Associations of Bedtime Schedules In Childhood With Obesity Risk In Adolescence

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Research Article

Keywords: children, adolescence, longitudinal, obesity, adiposity, bedtime, Millennium Cohort Study.

Posted Date: October 18th, 2021

DOI: https://doi.org/10.21203/rs.3.rs-969124/v1

Abstract

Objective: To investigate long-term associations of bedtime schedules and bedtimes in childhood with obesity risk and adiposity in later years.

Methods: This cohort study is a secondary analysis of non-obese 7-year-old singleton children participating in the Millennium Cohort Study, a nationally representative prospective cohort of children born between 09/2000 and 01/2002 in the UK. Bedtimes and regularity of bedtimes of 7-year-olds were reported by parents. Obesity, from objectively body mass index, and bio-electric impedance body fat percentage (BFP) measurements at 11 and 14 years were considered outcomes.

Results: In total, 11044 and 9898 children representing 87.3% and 78.3% of eligible sample were followed at 11 and 14 years, respectively. Obesity risk at 11 and 14 years was higher among children with never regular bedtimes at 7 years compared with those with always regular bedtimes (Risk Ratio, RR, 2.8 [95% CI, 1.8–1.4] and 2.3 [95% CI, 1.5–3.6], respectively). Increasing irregularity of childhood bedtime was associated with increasing risk of obesity at both 11 and 14 years in a dose–response manner (*P*trend <0.001; and *P*trend = 0.002, respectively). BFP at 11 years increased by 1.1% (95% CI, 0.8–1.5) for boys and 1.0% (95% CI, 0.6–1.4) for girls for every hour delay in childhood bedtime.

Conclusions: Irregular bedtime schedules and later bedtimes in childhood were associated with increased risk of obesity in early- and mid-adolescence in a dose–response manner. There was marginal, but significant, increases in BFP during adolescence for children with later bedtimes.

What Is Known

- Emerging evidence shows a relationship between sleep duration and paediatric obesity risk.
- Bedtime is the easily modifiable component of sleep duration, but the relationship between childhood bedtime schedules and obesity in adolescence is understudied.

What is New

- Irregular and later bedtimes during childhood are associated with higher risk of obesity in adolescence in a dose–response manner.
- Late bedtimes are associated with significant marginal increases in body fat percentage in adolescence.

Introduction

Obesity remains a major paediatric and public health concern worldwide. Over the last 40 years, the prevalence of paediatric obesity has increased by approximately 10-fold with about 41 million 4- to 16-year-olds classified as overweight or obese, globally.[1,2] In the UK, the Royal College of Paediatrics and Child Health reports that the rise in obesity prevalence remains noticeable among adolescents.[3] The

economic and public health consequences of obesity are immense; obesity-related chronic diseases can impose physical limitations on daily activities much as psychological effects can persist or even become aggravated later in life.[4–6] While the ongoing physiological and psychological development during childhood can make it a vulnerable phase for adverse consequences of obesity, it may also provide a critical window for the implementation of healthy interventions that could have lasting benefits.

To date, global and UK guidance to tackle the obesity epidemic in children have mainly focused on diet and physical activity which are the critical components of energy intake and expenditure.[7,8] Meanwhile, there is evidence showing the importance of optimal sleep duration and quality for biochemical functions such as hormonal regulation and carbohydrate metabolism.[9,10] Yet, relative to physical activity and diet, the role of sleep in childhood, and in particular, regular bedtime schedules on obesity is emerging. During childhood, there is an increased physiological demand for long sleep duration and this tapers off with age.[11] For school-aged children, fixed school schedules and social activities tend to further delay bedtime and potentially reduce sleep duration beyond the physiological decline.[12] In fact, recent studies suggest historic rise in the proportion of school-aged children having insufficient sleep over the past decades.[13,14]

To ensure sufficient sleep duration among early school-aged children, it is important that early and regular bedtimes are established.[15] The limited literature on children's bedtime schedules and health suggest that those with less structured bedtimes are at risk of insufficient sleep duration and poor cognitive development.[16,17] Studies investigating associations between bedtimes schedules in childhood and adolescent obesity are also scanty; while few used objective anthropometric measures, none assessed body fat.[18–21] The present study goes beyond previous studies by using a larger national longitudinal cohort with objective anthropometric measures and bioelectric impedance measurement of body fat percentage (BFP) to investigate the associations between bedtime schedules in non—obese childhood and obesity risk later on in early- and mid-adolescence.

