

Title: Overweight and obesity in childhood and adolescence: findings from the UK Millennium Cohort Study, up to age 14

Running title: overweight and obesity in early life

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Conflict of Interest statement

The authors declare no conflict of interest.

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Abstract

Background: The aims of this work are threefold: (1) Show the pathway of overweight and obesity, for current generation of adolescents, since early childhood in the UK. (2) Identify factors associated with the risk of overweight/obesity at age 14. (3) Study transitions into and out of overweight/obesity, from early adolescence to mid-adolescence.

Methods: A sample of 10825 children in the UK Millennium Cohort Study was selected for analysis. BMI was calculated using measured height and weight available at every sweep since age 3, and overweight and obesity were defined using the IOTF classification. Possible factors associated with the risk of excess weight include sociodemographic characteristics, early life circumstances, and behavioral and lifestyle factors in adolescence.

Results: 19% of the sample of 14-year olds in 2015/16 is classified as overweight (95% CI 18.4-20.0), and 7.5% as obese (95% CI 7.0-7.9), with proportions very similar across sexes. Protective factors for excess weight include high maternal education, breastfeeding, home ownership and child's active behavior. The likelihood of transiting out of excess weight/obesity between 11 and 14 is higher than likelihood of transiting in. Predictors of transiting out of excess weight/obesity include child's active behavior and puberty onset.

Conclusions: This study provides new evidence that the profile of rising trends in excess weight observed during childhood had stabilized by mid-adolescence. However, rates of excess weight remain high, overweight and obesity in childhood and adolescence remain of major public health concern. The study identifies some risk and protective factors to reinforce the Government commitment to reducing excess weight in childhood.

Introduction

Childhood overweight and obesity are of major concern in the majority of industrialized nations, and the childhood obesity epidemic is growing globally, with large variations in secular trends across countries (Wang & Lobstein, 2006). Globally, the prevalence of overweight and obesity combined has risen by 47.1% for children over the period 1980 to 2013 (compared to 27.5% for adults). Remarkable increases have been observed in developed countries over this period, with 23.8% of boys and 22.6% of girls being either overweight or obese in 2013, compared to 16.9% and 16.2% respectively in 1980. Sex differences in the levels of and trends in overweight and obesity are small (Ng et al., 2014). A recent study of worldwide trends in Body Mass index (BMI) in children and adolescents finds that the rising trends in children's and adolescents' BMI have levelled off in many high-income countries, albeit at high levels, but have accelerated in parts of Asia (Abarca-Gómez et al., 2017).

In the UK, research on school-aged children, spanning 1974 to 1998 (Chinn & Rona, 2001; Lobstein, James, & Cole, 2003) found that in 1998 the prevalence of overweight boys and girls was 17% and 23.6% respectively. This represented an increase of 150% since 1974. In England, the period 1995 to 2005 witnessed a general increase in childhood obesity from around 12% to 18%, which has since levelled off (Conolly & Neave, 2016). The Health Survey for England found that among children aged 11 to 15, the prevalence of obesity has fluctuated between 16% and 20% during the period 2008 to 2015. Findings from the Millennium Cohort Study (MCS) show a stark increase in rates of obesity between ages 7 (2007/08) and 11 (2011/12), from 13% to 20% (Platt et al., 2014).

Children who are overweight or obese face an increased risk of many health problems, including asthma (Lang, 2012), cardiovascular disease (Bridger, 2009), type 2 diabetes (Pulgaron & Delamater, 2014), cancer (Renehan, Tyson, Egger, Heller, & Zwahlen, 2008) and chronic kidney disease (Asia Pacific Cohort Studies Collaboration, 2004; Emerging Risk Factors Collaboration, 2011). Childhood overweight and obesity is also associated with psychological problems such as low self-esteem and depression, and can have a major and enduring impact on an individual's life (Russell-Mayhew, McVey, Bardick, &

Ireland, 2012). Overweight/obesity in childhood is a strong predictor of overweight and obesity in adulthood (Guo, Wu, Chumlea, & Roche, 2002). Younger generations are likely to accumulate greater exposure to overweight or obesity throughout their lives (2015), to the extent that cohorts born after the 1980s already have probabilities of overweight or obesity in childhood that are two to three times greater than for cohorts born before the 1980s (Johnson et al., 2015).

