ponderal index or BMI within each of the identified periods of age) are then estimated using multilevel models (two levels: measurement occasions nested within individuals). These models create a full trajectory for each individual with one or more anthropometry measurement, regardless of their exact number of measures and ages at measurement, under a missing at random assumption. The full details of the model have been presented elsewhere (Howe et al., 2010). To explore maternal education differences in trajectories of ponderal index and BMI, interactions between the four-category maternal education variable and the intercept and each linear slope were included in the multilevel model, permitting the estimation of separate average trajectories for each maternal education category. Of the 13,988 ALSPAC participants alive at one year, 12,246 were included in the analysis of ponderal index trajectories and 11,380 for the BMI trajectories.

For objective 2 (*Are there socio-economic inequalities in cardiovascular risk factors in childhood?*), the association between maternal education and each cardiovascular risk factor was assessed in children attending a research clinic at approximately age ten years (N=7,772), using multivariate multiple imputation to impute missing outcome data where necessary (approximately 35%, mostly because children who did not consent to a blood test). The slope index of inequality (Sergeant & Firth, 2006) was used to quantify the estimated mean difference between highest and lowest maternal education. Full details of the methodology have been presented elsewhere (Howe et al., 2010b).

For objective 3 (*Are there socio-economic differences in tracking of overweight/obesity across childhood?*), I calculated BMI status (underweight, normal weight, overweight or obese) for BMI measures from research clinics held at approximately seven years old (the youngest age for which there are comparable measures for a large number of children) and 15 years old (the oldest age for which there are comparable measures for a large number of children), using categories of BMI rather than the continuous measure, since interventions are often targeted based on these thresholds. I first cross-tabulated the BMI categories at each age separately for each category of maternal education, in order to examine in detail movement between all four categories of BMI between the two ages, and whether this differs by maternal education category. Subsequently, I assessed whether there are maternal education differences in the chances of i) children who are overweight/obese at age seven returning to a normal BMI by age fifteen, or ii) children of normal BMI at age seven becoming overweight/obese by age fifteen, using tabulations and logistic regression. Due to small numbers in the obese category, overweight and obese groups were combined. Children who were underweight at either age were excluded from this analysis. Gender differences in this association were assessed using tests for interaction. BMI measures at ages seven and fifteen are available for 4,243 children who also have data on maternal education.

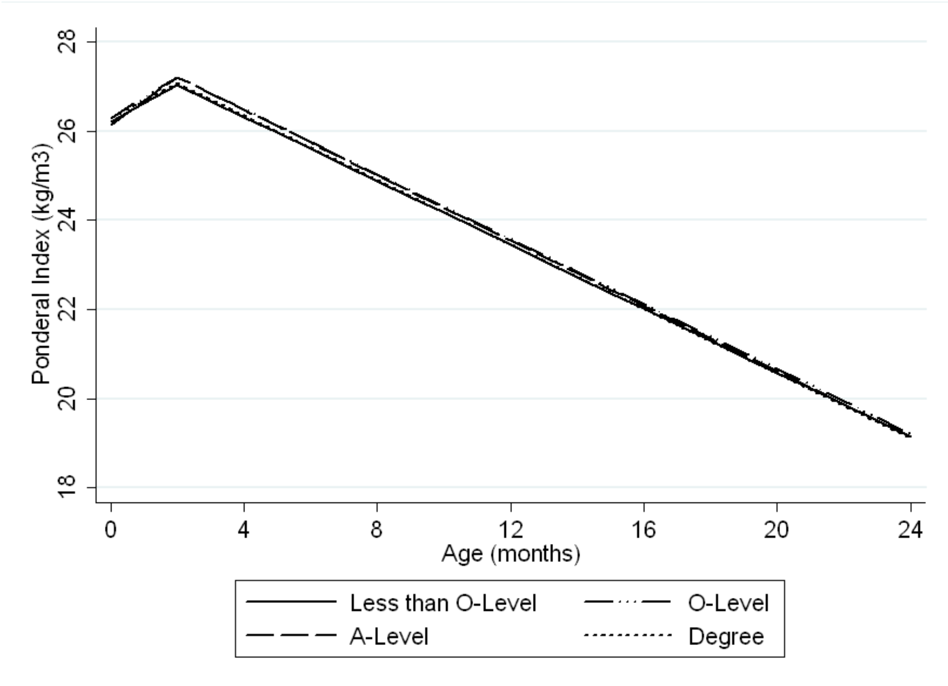
3. Socio-economic inequalities in childhood adiposity trajectories, cardiovascular risk factors, and the tracking of overweight/obesity