Methods

Data sources

Data from adolescents participating in the UK Millennium Cohort Study (MCS) were used. The UK MCS is a nationally representative prospective cohort of children born in the UK between 09/2000 and 01/2002. Detailed sampling and recruitment strategies are explained elsewhere.[22] Briefly, children who were eligible beneficiaries of a government child support scheme, with almost universal coverage, were recruited into the MCS when they were 9 months old.[22] The MCS sample was drawn from 398 electoral wards nested in 9 sampling strata, two from each of the four nations of the UK (England, Scotland, Wales, and Northern Ireland) and an ethnic minority stratum for England.[23] To date, there have been seven sweeps of MCS follow-up, but the most recent data available is the sixth sweep (MCS6) when children were approximately 14 years old (01/2015–04/2016).[24] The baseline sample for the present study is a subpopulation of non—obese singleton children from the fourth sweep (MCS4, age 7 years, =12645) who

were followed at MCS5 (at 11 years, N =11044, 87.3%) and at MSC6 (N =9898, 78.3%) (Figure 1). Since the MCS is an open cohort, children who participated in MCS4, but missed MCS5, could return at MCS6. Informed consent was obtained from parents of MCS children. Ethical approval for the MCS was provided by the UK National Health Service (NHS) and regional Research Ethics Committees (07/MRE03/32, 11/YH/0203, 13/LO/1786) in line with the Declaration of Helsinki.

Measures

Bedtimes and bedtime schedules

At MCS4, mothers responded to questions about their children's bedtime. Specifically, mothers were asked "On weekdays during term-time, does your child go to bed at a regular time?" and given the following response options (*Never, sometimes, usually* and *always*). Mothers who chose any of the latter three options were further probed for weekday term-time bedtime of their children. Where mothers provided a time range, the earliest was recorded. For the purpose of this paper, bedtime was used as both a continuous variable and a categorical variable (*7:30 PM or earlier, 7:31–8:00 PM, 8:01–8:30 PM, 8:31–9:00 PM*, and *after 9:00 PM*).

Anthropometric and BFP measures

Anthropometric and BFP measures of children at 7, 11 and 14 years using electronic Tanita™ scales for weight and BFP, and Leicester Height Measure Stadiometers for height were taken by trained investigators. Each child's body mass index (BMI) estimated in kg/m^2 was transformed to standardised scores. Obesity and overweight status were determined by using the International Obesity Task Force (IOTF) age- and sex-specific BMI thresholds.[25] The prevalence of obesity at 7 years among singleton children was 5.7%. To accurately investigate the relationship between childhood bedtime habits and the incidence of obesity in adolescence, statistical analyses were performed only on the subpopulation of children who were not obese at 7 years. BMI data was available for 10780 (97.6%) and 9391 (94.9%) of those followed at aa and 14 years, respectively (Figure 1).

Sociodemographic data

Potential confounders were identified using directed acyclic graphs (DAGs) and selected *a priori* from MCS household and parent-derived datasets.[24] The following variables were identified as potential confounder: child's age, sex, ethnicity, parental socioeconomic status (SES), highest level of parental education/vocational training, and number of people in household at bedtime assessment. The higher SES class of either parent (where both were available) was selected from the National Statistics Socioeconomic Classification (NS-SEC, 3-level version) with a fourth level when the only or both parents were unemployed. The higher of either parent's highest level of education or vocational qualification was

also chosen. Covariates that were not identified as confounders by DAGs were selected from the database and used in sensitivity analyses.

Statistical analysis

Poisson regression models were performed to assess the risk ratio (RR) of obesity at 11 and 14 years in relation to childhood bedtime regularity (reference category: *always regular*), or in relation bedtime (reference category: *7:30 PM or earlier*). Plausible linear trends in bedtime regularity categories and the risk of obesity were examined. Linear regression analyses were performed to examine the associations between childhood bedtime regularity or bedtime and BFP. Mean difference (MD) in BFP between each of the categories and the corresponding reference category were calculated. Where bedtime was used as a continuous variable, regression coefficients were calculated instead. Confounders and covariates were child, parent and household characteristics collected at 7 years.