Overweight and obesity are complex and multifactorial conditions affected by several genetic, behavioral, environmental, socioeconomic factors (Güngör, 2014; Han, Lawlor, & Kimm, 2010). A number of studies have investigated risk factors, including breastfeeding, whose association with overweight and obesity in late childhood and adolescence is inconsistent across studies (Gillman et al., 2001; Hediger, Overpeck, Kuczmarski, & Ruan, 2001; Kramer et al., 2009), and maternal smoking during pregnancy, associated with increased risk of overweight and obesity (Toschke, Koletzko, Slikker, Hermann, & von Kries, 2002; Von Kries, Toschke, Koletzko, & Slikker Jr, 2002; Widerøe, Vik, Jacobsen, & Bakketeig, 2003). A review of international studies found socio-economic status to be inversely associated with overweight/obesity (Shrewsbury & Wardle, 2008); lifestyle behaviours, such as physical activity, sleep, diet, are also known correlates of overweight /obesity in adolescence, reducing the risk of having excess weight (Thibault, Contrand, Saubusse, Baine, & Maurice-Tison, 2010; Vieno, Santinello, & Martin, 2005; Wilkie, Standage, Gillison, Cumming, & Katzmarzyk, 2016).

In this paper we use data from the UK Millennium Cohort Study (MCS) to examine objective measures on BMI and overweight/obesity status among adolescents aged 14 in 2015, and analyze prevalence and trends across childhood (from age 3). The contributions of the paper are threefold. First, we show the profile of overweight and obesity in the UK, for today's generation of adolescents, since early childhood. Second, we identify factors that are associated with the risk of overweight and obesity at age 14, and third, we study transitions into and out of overweight/obese statuses, from early adolescence (age 11) to mid-adolescence (age 14), an important transitional stage when individuals increase significantly in their autonomy and independence (Wray-Lake, Crouter, & McHale, 2010). The overarching aim is to inform policy by providing up to

date evidence on the current risk of overweight and obesity of adolescents, alongside understanding the factors associated with changes in weight status over time.

Methods

Participants

The MCS is a large-scale longitudinal cohort study following the lives of children born in the UK in 2000-02. 18,552 families (18,818 children) were recruited to the cohort at baseline to be nationally representative (Connelly & Platt, 2014; Joshi & Fitzsimons, 2016). There have been six sweeps of data collection available for analysis to date, at ages 9 months and 3, 5, 7, 11 and 14 years. Since age 3, the MCS has collected objective measurements of study participants' height and weight, making it a unique, nationally-representative resource for the study of childhood overweight and obesity.

11,726 families were interviewed at age 14, corresponding to 11,872 children. In this study, we exclude twins and triplets (N=308). This is to avoid the issue of non-independence of observations, and is justified by the very modest number of twins/triples in the sample (2.6%). Individuals had their weight and height objectively measured by trained interviewers, following well-established protocols (Fitzsimons, 2017). 739 (6.4%) of the 11,564 singleton respondents did not provide valid measure of BMI, therefore information on BMI is available for 10,825 singleton children. When considering transitions from age 11 to 14, the sample comprises respondents taking parts in sweeps 5 and 6 (N=10,123). Figure A1 in the Supporting Information illustrates the process of sample selection at sweep 6.

To estimate prevalence of overweight and obesity in childhood and adolescence, we selected respondents with complete records on weight and height in the specific sweep – rather than respondents with complete records in all sweeps - in order to maximise sample size at each sweep.

Two types of survey weights are used - cross-sectional and longitudinal (Mostafa & Ploubidis, 2017). Cross-sectional weights maximize the representativeness of each sweep as standalone study, whilst longitudinal weights adjust for non-response due to

attrition. All descriptive statistics use cross-sectional weights (results presented in Tables 1, 2 and 3); longitudinal weights are used in the logit models for excess weight at age 14 and transition analyses (Tables 4 and 5 respectively). All analyses allow for the data being clustered by ward of initial residence. If individuals living in specific areas are more similar than individuals living elsewhere, the data will be correlated. This means a straightforward estimate of standard errors will be incorrect and the significance tests invalid. To ensure this does not occur, we use clustered robust standard errors in standard analysis, in agreement with MCS guidelines (Ketende & Jones, 2011). Data for this analysis are publicly available and obtained from the UK Data Archive, University of Essex.

Outcome variables: excess weight and obesity statuses

BMI is the most frequently used measure for child obesity prevalence in the UK. Children are normally classified as overweight or obese by comparing their BMI with a reference population that describes the distribution of BMI within a population by age and sex. This is necessary because a child's BMI changes with age and sex so fixed thresholds, as applied to adults, cannot be used. The most widely used methods used in the UK are cut-offs based on the UK1990 growth reference and the international classification system commonly referred to as the International Obesity Task Force (IOTF) cut-offs. A short description of each is provided in the Supporting Information 1. In this paper, we use the IOTF system for classification. UK90-based prevalence of overweight and obesity were also estimated as a sensitivity analysis and are available upon request.

We consider overweight and obesity combined (referred to as "excess weight"), as well as obesity only. Underweight, as defined by Cole and colleagues (Cole, Flegal, Nicholls, & Jackson, 2007), was combined with normal weight due to its very low prevalence in the categories of thinness and severe thinness (grades 2 and 3 respectively) at around 1.5% at age 14 (see Supporting Information Table A1).