3.1. At what age do socio-economic inequalities in adiposity emerge?

The age at which socio-economic differences emerge in contemporary children and adolescents is unclear. A systematic review of cross-sectional studies, and a cross-national cross-sectional study not included in the review suggest that socio-economic differentials are present from at least age five (Shrewsbury & Wardle, 2008; Wang, 2001). The few studies that have used longitudinal data have explored trajectories from late childhood only. For example, one study explored differentials in trajectories from age eleven (Wardle, Henning Brodersen, Cole, Jarvis, & Boniface, 2006), a second from age nine (Wright, Parker, Lamont, & Craft, 2001), and a third from age seven (Braddon, Rodgers, Wadsworth, & Davies, 1986). Within the ALSPAC cohort, height and weight measurements are available from birth.

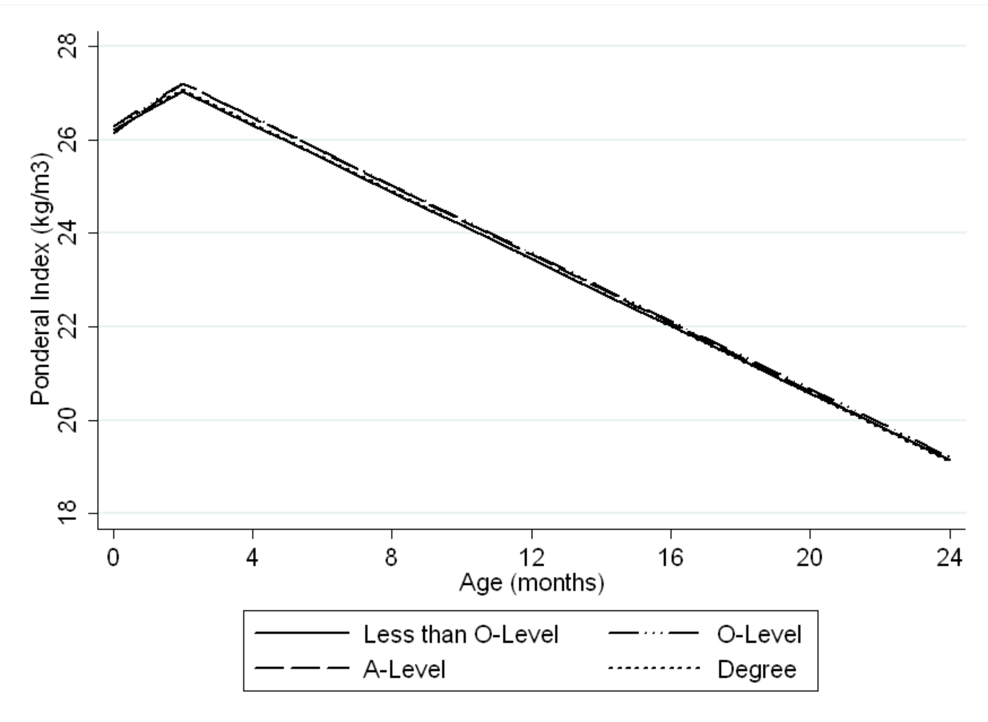
Within the ALSPAC data, there is no clear socio-economic patterning of PI between birth and age two (Figures 1 and 2). Amongst boys, all maternal education categories have similar BMI levels from two to four years (Figure 3). Between two and six

Figure 1. Trajectories of ponderal index (kg/m3) from birth to age two by categories of maternal education