All models were adjusted for previously mentioned confounders (Model I). Sensitivity analyses were performed on the adjusted models under various conditions: (i) further adjustment for baseline overweight status or BFP – Model II, (ii) inclusion of bedtime regularity and bedtime in the same model adjusting for same confounders as in Model II – Model III, and (iii) additional adjustment of Model III for TV and computer hours, and frequency of physical activity and bedwetting at baseline – Model IV.

Since there is strong evidence for age at menarche and the BFP in adolescent girls,[26] analyses of bedtime or bedtime regularity and BFP were stratified by sex and adjusted for menarche status (at 11 years) and age at menarche (at 14 years) for girls.

Complete-case analyses were employed in all statistical analyses using Stata SE/13.1 (Stata Corp, College Station, TX). All analyses accounted for survey weights which consists of sampling and attrition weights as well as population correction factor. Significance was defined as $p < 0.05$ from 2-tailed hypothesis tests.

Results

Sample characteristics

Baseline characteristics for obesity- and bedtime-related measures were similar between children lost to follow-up at 11 and 14 years. However, those lost to follow-up were more likely to boys, black, slightly older, have parents with low/no academic or vocational qualification, and from a low SES family (Supplementary Table 1). The prevalence of overweight among the non—obese 7-year-olds was approximately 15%. Of the sample followed at 11 and 14 years, 59.5% and 59.3% had *always regular* bedtime schedule whiles 3.8% and 3.6% had *never regular* bedtime schedules, respectively. Weighted mean bedtime was 8:00 PM (95% CI, 7:58–8:01) and about two-thirds of children went to bed by 8:00 PM. There was no sex-difference in the distribution of regularity of bedtime schedules nor bedtimes. On average, children whose bedtimes were *usually* and *sometimes regular* had 10.8 minutes (95% CI, 9.0–

12.7) and 27.3 minutes (95% CI, 23.6–31.2) later bedtimes than those who had *always regular* bedtime schedules, respectively.

Whiles the incidence of obesity in the entire cohort at 11 and 14 years was 2.9% and 4.9% respectively, the incidence was highest (7.8% and 11.0%, respectively) among the children who had *never regular* bedtime schedule at 7 years (Figure 2). Likewise, obesity incidence at both adolescent years was lowest for those whose childhood bedtime was before/at 7:30 PM and highest for those who went to bed after 9:00 PM (2.2% v 5.1%; and 3.5% v 10.0%, Supplementary Table 2). Also, Mean BFP was lowest children who went to bed by 7:30 PM, 20.6% at both 11 and 14 years, whiles those who went to bed after 9:00 PM, recorded the highest mean BFP at adolescence, 23.5% and 23.4%, respectively (Table 1). There were no sex-differences in obesity incidence at both 11 and 14 years, however, on average, girls had 4.6% (95% CI, 4.3–4.9) and 10.4% (95%CI, 10.0–10.8) more PBF than boys, respectively.

Table 1
Weighted mean body fat percentage (95% CI) at 11 and 14 years by term-time bedtimes and bedtime schedules at 7 years