Predictors of excess weight and obesity at age 14

The factors identified as possible risk factors of overweight and obesity include sociodemographic characteristics, early life circumstances and behaviours, and current behavioural and lifestyle factors. Previous studies have identified predictors of excess weight in childhood (see for example Apfelbacher et al., 2008; Massion et al., 2016) and adolescence (Inchley, Currie, Jewell, & Breda, 2017). We draw on existing literature and select predictors also in accordance with the characteristics and objectives of this study. They include child sex, ethnicity and country of birth; early life information including on birth weight, breastfeeding for at least 90 days, maternal smoking during pregnancy, maternal alcohol consumption at child age 9 months; maternal education, distinguishing five levels of education in a multi-categorical variable; number of siblings, family structure at age 14 (whether single parent household or not), and home ownership at age 14. We also include the following lifestyle and behavioural factors of the study member at age 14: whether ever engaged in binge drinking; whether ever smoked; physical activity (days last week spent doing moderate to vigorous physical activity); sedentary behaviour/inactivity (TV watching); sleeping behaviour (weekday bedtime); and healthiness of diet, captured by four-item “Eating Choices Index” (ECI) which comprises four elements: (i) consumption of breakfast; (ii) consumption of fruit; (iii) type of milk consumed; and (iv) type of bread consumed, on a score ranging from 4 to 20, with a score of 20 indicating the healthiest diet (Pot, Richards, Prynne, & Stephen, 2014). Finally, based on existing studies we included as a predictive factor an indicator of pubertal status (Li, Liu, Deng, Chen, & Liu, 2017) consisting of menarche for females (Al-Awadhi et al., 2013; Bralic et al., 2012), and voice deepening for males (Tanner, 1962), reported by participants at age 14.

Statistical Analysis

To describe the distribution of prevalence of overweight and obesity, significance of differences across classes are tested using chi-square tests.

To identify possible factors positively and negatively associated with the risk of overweight, multivariable logistic models are estimated using longitudinal weights to adjust for non-response. Models are run separately for the risk of excess weight and

obesity. Additionally, we estimate multinomial logistic regression for a categorical outcome distinguishing normal weight (reference category), overweight and obesity, reporting results as relative risk ratios (RRR).

Changes in normal weight, overweight or obesity status are studied distinguishing changes from late childhood (age 11) to adolescence (age 14). This is to understand pathways out of and into overweight between these important lifecycle stages. We chose this transition as particularly policy relevant, representing the move from primary to secondary school, and an important shift in autonomy and decision making, with young people taking on more of their own decisions around health, nutrition, and exercise. We first create transition matrices separately for normal weight and overweight/obesity status between age 11 and 14, from the period of late childhood to adolescence. We next estimate logistic models to examine predictors of the likelihood of transiting out of excess weight (model 1) and obesity (model 2), conditional respectively on being excess weight and obese at age 11.

All analyses were conducted using STATA statistical software, version 14 SE.

Results

Trends in prevalence of overweight and obesity with 95 confidence intervals are presented by sex, from age 3 to 14 years in Table 1. Both overweight and obesity increase as respondents grow up, with proportions slightly higher among females compared to males, but no major sex differences. A stark increase in overweight is observed between ages 7 and 11, with proportions rising from 15% to 21% in girls and from 12% to 18% in boys. Between ages 11 and 14, the prevalence of overweight and obesity is substantially stable, with 20% and 18% of female and male respondents classified as overweight and 8% and 7.8%, respectively, as obese. This equates to 28% of females and 26% of males being of excess weight status at age 14. Hence, from age 11 we observe a slight decline in overweight among females and a slight increase in obesity for both sexes.

The lower part of Table 1 presents proportions of overweight and obesity from age 3 to 14 by country, with 95% confidence intervals. Trajectories are similar across countries, especially for overweight. At almost every age, Northern Ireland has the highest prevalence of both overweight and obesity, closely followed by Wales, while Scotland

and England present the lowest prevalence of overweight and obesity at each age. At age 14, proportions of overweight status range from 19% in England (95% CI 18.0; 19.9) to 21% in Northern Ireland (95% CI 18.7-23.6) and proportions of obese status range from 7.1% in Scotland (95% CI 5.6-8.6) to 9.3% in Wales (95% CI 7.8-10.7). Country differences in overweight and obesity are significantly different from each other at the 10% level (Based on chi-square tests. For overweight p-value=0.078, for obesity p-value=0.086).