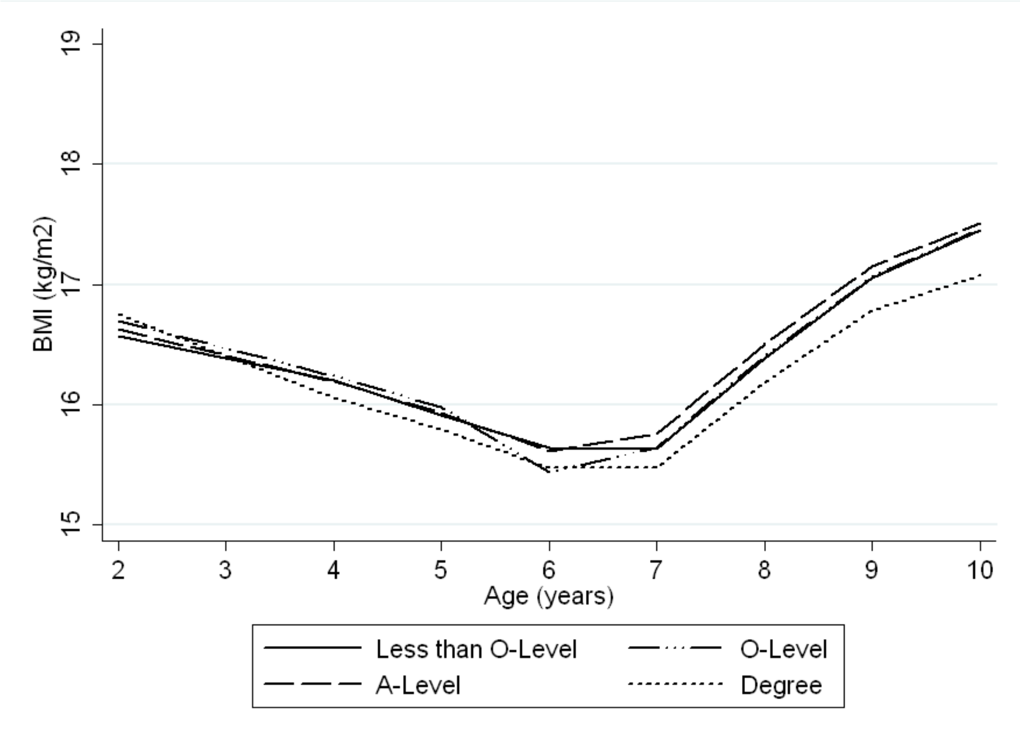
Notes. *Boys, N=6,323. From Howe et al. 2010.*

Figure 2. Trajectories of ponderal index (kg/m3) from birth to age two by categories of maternal education



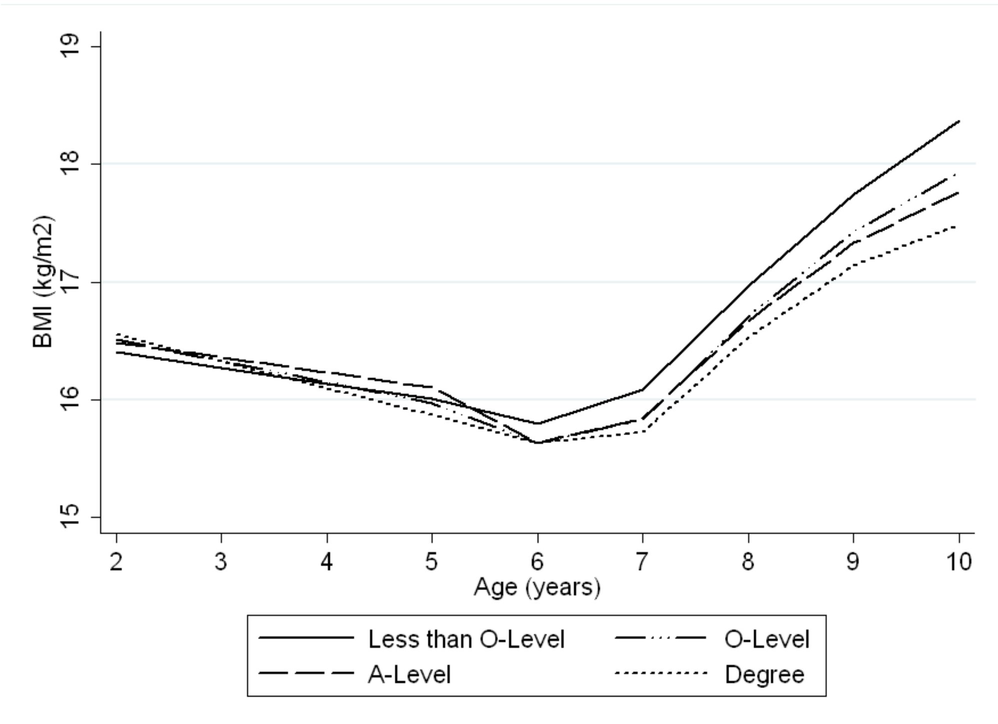
Notes. *Girls, N=5,923. From Howe et al. 2010.*

Figure 3. Trajectories of body mass index (kg/m2) from age two to age ten by categories of maternal education



Notes. *Boys, N=5,850. From Howe et al. 2010.*

Figure 4. Trajectories of body mass index (kg/m2) from age two to age ten by categories of maternal education.