	MCS5 (11 years)			**MCS6 (14 years)**		
	All	Boys	Girls	All	Boys	Girls
All non-obese 7-year-olds	21.4 (21.2; 21.6)	19.2 (19.0; 19.4)	23.8 (23.6; 24.0)	21.1 (20.9; 21.3)	16.1 (15.8; 16.4)	26.6 (26.3; 26.8)
Regularity of bedtime						
Always regular	21.3 (21.1; 21.5)	19.1 (18.8; 19.3)	23.7 (23.4; 24.0)	21.0 (20.6; 21.3)	16.1 (15.7; 16.5)	26.5 (26.2; 26.9)
Usually regular	21.4 (21.1; 21.7)	19.1 (18.8; 19.5)	23.7 (23.3; 24.1)	21.1 (20.7; 21.4)	16.0 (15.5; 16.5)	26.4 (26.0; 26.8)
Sometimes regular	22.2 (21.5; 22.9)	20.3 (19.3; 21.3)	24.2 (23.3; 25.2)	21.8 (20.8; 22.8)	16.5 (15.5; 17.8)	27.7 (26.7; 28.7)
Never regular	22.6 (21.8; 23.5)	20.6 (19.3; 21.8)	24.5 (23.5; 25.6)	22.6 (21.3; 23.9)	17.6 (15.8; 19.3)	27.3 (25.9; 28.8)
Bedtimes						
7:30 PM or earlier	20.6 (20.3; 20.9)	18.2 (17.8; 18.6)	23.0 (22.6; 23.4)	20.6 (20.1; 21.0)	15.4 (15.0; 15.9)	25.9 (25.4; 28.4)
7:31 PM – 8:00 PM	21.3 (21.0; 21.6)	19.0 (18.7; 19.4)	23.8 (23.4; 24.2)	20.9 (20.5; 21.2)	16.0 (15.5; 16.4)	26.5 (26.2; 26.9)
8:01 PM – 8:30 PM	21.9 (21.5; 22.3)	19.8 (19.3; 20.3)	24.2 (23.7; 24.7)	21.2 (20.6; 21.8)	16.0 (15.4; 16.6)	27.1 (26.5; 27.7)
8:31 PM – 9:00 PM	22.8 (22.3; 23.3)	20.9 (20.3; 21.6)	24.8 (24.2; 25.5)	22.5 (21.8; 23.2)	17.9 (16.9; 18.9)	27.6 (26.8; 28.3)
After 9:00 PM	23.5 (22.5; 24.5)	21.6 (20.0; 23.1)	25.4 (23.9; 26.8)	23.4 (22.0; 24.7)	18.5 (16.7; 20.4)	28.0 (26.4; 29.6)

Obesity risk by bedtime and bedtime regularity

Compared to children who had *always regular* bedtimes, the risk of obesity at 11 years was by two- and three-folds higher among those whose bedtimes were *sometime regular* and *never regular*, respectively (Table 2). The risk of obesity at 14 years remained higher among those with *never regular* bedtimes at 7 years compared with those with *always regular* bedtimes (RR, 2.3; 95% CI, 1.5– 3.6). There was a significant linear gradient of increasing obesity risk at both 11 and 14 years with increasing irregularity of bedtimes at 7 years even after adjusting for confounders and baseline overweight status (*ptrend* < 0.001 and *ptrend* = 0.002, respectively). After adjusting for several covariates and including both bedtime regularity and bedtimes in sensitivity analyses (Model IV), the trend in increasing obesity risk with

increasing bedtime regularity persisted at 11 years (*ptrend* = 0.008), but not at 14 years. For those not in the *never regular* category, bedtimes after 8:30 PM were consistently associated with higher risk of obesity at 11 and 14 years. Hourly delay in bedtimes at 7 years was however associated with 50% higher risk of obesity across both adolescent years, although attenuated to 20% in sensitivity analyses (Model IV in Table 2).

Table 2
Risk ratios (95% CI) of obesity at age 11 and 14 years by bedtime regularity and bedtimes at 7 years

	Model I	Model II	Model III	Model IV
Obesity at 11 years				
Regularity of bedtime				
Always regular (Reference)	1.0	1.0	1.0	1.0
Usually regular	1.2 (0.9 to 1.7)	1.2 (0.9 to 1.6)	1.2 (0.9 to 1.6)	1.2 (0.9 to 1.7)
Sometimes regular	2.1 (1.4 to 3.3)	2.0 (1.3 to 3.0)	1.9 (1.2 to 2.8)	1.9 (1.2 to 2.8)
Never regular	2.8 (1.8 to 4.4)	2.9 (2.0 to 4.2)	—	—
*P*trend	<0.001	<0.001	0.013	0.008
Bedtimes (continuous)[a]	1.5 (1.2 to 1.8)	1.2 (1.0 to 1.5)	1.2 (1.0 to 1.4)	1.2 (1.0 to 1.4)
7:30 PM or earlier (Reference)	1.0	1.0	—	—
7:31 PM – 8:00 PM	1.1 (0.8 to 1.6)	1.0 (0.7 to 1.4)	—	—
8:01 PM – 8:30 PM	1.5 (1.0 to 2.2)	1.2 (0.8 to 1.7)	—	—
8:31 PM – 9:00 PM	1.9 (1.2 to 3.7)	1.4 (0.9 to 2.0)	—	—
After 9:00 PM	2.4 (1.1 to 5.0)	1.6 (0.8 to 3.1)	—	—
Obesity at 14 years				
Regularity of bedtime				
Always regular (Reference)	1.0	1.0	1.0	1.0
Usually regular	1.0 (0.7 to 1.3)	1.0 (0.7 to 1.2)	0.9 (0.7 to 1.2)	0.9 (0.7 to 1.2)
Sometimes regular	1.5 (1.0 to 2.3)	1.3 (0.9 to 1.9)	1.2 (0.8 to 1.8)	1.2 (0.8 to 1.7)
Never regular	2.3 (1.5 to 3.6)	2.3 (1.5 to 3.4)	—	—
*P*trend	0.002	0.002	0.760	0.900
Bedtimes (continuous)[a]	1.5 (1.2 to 1.8)	1.3 (1.1 to 1.5)	1.2 (1.0 to 1.5)	1.2 (1.0 to 1.5)