Table 1. Overweight and obesity, by age, sex and country

		Age 3	Age 5	Age 7	Age 11	Age 14	
Sex	Females	Over-weight	12.96 (11.99; 13.93)	16.62 (15.56; 17.68)	15.31 (14.3; 16.32)	21.43 (20.29; 22.56)	20.4 (19.32; 21.48)
		Obesity	4.47 (3.99; 4.96)	5.74 (5.17; 6.31)	6.55 (5.95; 7.14)	6.65 (6.03; 7.26)	8.22 (7.48; 8.95)
	Males	Over-weight	12.38 (11.44; 13.32)	12.92 (11.97; 13.86)	12.03 (11.13; 12.93)	18.29 (17.23; 19.35)	18.03 (17.02; 19.05)
		Obesity	4.31 (3.84; 4.78)	4.9 (4.38; 5.43)	4.89 (4.38; 5.41)	6.28 (5.68; 6.87)	7.82 (7.11; 8.53)
Country	England	Over-weight	13.09 (12.4; 13.78)	15 (14.23; 15.77)	14.21 (13.47; 14.95)	20.96 (20.08; 21.84)	18.95 (18.04; 19.86)
		Obesity	4.29 (3.87; 4.7)	5.25 (4.77; 5.73)	5.7 (5.21; 6.19)	6.36 (5.84; 6.89)	8.01 (7.38; 8.64)
	Scotland	Over-weight	13.84 (12.17; 15.51)	14.73 (12.94; 16.52)	15.1 (13.32; 16.88)	20.22 (18.12; 22.31)	19.38 (17.1; 21.65)
		Obesity	5.13 (4.06; 6.19)	5.39 (4.25; 6.53)	4.36 (3.35; 5.38)	5.21 (4.05; 6.37)	7.07 (5.59; 8.55)
	Wales	Over-weight	15.23 (13.68; 16.79)	17.36 (15.64; 19.08)	16.01 (14.38; 17.63)	20.75 (18.87; 22.62)	20.35 (18.34; 22.35)
		Obesity	4.14 (3.28; 5)	5.16 (4.16; 6.17)	6.79 (5.67; 7.9)	8.65 (7.35; 9.95)	9.27 (7.82; 10.71)
	Norther Ireland	Over-weight	15.61 (13.65; 17.57)	18.45 (16.33; 20.58)	17 (14.97; 19.02)	23.87 (21.5; 26.23)	21.15 (18.67; 23.63)
		Obesity	5.36 (4.14; 6.58)	6.85 (5.47; 8.23)	7.45 (6.04; 8.87)	8.33 (6.8; 9.86)	8.25 (6.58; 9.92)

Proportions are based on cross-sectional samples and weighted with cross-sectional weights.

Predictors of overweight and obesity at age 14

Table 2 presents descriptive statistics of overweight and obesity at age 14, by categories of predictive factors. The most striking differences are by ethnicity and maternal

education. For instance, 40% of Black children are classified as having excess weight at age 14, compared to 26.2% of White children. Around 32% of children of mothers with GCSE or lower qualifications are classified as having excess weight, compared to 18% of children of mothers with a degree or higher qualification. Differences between active and inactive children are also noteworthy: the prevalence of excess weight is 21% among children exercising five days a week or more, compared to 33% among those exercising one or two days a week. Finally, the prevalence of excess weight among children who were breastfed for at least 3 months is significantly lower than among those who were not, at 21% and 29% respectively.

Table 2. Excess weight, and overweight and obesity at age 14: descriptive statistics

Factors		N ^a	% excess weight	p-value	% over weight	p-value	% obese	p-value
Sex ^b	Female	5,326	28.6	0.002	20.4	0.001	8.2	0.801
	Male	5,499	25.9		18		7.8	
Ethnicity	White	8,491	26.4	<0.001	18.9	<0.001	7.5	<0.001
	Mixed	504	24.20		15.1		9.1	
	Indian	290	26.40		20.8		5.6	
	Pakistani, Bangladeshi	781	33.60		20.9		12.7	
	Black or Black British	338	38.40		29.6		8.8	
	Other Ethnic group	267	30.00		19		10.9	
Country ^b	England	7,122	27.0	0.006	19.0	0.072	7.9	0.186
	Wales	1,500	29.8		20.4		9.4	
	Scotland	1,158	26.3		18.6		7.6	
	Northern Ireland	1,045	29.6		21.2		8.4	
Mother's education	No academic/Other a	1,549	31.7	<0.001	21.0	<0.001	10.8	<0.001
	GCSE D-G w/ voc>=L3	1,142	32.5		21.5		11.0	
	GCSE A-C & A lev w/ A lev + voc>= L3 &	3,821	27.2		19.3		8.0	
	Degree or higher de	1,290	22.7		17.4		5.4	
Exclusive breastfeeding for 90 days	No	8,100	28.8	<0.001	20.0	<0.001	8.9	<0.001
	Yes	2,718	21.1		16.2		4.9	
Moderate/vigorous physical activity	5+ days a week	4,110	21.1	<0.001	15.8	<0.001	5.2	<0.001
	3-4 days a week	3,632	29.2		20.4		8.9	
	1-2 days a week	2,562	33.4		22.8		10.7	
	Not at all	454	28.4		19.8		8.6	

Proportions measured using cross-sectional weights at sweep 6

^a N is based on respondents having complete records on BMI and specific predictive factor, as a consequence not all groups sum up to 10,825.