Notes. *Girls, N=5,530. From Howe et al. 2010.*

years, the BMI of boys with degree-educated mothers is decreasing at a faster rate than the other maternal education categories. By seven years, the socio-economic patterning of BMI in boys has stabilised, with sons of degree-educated women having lower BMI and a lower rate of BMI increase than the other three maternal education categories. The mean BMI trajectories of sons of the three lower maternal education categories remain similar. The magnitude of the BMI difference between sons of the degree-educated mothers and the other categories increases over time between seven to ten years. By ten years old, boys in the degree category of maternal education have on average a BMI 0.38kg/m^2 lower than boys in the less then O-Level maternal education category (note that the standard deviation of boys' BMI measures between 105-120 months of age is 2.54, so this difference represents approximately 15% of a standard deviation). Amongst girls, daughters of degree-educated women have slightly higher BMI at two years than the lower maternal education categories (mean BMI in degree group 16.55kg/m^2 compared with 16.40kg/m^2 in less than O-Level group) and their BMI decreases at a faster rate than the other maternal education categories between two and six years. By four years old, daughters of degree-educated women have lower BMIs than lower maternal education categories. From seven years onwards, the socio-economic differential in BMI across all categories of maternal education increases (Figure 4). By eight years old, there is a clear socio-economic gradient of BMI across all four categories of maternal education, with a stepwise decrease in mean BMI for each increasing category of maternal education. By ten years old, girls in the degree category of maternal education have, on average, a BMI 0.89kg/m^2 lower than girls in the less then O-Level maternal education category (note that the standard deviation of girls' BMI measures between 105-120 months of age is 2.68, so this difference represents approximately 33% of a standard deviation).

3.2. Are there socio-economic inequalities in cardiovascular risk factors in childhood?

There is evidence that levels of cardiovascular risk factors 'track' across the life course (de Swiet, Fayers, & Shinebourne, 1992; Webber, Srinivasan, Wattigney, & Berenson, 1991; Nicklas, von Duvillard, & Berenson, 2002; Bao, Srinivasan, & Berenson, 1993). In the Young Finns cohort study, levels of low-density lipoprotein cholesterol (LDL-c), body mass index (BMI), and systolic blood pressure measured in childhood (age 12-18 years) showed the same magnitude of association with carotid artery intima-media thickness (CIMT) measured 21 years later, as the same risk factors measured at the same time as CIMT assessment (Raitakari et al., 2003). In older generations, socio-economic inequalities in obesity were not generally seen in childhood (Batty & Leon, 2002). A review of studies published up to the year 2000 found little socio-economic patterning of blood pressure, cholesterol, C-reactive protein, homocysteine or fibrinogen during childhood or early adulthood, but most studies were small (Batty & Leon, 2002

). One study in Denmark (n=933), Estonia (n=1103) and Portugal (n=1153) demonstrated socio-economic differentials in BMI, waist circumference, lipids (high density lipoprotein, low density lipoprotein, and triglycerides) and circulating insulin (Lawlor et al., 2005). In Estonia and Portugal (relatively low-income countries), the socio-economic differential in BMI was the opposite (lower BMI and waist circumference in those from poorer and less well educated families) of that seen in Denmark, a high-income country, where findings were consistent with results from other high income countries (Shrewsbury & Wardle, 2008), i.e. BMI and waist circumference were higher in those from poorer and less well educated families. The socio-economic gradients in metabolic markers were in the directions that would be anticipated given the observed relationships between SEP and BMI, i.e. levels of low density lipoprotein, triglycerides and circulating insulin were higher amongst those of lower SEP in Denmark and lower amongst those of lower SEP in Estonia and Portugal, and vice versa for high density lipoprotein. Data from the 1992-2002 National Health and Nutrition Examination Survey from the USA showed that neither income nor education were associated with the metabolic syndrome in adolescents (based on having three or more extreme values for waist circumference, blood pressure, triglycerides, or fasting glucose, using national reference data) (Loucks et al., 2007). A study in Northern Ireland (N=509) found little socio-economic difference in biological risk factors for coronary heart disease at ages 12 or 15, but did find differences in behaviours such as physical activity, diet and smoking, leading to the suggestion that socio-economic differences in risky behaviours are likely to emerge earlier than differences in physiological factors (van Lenthe et al., 2001).