^b Prevalence differs slightly from those illustrated in Table 1 due to different sample selection

Table 3 presents the coefficients and standard errors from logistic models. Predictors of excess weight at age 14 include those described in section 2.3. In line with the unadjusted statistics in Table 2, children from Pakistani and Bangladeshi and Black ethnic backgrounds have a higher probability of having excess weight compared to White children. Having a mother with a degree or higher qualification, compared to one without a formal qualification, is associated with a reduced odds of excess weight of almost 30% (OR=0.69, 95% CI= 0.55-0.87), while no significant differences are observed between intermediate levels of maternal education and no maternal qualification. Birth weight is positively associated with the probability of excess weight at age 14, with the odds for excess weight 33% higher per birthweight unit increase (100 grams). Children of mothers who smoked during pregnancy present higher odds of excess weight, as do those who were breastfed for less than 90 days. The indicator of puberty at age 14 shows that females and males who have started puberty have higher odds of excess weight but not obesity. Looking at behaviours, children who have ever smoked present higher odds of excess weight; children exercising 5 days a week or more are less likely to have excess weight. The indicator of a healthy diet is significantly associated with the odds of excess weight, but the odds ratio is very close to 1 indicating that a unit increase in the ECI scale impacts very modestly the risk of excess weight. Finally, sleeping behaviour is associated with excess weight (significance 10%), with children going to sleep after midnight having a higher odds of excess weight.

Predictors of obesity are similar to those described above, and the magnitudes of the associations are in most cases larger. For instance, ethnic differences are starker in case of Pakistani and Bangladeshi children, while no difference is observed between White and Black children. Maternal education, house ownership, maternal smoking behaviour during pregnancy, breastfeeding and birthweight, are all predictive factors of obesity, and of a larger magnitude than observed for excess weight. On the other hand no difference in the odds of being obese was found between children with different sleeping and smoking habits.

Table 3. Logit models, dependent variables: excess weight at age 14, and obesity at age 14

Predictive factors		Excess weight		Obesity	
		OR (1)	S.E. (2)	OR (3)	S.E. (4)
Sex (ref. Female)		0.958	(0.063)	0.954	(0.100)
Puberty started (ref. No)		1.294***	(0.114)	0.86	(0.137)
	Mixed	0.909	(0.121)	1.246	(0.276)
	Indian	1.238	(0.265)	0.987	(0.346)
Ethnicity (ref. White)	Pakistani, Bangladeshi	1.892***	(0.203)	2.476***	(0.474)
	Black or Black British	2.061***	(0.329)	1.294	(0.313)
	Other ethnic group	1.319	(0.281)	1.68	(0.569)
Mother's education (ref. no qualification)	GCSE D-G w/ voc>=L3+ GCSE D-C or less	1.101	(0.124)	1.125	(0.189)
	GCSE A-C & A lev w/ voc>=L3	0.963	(0.082)	0.896	(0.123)
	A lev + voc>= L3 & diplomas in HE	0.843	(0.092)	0.702*	(0.140)
	degree or higher degree	0.695***	(0.075)	0.453***	(0.108)
	Wales	1.171*	(0.097)	1.24	(0.164)
Country (ref. England)	Scotland	1.006	(0.094)	1.021	(0.173)
	Northern Ireland	1.277**	(0.128)	1.185	(0.213)
Number of siblings		0.891***	(0.027)	0.856***	(0.041)
Single parent household		0.924	(0.063)	0.95	(0.105)
Own house		0.666***	(0.045)	0.547***	(0.064)
Mother smoked during pregnancy		1.240***	(0.091)	1.247*	(0.152)
Breastfed 90+ days		0.794***	(0.056)	0.713**	(0.105)
Birth weight		1.337***	(0.069)	1.467***	(0.146)
ECI		1.054***	(0.014)	1.049**	(0.023)
Ever drunk heavily		0.964	(0.096)	0.911	(0.171)
Ever smoked		1.265***	(0.114)	1.08	(0.178)
Exercise (ref. 5-7 days a week)	3-4 days a week	1.589***	(0.104)	1.809***	(0.219)
	1-2 days a week	1.872***	(0.138)	2.120***	(0.268)
	Not at all	1.316**	(0.180)	1.475*	(0.340)
Hours watched TV per day (ref. never)	< 1hr	1.218	(0.350)	1.621	(0.738)
	1-2 hrs	1.057	(0.291)	1.516	(0.624)
	3+ hrs	1.319	(0.369)	2.019*	(0.841)
Bed time during the week (ref. Before 9pm)	9 - 9:59pm	0.95	(0.135)	0.85	(0.181)
	10 - 10:59pm	0.932	(0.130)	1.004	(0.216)
	11 -midnight	1.146	(0.169)	1.177	(0.248)
	after midnight	1.400*	(0.268)	1.391	(0.362)
<i>Observations</i>		10,825		10,818	

*** p<0.01, ** p<0.05, * p<0.1

OR=odds ratio; Voc=vocational; ECI=Eating Choices Index; hrs=hours

We also estimate a multinomial logit model to understand the factors associated with overweight and obesity separately, relative to normal weight. Relative risk ratios are presented in Table A2 in the Supporting Information. Results are very consistent with those in Table 3, suggesting that excess weight, which combines overweight and obesity, does not mask different directions or magnitude of effects between overweight and obesity. The most relevant finding is that in this model, not exercising at all compared to exercising 5+ days per week increases the odds of both overweight and obesity, although significance levels are low (10% and 5% respectively).

Transitions between ages 11 and 14

Table 4 shows matrices of transitions between normal weight and excess weight between ages 11 and 14 (light grey area) and between obesity and non-obesity (dark grey area), separately by sex. Of males classified as normal weight at age 11, 91% remain so at age 14, and 19% have excess weight. Of males having excess weight at age 11, 76% remain so at age 14, and 24% become normal weight. For females, of those classified as normal weight at age 11, 90% remain so at age 14, and 10% switch to excess weight status; and amongst females classified as having excess weight at age 11, 74% remain so at age 14, and 26% become normal weight. Therefore, transitions are very similar across sexes, if slightly more positive for males than for females. Transitions from obesity to non-obesity (i.e. normal weight and overweight) between ages 11 and 14, separately by sex, are presented in the lower part of the table, and are also slightly more positive for males than females, especially in terms of transition out of obesity, with 34% of males and 27% of females classified as obese at age 11 transiting out to non-obese status at age 14.

Table 4. Transition between excess weight (obesity) and normal weight (non-obesity) from age 11 to age 14, by sex

			Males				Females			
			Normal weight	Excess weight	Non-obese	Obese	Normal weight	Excess weight	Non-obese	Obese
Age	Normal weight	row %	91.3	8.7			89.7	10.3		
		N	(3,549)	(309)			(3,273)	(356)		

Excess weight	row % N	24.4 (313)	75.6 (948)			26.3 (355)	73.7 (1,020)		
Non-obese	row % N			96.8 (4,637)	3.2 (146)			96.1 (4,537)	3.9 (167)
Obese	row % N			33.8 (94)	66.2 (206)			27.4 (96)	72.6 (204)

Percentages are row percentages and measured using longitudinal weights at sweep 6. N=subsample size is not weighted.

Modelling transitions

We next estimate a model to understand the factors associated with the likelihood of transiting out of excess weight between ages 11 and 14. Results are shown in Table 4. The most striking result is the association between reaching puberty and both overweight and obesity: respondents of excess weight status at age 11 had an almost 50% higher likelihood of switching to normal weight at 14 if they had reached puberty by then; for transition out of obesity the correlation is even larger, with respondents who had reached puberty three times more likely to become non-obese at age 14, compared to those who had not reached puberty. The other factors associated with transitions to normal weight from age 11 to 14 include: high level of maternal education, associated with an increased likelihood of transiting out of excess weight (significant at the 10% level), home ownership, birthweight, with higher birthweight associated with lower odds of transiting out excess weight at age 14. Some health-related behaviours of respondents show a strong association with the probability of transiting from excess to normal weight between 11 and 14: respondents who have never smoked and those doing vigorous physical activity 5+ days a week present higher chances of transiting out excess weight at age 14. For transition out of obesity between 11 and 14, almost no factor is significant. Physical activity is the exception, with frequent exercise being a protective factor. The lack of significance is likely related to low power, with 600 respondents obese at age 11.

Table 5. Logit models: ORs of transiting out of excess weight and obesity at age 14, from age 11