By the age of ten, socio-economic inequalities in several cardiovascular risk factors are already present in the ALSPAC participants, with socio-economic differentials generally being wider in girls than boys. Weak associations were observed between maternal education and CRP, apolipoprotein B, leptin and IL6. Stronger associations were observed for systolic and diastolic blood pressure (inequalities in diastolic blood pressure were present only in girls). Children of less educated mothers had higher values of each of these risk factors (Table 1). There was little evidence of socio-economic differentials in triglycerides, apolipoprotein A1, adiponectin or HDL-C.

Table 1. Inequalities in cardiovascular risk factors at ten years, quantified by the Slope Index of Inequality (SII) by maternal education

	Boys, N=3,809		Girls, N=3,913	
	SII	**(95% Confidence Interval)**	**SII**	**(95% Confidence Interval)**
(difference in means comparing most to least deprived (null value = 0)				
Cholesterol (mmol/l)	0.094	(-0.0059 to 0.19)	0.098	(-0.017 to 0.21)
Triglycerides (mmol/l)	0.0016	(-0.088 to 0.091)	0.011	(-0.092 to 0.11)
High density lipoprotein (mmol/l)	0.017	(-0.027 to 0.061)	-0.021	(-0.066 to 0.024)
Apolipoprotein A1 (mg/dl)	2.20	(-0.66 to 5.05)	0.60	(-2.50 to 3.70)
Apolipoprotein B (mg/dl)	2.57	(0.88 to 4.26)	3.53	(1.55 to 5.52)
Adiponectin (mg/ml)	0.41	(-0.34 to 1.16)	-0.44	(-1.35 to 0.47)
Systolic blood pressure	2.63	(1.52 to 3.73)	2.82	(1.69 to 3.94)
Diastolic blood pressure	1.25	(0.45 to 2.04)	1.73	(0.97 to 2.49)
(% difference comparing most to least deprived (null value = 0)				
C-reactive protein (mg/l)	27	(3 to 57)	43	(20 to 70)
Leptin (ng/ml)	10	(-2 to 34)	25	(10 to 41)
Interleukin 6 (pg/ml)	16	(6 to 33)	10	(-4 to 27)

Notes. *N = 7,722 participants with multivariate imputation. SII represents the mean difference (or mean % difference for outcomes that were right-skewed and therefore analysed on the log scale) between the individuals of lowest and highest socio-economic position on the hypothetical underlying continuous distribution of maternal education. All analyses are adjusted for exact age at outcome assessment. Adapted from Howe et al (2010b).*

3.3. Are there socio-economic differences in tracking of overweight/obesity across childhood?

Adiposity is known to track relatively strongly across childhood and adolescence (Singh, Mulder, Twisk, Van Mechelen, & Chinapaw, 2008). A fairly low proportion of children who become overweight or obese will return to a healthy BMI. There is evidence, however, that those who do return to a normal BMI may also reduce their levels of cardiovascular risk factors to, or at least towards, those observed in children who have never been overweight or obese (Juonala et al., 2011; Lawlor et al., 2010). Examining which groups of overweight/obese children are more likely to return to a normal BMI is important, since if there are socio-economic differentials in this reversal of overweight/obesity, this could be an important focus for interventions. One small study (N=384) from Denmark examined socio-economic differences in the tracking (stability) of overweight/obesity across childhood and adolescence, and found that low SEP participants were twice as likely to maintain overweight between ages 8-10 years and 14-16 years compared with high SEP participants, and twice as likely to develop overweight between the two time points (Kristensen et al., 2006). Another study has looked at racial differences in overweight/obesity tracking between childhood and adulthood in a biracial cohort in the USA (Freedman et al., 2005). This study found that, despite initial BMI being similar in black and white children (aged five to 14 years), BMI increased more with age in black than white individuals, and overweight children were more likely to become obese adults (84% of black girls compared with 65% of white girls, with similar findings in males).