Predictive factors	Pr(normal weight at 14 excess weight at 11)	Pr(non-obese at 14 obese at 11)
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		OR (1)	S.E. (2)	OR (3)	S.E. (4)
Sex (ref. Female)		0.972	(0.128)	1.487	(0.377)
Puberty started (ref. No)		1.496**	(0.277)	3.420***	(1.329)
	Mixed	0.839	(0.208)	0.62	(0.353)
	Indian	1.283	(0.463)	0.624	(0.501)
Ethnicity (ref. White)	Pakistani, Bangladeshi	0.618*	(0.157)	0.61	(0.304)
	Black or Black British	0.72	(0.200)	1.229	(0.687)
	Other ethnic group	0.489	(0.222)	0.962	(0.686)
	GCSE D-G w/voc>=L3+ GCSE D-C or less	1.061	(0.252)	0.549	(0.216)
Mother's education (ref. no qualification)	GCSE A-C & A lev w/ voc>=L3	1.365*	(0.243)	0.474**	(0.158)
	A lev + voc>= L3 & diplomas in HE degree or higher degree	1.234	(0.295)	0.707	(0.342)
		1.498*	(0.359)	1.174	(0.710)
	Wales	0.835	(0.161)	0.691	(0.275)
Country (ref. England)	Scotland	0.825	(0.154)	0.86	(0.394)
	Northern Ireland	1.249	(0.234)	0.709	(0.265)
Number of siblings		1.007	(0.056)	1.059	(0.098)
Single parent household		1.102	(0.170)	0.827	(0.266)
Own house		1.362**	(0.196)	1.399	(0.397)
Mother smoked during pregnancy		0.876	(0.119)	1.344	(0.358)
Breastfed 90+ days		1.006	(0.155)	0.803	(0.266)
Birth weight		0.824*	(0.086)	0.876	(0.194)
ECI		0.969	(0.022)	1.002	(0.054)
Ever drunk heavily		1.022	(0.181)	1.035	(0.407)
Ever smoked		1.395*	(0.248)	1.469	(0.478)
	3-4 days a week	0.604***	(0.084)	0.426***	(0.127)
Exercise (ref. 5-7 days a week)	1-2 days a week	0.565***	(0.087)	0.623	(0.182)
	Not at all	0.678	(0.179)	0.201*	(0.176)
Hours watched TV per day (ref. never)	< 1hr	0.916	(0.554)	5.13	(7.779)
	1-2 hrs	0.838	(0.481)	3.817	(5.742)
	3+ hrs	0.882	(0.518)	4.091	(6.127)
	9 - 9:59pm	1.245	(0.342)	2.771	(2.097)
Bed time during the week (ref. Before 9pm)	10 - 10:59pm	1.146	(0.299)	1.554	(1.180)
	11 -midnight	1.239	(0.337)	1.713	(1.291)
	after midnight	0.735	(0.262)	1.174	(0.943)
<i>Observations</i>		2,635		599	

*** p<0.01, ** p<0.05, * p<0.1

OR=odds ratio; Voc=vocational; ECI=Eating Choices Index; hrs=hours

Discussion

This study uses unique data from the UK Millennium Cohort Study and presents new evidence on levels of, and trends in, overweight and obesity amongst a nationally

representative and contemporaneous sample of adolescents in the UK today. It shows that around 8% of 14-year olds are classified as obese and 20% overweight, with proportions similar across males and females. The study finds that the stark increases in excess weight previously observed between ages 7 and 11, from 20% to 28% (Platt et al., 2014)¹, have stabilized at 27% by age 14, by which point no sustained increases in overweight or obesity are observed. Whilst other recent research provide evidence of a secular plateauing (Collaboration NCDRF, 2017; Health Survey for England, 2013) of the increasing trends in childhood overweight and obesity in the most recent generations of children, our study provides important new evidence that increasing trends in excess weight have stabilized, based on life-course analysis of a cohort born around the Millennium. Whether this plateauing persists as the cohort continues to age remains to be seen and future MCS sweeps will allow for monitoring of this phenomenon. It remains unknown to what extent future young generations will be affected by the obesity epidemic. What is reasonable to expect is that the prevalence of overweight and obese children and adolescents will be affected by, and indeed reinforces, the Government commitment to reducing obesity in childhood. Hence, a continuous monitoring of trends will be essential and needed in the upcoming years. Moreover, experience learnt from today's young generations is an important instrument to take on this challenge.

For this reason, the second objective of this work was to identify factors associated with risk of overweight and obesity at age 14. The intention was to identify high-risk profiles to inform policy making and help shape and target interventions appropriately. For example, we find that ethnic differences in BMI are stark, with children from Indian, Pakistani and Bangladeshi and Black ethnic backgrounds displaying a higher probability of excess weight status than White children. An important consideration when considering ethnic inequality, however, is that ethnic differences in body composition can be very important when developing BMI cut-points, especially for Asian children (Liu et al., 2011). We do not consider ethnic-specific BMI cut-points in order to be consistent with previous studies and aid comparability, but acknowledge this potential limitation.

¹ Platt et al. used UK 1990 thresholds to classify overweight and obesity, hence their estimates are different, but direction of trends is the same. THIS IS IMPORTANT INFORMATION – PERHAPS PUT IN THE TEXT

We also identify background characteristics that are associated with reduced risk of excess weight: high maternal education, breastfeeding, and home ownership; and risk factors associated with raised risk of excess weight, including maternal smoking during pregnancy, for which our findings are in line with recent and less recent studies that found that intrauterine exposure to inhaled smoke products rather than lifestyle factors associated with maternal smoking accounts for the association between overweight/obesity and maternal smoking during pregnancy (Harris, Willett, & Michels, 2013; L. Li et al., 2016; Toschke et al., 2002; Von Kries et al., 2002). It is important to distinguish between factors relating to early life and characteristics in adolescence, to aid in targeting both the optimal time and way to intervene. In the case of the MCS cohort, specifically, knowing how respondents' behaviours are associated with the risk of overweight or obesity would permit the design and implementation of targeted interventions to impact the cohort members' lives. We find that the most important individual protective behavioural factor is frequent exercise. Current national physical activity guidelines for children aged 5 to 18 recommend that children and young people engage in moderate to vigorous intensity physical activity for at least 60 minutes every day (Department of Health, 2011). Our results support the guidelines that exercise should be done every day, as we find that even those who exercise 3-4 days a week have higher risk of excess weight compared to those who exercise 5 days a week or more. Also, smoking and poor sleeping behaviours show some association with overweight, but not with obesity. The composite indicator of a healthy diet does not appear protective against excess weight, contrary to what we had expected. Therefore, we rerun the multivariate model presented in Table 3 including the items composing the index separately and all together (results are available upon request), but results do not change, with the exception of breakfast which correlates as expected: those having breakfast every day have lower odds of overweight and obesity. Further research is needed to understand the role of diet in terms of both calorie intake and healthy eating habits.

Another contribution of this work is to study transitions into and out of overweight/obese statuses, from early adolescence to mid-adolescence, a critical stage coinciding with the transition from primary to secondary school, increased

independence, and important physiological change. For the large part, we observe considerable persistence in weight status from 11 to 14, in agreement with results of the study of Geserick et al. just published on the New England Journal of Medicine (Geserick et al., 2018). Where transitions occur, the direction tends to be positive, with a higher probability of transiting out of excess weight/obesity than into it. This important finding is suggestive of a positive trend in adolescents' development. However, it must be regarded alongside some limitations. First, the change in BMI resulting in a change in status could be very small and may largely reflect those on the border of excess weight. Second, we considered two age points in adolescence development, 11 and 14, and were unable to capture fluctuations between these ages. Finally, restricting the analysis to those having excess weight at age 11 results in a large reduction in sample size and statistical power, particularly in the case of transitions out of obesity. Nevertheless, some striking results have emerged, particularly regarding puberty. Amongst those of excess weight at age 11, females who have had their menarche and males who have experienced voice deepening have higher odds of transiting to normal weight compared to those who have not had these pubertal changes. The literature has mostly explored the association between obesity/overweight and puberty in terms of the former determining the latter, and obesity has been found to contribute to early onset of puberty in females, while in males there is insufficient data (Li et al., 2017). The direction of the association we find may appear counterintuitive. However, it is important to bear in mind that we are considering only a select sample of children who were overweight or obese at age 11. Among this subsample the proportion of children that had reached puberty by age 11 was larger than among their normal weight peers, and it may be that in this case having reached puberty is associated with transitions as a protective factor. We believe these findings can have important implications, particularly relevant in terms of policy targeted at adolescents and young adults as well as children approaching adolescence. Results are supported by some unique strengths of this study, that must however be considered alongside limitations. We use a very rich longitudinal cohort study representative of contemporary adolescents, and this allows us to know in depth many spheres of their lives. At least two limitations arise when we study changes across adolescence, such as overweight and obesity transitions, that are influenced by

both genetic and non-genetic factors. The first is that in this study we can explore only non-genetic factors such as socio-economic environment; the second is that the time intervals across surveys do not allow us to monitor and capture intermediate changes and we may be able to capture only the results of processes that have taken place between age 11 and 14. Moreover, no causal effects can be claimed from results of analyses. We identify risk factors for overweight and obesity, but cannot claim that their association with the risk of overweight/obesity is causal, nor the underlying mechanisms through which they act, or the direction of association, as was briefly discussed in regards to puberty. Nevertheless, the identification of predictors of overweight and obesity is an important first step to monitor subjects at risk and to collect appropriate information on the possible mechanisms through which they may affect BMI.

What is already known on this subject

- Childhood obesity and overweight epidemic is growing globally
- Children who are overweight or obese face an increased risk of many health problems
- Overweight and obesity rates in childhood increase as children grow up

What this study adds

- Proportion of excess weight have stabilized from age 11 to age 14, though at an alarmingly high level
- Boys are slightly more likely than girls to become normal weight at age 14 having been overweight or obese at 11.
- Predictors of transiting out of excess weight and obesity include child's active behaviour and puberty onset.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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Figure 2. Overweight and obesity, by age and country ^a

^a Proportions are based on cross-sectional samples and weighted with cross-sectional weights.

Table 1. Excess weight, and overweight and obesity at age 14: descriptive statistics

Proportions measured using cross-sectional weights at sweep 6

^a N based on respondents having complete records on all variables included in the model presented in table 3.

^b Prevalence differs slightly from those illustrated in Figures 1 and 2 due to different sample selection

Table 2. Linear probability models, dependent variables: excess weight at age 14, and obesity at age 14

*** p<0.01, ** p<0.05, * p<0.1

Table 3. Transition between excess weight (obesity) and normal weight (non-obesity) from age 11 to age 14, by sex

Proportions measured using longitudinal weights at sweep 6. First figure in each cell is sample size; second figure is percentage.

Table 4. Probability of transiting out of excess weight and obesity at age 14, from age 11

^a Measured at age 11 (sweep 5).

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