Of the 4,243 ALSPAC participants for whom BMI was measured at research clinics held at ages seven and fifteen, children from lower maternal education categories were more likely to be overweight or obese at age seven (Table 2). There were no clear maternal education differences in the proportion of overweight seven year-olds becoming obese by age fifteen (17% in the lowest maternal education category, 14%, 11% and 16% in each increasing category of maternal education) (Table 2). There was, however, some indication that normal BMI seven year olds were more slightly likely to become overweight by age fifteen if they were from lower maternal education categories (11% in the lowest maternal education category, 11%, 9% and 7% in each increasing category of maternal education) (Table 2). There was a stepwise decrease in the odds of moving from normal BMI at age seven to overweight/obese at age fifteen with each increasing category of maternal education; compared with the less than O-Level group, the degree or above maternal education category have half the odds of moving from normal BMI to overweight obese (odds ratio 0.54, 95% confidence interval 0.38 to 0.79) (Table 3). Similarly, there is evidence that children from higher maternal education categories are more likely to return from overweight/obese at age seven to a normal BMI at age fifteen compared with children from lower maternal education groups; compared with the less than O-Level group, the degree or above maternal education category have almost twice the odds of changing from overweight/obese at age seven to normal BMI at age fifteen (odds ratio 1.84, 95% confidence interval 1.00 to 3.36) (Table 3). No gender differences were observed for any of these associations (p values for interaction tests all ≥0.2 and no substantive differences in the magnitude or direction of associations).

Table 2. Changes in BMI categories between ages 7 and 15 by category of maternal education

BMI status at 7 years by maternal education	Total N (%) in each category at 7 years	Underweight at 15 years	Normal BMI at 15 years	Overweight at 15 years	Obese at 15 years
Maternal education < O-level, N=736					
Underweight	27 (3.7%)	4 (14.8%)	23 (85.2%)	0	0
Normal weight	581 (78.9%)	11 (1.9%)	494 (85.0%)	66 (11.4%)	10 (1.7%)
Overweight	92 (12.5%)	0	29 (31.5%)	47 (51.1%)	16 (17.4%)
Obese	36 (4.9%)	0	3 (8.3%)	13 (36.1%)	20 (55.6%)
Maternal education O-level, N=1,464					
Underweight	55 (3.8%)	17 (30.9%)	38 (69.1%)	0	0
Normal weight	1,200 (82.0%)	26 (2.2%)	1,026 (85.5%)	132 (11.0%)	16 (1.3%)
Overweight	167 (11.4%)	0	64 (38.3%)	80 (47.9%)	23 (13.8%)
Obese	42 (2.9%)	0	5 (11.9%)	14 (33.3%)	23 (54.8%)
Maternal education A-Level, N=1,229					
Underweight	34 (2.8%)	10 (29.4)	24 (70.6%)	0	0
Normal weight	1,021 (83.1%)	26 (2.6%)	895 (87.7%)	92 (9.0%)	8 (0.8%)
Overweight	133 (10.8%)	0	59 (44.4%)	59 (44.4%)	15 (11.3%)
Obese	41 (3.3%)	0	6 (14.6%)	17 (41.5%)	18 (43.9%)
Maternal education degree or above, N=814					
Underweight	20 (2.5%)	9 (45.0%)	11 (55.0%)	0	0
Normal weight	715 (87.8%)	16 (2.2%)	645 (90.2%)	51 (7.1%)	3 (0.4%)
Overweight	70 (8.6%)	0	29 (41.4%)	30 (42.9%)	11 (15.7%)
Obese	9 (1.1%)	0	1 (11.1%)	6 (66.7%)	2 (22.2%)

Table 3. The association between maternal education and change from overweight/obese at age 7 to normal BMI status at age 15

Changes from overweight/obese at age 9 to normal BMI at age 15

Maternal education	*Number of children overweight/obese at age 7*	*Number (%) of these returning to a normal BMI at age 15*	*Odds ratio for returning to a normal BMI*	*95% confidence interval*	*P value*
< O-Level	128	32 (25.0%)	1 (ref)		
O-Level	209	69 (33.0%)	1.48	0.90 to 2.42	0.12
A-Level	174	65 (37.4%)	1.79	1.08 to 2.96	0.02
Degree or above	79	30 (38.0%)	1.84	1.00 to 3.36	0.05

Changes from normal BMI at age 9 to overweight/obese at age 15

Maternal education	*Number of normal BMI children at age 7*	*Number (%) of these becoming overweight/obese by age 15*	*Odds ratio for becoming overweight/obese*	*95% confidence interval*	*P value*
< O-Level	581	76 (13.1%)	1 (ref)		
O-Level	1,200	148 (12.3%)	0.94	0.70 to 1.26	0.67
A-Level	1,021	100 (9.8%)	0.73	0.53 to 1.00	0.05
Degree or above	715	54 (7.6%)	0.54	0.38 to 0.79	0.001

4. Discussion and conclusions

Overweight and obesity is a global concern. As energy-dense diets become more accessible and sedentary lifestyles become more possible, obesity prevalence is increasing rapidly across low- and middle-income settings. Prevalence in both adults and children remains high across industrialised countries. Obesity in adulthood is associated with diabetes, cardiovascular disease, arthritis, some cancers (e.g. breast cancer and prostate cancer), infertility, and depression. In the UK alone, 30,000 people are estimated to die prematurely as a result of obesity-related conditions (NHS Information Centre, 2008). Children who are overweight are highly likely to go on to be overweight or obese adults (Singh et al., 2008), and have increased health risks in adulthood (Owen et al., 2009). Socio-economic inequalities in obesity mean that a disproportionate burden of both child (Shrewsbury & Wardle, 2008) and adult (McClaren, 2007) obesity and the resultant health, social, psychological and economic consequences is experienced by those from less advantaged socio-economic backgrounds. Addressing childhood obesity and socio-economic inequalities in it, is therefore a matter of extremely high social importance. In order to achieve reductions in obesity prevalence and reduce socio-economic inequalities, we need well-designed policies and interventions. Underpinning these interventions with high-quality research is essential in order to design and target the interventions optimally. Since obesity development across the life course is a dynamic process, longitudinal studies are essential.

In this analysis, I have reviewed two previously published studies focused on two important research questions – the age at which socio-economic inequalities in adiposity emerge, and whether there are socio-economic inequalities in cardiovascular risk factors in young children in a contemporary population. I have also presented new analysis on a third question – whether there are socio-economic differences in the tracking of overweight/obesity across childhood and adolescence.

My results show that there was very little socio-economic inequality in adiposity in the first few years of life; inequality in BMI began to emerge at approximately age four years and widened as the children got older. By ten years the mean BMI difference between the highest and lowest maternal education category was 0.38kg/m^2 for boys and 0.89kg/m^2 for girls. Previous cross-sectional studies have also demonstrated that inequalities in obesity start to emerge at a young age in contemporary high-income country populations (Shrewsbury & Wardle, 2008; Wang, 2001), but this was to our knowledge the first study to use detailed longitudinal measures of the development of obesity inequalities from early childhood.

By the age of ten, there was also evidence of socio-economic inequality in several cardiovascular risk factors. These risk factors are known to track across the life course (de Swiet et al., 1992; Webber et al., 1991), and childhood levels of such risk factors have even been shown to be associated with atherosclerosis in adulthood even after adjustment for the same risk factors measured in adulthood (Raitakari et al., 2003). Studies of older generations did not in general observe socio-economic inequalities in cardiovascular risk factors in children and young adults (Colhoun, Hemingway, & Poulter, 1998; Batty & Leon, 2002).

I observed wider inequalities in adiposity and cardiovascular risk factors in girls compared with boys. This is consistent with findings in adults (McClaren, 2007; Howe, Patel, & Galobardes, 2010c), but a systematic review of studies of children from developed countries published since 1989, showed no gender difference in inequalities in adiposity in over half of the 19 studies reporting associations separately for boys and girls, and mixed findings in the remaining studies (Shrewsbury & Wardle, 2008). The reasons for inequalities in adiposity being wider in girls are unclear. There is some evidence that boys are more likely than girls to participate in sport, regardless of their SEP (Fairclough, Boddy, Hackett, & Stratton, 2009) and that the inverse association between physical activity and adiposity tends to be stronger among boys than girls (Jimenez-Pavon, Kelly, & Reilly, 2009; Ness et al., 2007). However, there is little evidence of a socio-economic gradient in objectively measured physical activity within ALSPAC, although there is evidence that boys are more likely to participate in moderate to vigorous activity (Riddoch et al., 2007), which has been shown to be more strongly associated with reduced fat mass than total activity (Ness et al., 2007). In the context of adults, McLaren discusses the possibility that men place value on larger body size, associating it with power and dominance, whereas women value thinness, and proposes this as at least a partial explanation for the wider inequalities in adiposity in women compared with men (McClaren, 2007). The relevance of this to young children is questionable, although there is some evidence from a study of 10-14 year-olds that girls wish to be thinner whereas boys wish to be larger (McVey, Tweed, & Blackmore, 2005).

Children with less educated mothers were more likely than their more socially advantaged peers to go from a healthy BMI in childhood to being overweight as adolescents. They were also more likely to move from being overweight to obese. The proportion of overweight/obese children at age seven who returned to a normal BMI by age fifteen was also lower in low maternal education categories. Thus there is a double burden for children from low socio-economic backgrounds – more likely to become overweight, and less likely to regain a normal BMI once they have become overweight. This is consistent with a small Danish study, which showed greater tracking of BMI between childhood and adolescence in low SEP participants (Kristensen et al., 2006), and reiterates the importance of ensuring that interventions are in place that effectively prevent BMI increases and facilitate BMI reductions in children from lower socio-economic backgrounds. One limitation of the tracking analysis we have presented is that the time frame between the two ages is relatively small (8 years); as the ALSPAC participants become adults, it will be interesting to assess whether there are socio-economic differentials in the persistence of overweight/obesity into adulthood. A second important limitation, albeit shared by the majority of studies assessing the tracking between categories of BMI, is that membership of BMI categories is defined on a single measurement for each time point, and some movement between categories will be due to small fluctuations around the thresholds used to define categories. Thirdly, these analyses are only possible for the just under one third of the original ALSPAC cohort members with BMI measures available at seven and fifteen years. It is possible that those lost to follow-up are more likely to be of lower SEP, and potentially also more likely to develop obesity or less likely to return from overweight/obese to a normal BMI. This could result in an underestimation of the inequalities (Howe, Tilling, Galobardes, & Lawlor, 2012).

In older cohorts, socio-economic differentials in adiposity were not observed during childhood and early adulthood (Batty & Leon, 2002). For example, a study of Glasgow students (attending the university health service between 1948 and 1968) did not find social patterning of early adult adiposity (mean age 23 years in men and 20 years in women), but in these same individuals, childhood SEP predicted later adult BMI (mean age 39 years in men and 36 years in women), despite little heterogeneity in their adult SEP (Okasha, McCarron, McEwan, & Davey Smith, 2003). In participants of the 1958 birth cohort study, there was little or no socio-economic inequality in childhood adiposity; by contrast amongst the participants' offspring (born between 1982 and 1987) higher SEP was associated with lower adiposity (Li, De Moira, & Power, 2009). Together with these other studies, my research provides compelling evidence that socio-economic inequalities in obesity and related cardiovascular disease risk are emerging at earlier ages in contemporary populations.

I observe the emergence of socio-economic inequalities in adiposity in children as young as four years old, with widening inequalities in BMI with increasing age, at least partially driven by inequalities in the likelihood of developing overweight and obesity and of returning to a normal BMI once overweight/obese. These inequalities in BMI are already generating inequalities in cardiovascular risk factors in children as young as ten. The inequalities we observe are greater than those seen in older generations, suggesting that these children may well suffer even wider socio-economic inequalities in adulthood obesity, cardiovascular diseases, diabetes and other adverse consequences than those already experienced by contemporary adults. It is well known that many interventions are initially taken up to a greater extent by more socially advantaged groups (Victora, Vaughan, Barros, Silva, & Tomasi, 2000), leading to a widening of socio-economic differentials. In order to reduce socio-economic inequalities in overweight and obesity, cardiovascular disease and diabetes, it will be necessary to either target interventions at disadvantaged groups, or to attempt to promote their greater participation in population-wide interventions, since obesity levels are high in all socio-economic groups, which calls for interventions that target the entire population. The results also highlight the need for early intervention. Given the low proportion of children overweight/obese at age seven who returned to a healthy BMI by age fifteen, prevention interventions are imperative.

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