[a]Represents RR (95% CI) of obesity per hour delay of bedtime

Model I – Adjusts for sex and age, ethnicity, parental SES, parental education, and number of people in household; Model II – Model I further adjusted for overweight status at 7 years; Model III – Model includes both bedtime regularity (categorical) and bedtime (continuous) and adjusts for the same covariates as in Model II; Model IV – Model III further adjusted for TV hours on weekdays, computer hours on weekdays, frequency of physical activity, frequency of bedwetting.

	Model I	Model II	Model III	Model IV
7:30 PM or earlier (Reference)	1.0	1.0	—	—
7:31 PM – 8:00 PM	1.4 (1.0 to 1.8)	1.1 (0.9 to 1.5)	—	—
8:01 PM – 8:30 PM	1.5 (1.0 to 2.1)	1.2 (0.8 to 1.7)	—	—
8:31 PM – 9:00 PM	2.0 (1.3 to 3.0)	1.5 (1.0 to 2.1)	—	—
After 9:00 PM	2.6 (1.3 to 5.0)	2.0 (1.2 to 3.3)	—	—
[a]Represents RR (95% CI) of obesity per hour delay of bedtime				
Model I – Adjusts for sex and age, ethnicity, parental SES, parental education, and number of people in household; Model II – Model I further adjusted for overweight status at 7 years; Model III – Model includes both bedtime regularity (categorical) and bedtime (continuous) and adjusts for the same covariates as in Model II; Model IV – Model III further adjusted for TV hours on weekdays, computer hours on weekdays, frequency of physical activity, frequency of bedwetting.				

BFP by bedtime and bedtime regularity

Mean differences in BFP, for all adolescents, between each of the bedtime regularity categories and the *always regular* category were generally not statistically significant except for those with *never regular* bedtimes who had 0.9% higher body fat (95% CI, 0.0–2.2) at 11 years (Figure 3). Mean BFP for any irregular bedtime category was not significantly different from mean BFP for *always regular* category for both sexes after stratification and adjustment for menarche status for girls (Table 3). However, BFP at 11 years increased by 1.1% (95% CI, 0.8–1.5) and 1.0% (95%CI, 0.6–1.4) at for every hour delay in bedtime at 7 years for boys and girls, respectively. This linear increase persisted, albeit attenuated to 0.8%, at 14 years across both sexes. The marginal increase in BFP by late bedtimes was more evident in early adolescence when childhood bedtimes 7:31–8:00 PM was associated with significant higher BFP at 11 years (MD, 0.6%; 95% CI, 0.1–1.1) and 0.8%; 95% CI, 0.2–1.4, for boys and girls, respectively) compared to bedtimes before/at 7:30 PM. The dose–response association between later bedtimes in childhood and higher BFP in adolescence persisted even after adjusting for bedtime regularity and several covariates including baseline BFP in sensitivity analyses (Models IVA & IVB in Table 3).

Table 3
Associations between bedtime regularity and bedtimes at 7 years and obesity and BFP at 11 and 14 years among girls

	Boys		**Girls**	
	Model IA	Model IVA	Model IB	Model IVB
BFP at 11 years				
Regularity of bedtime				
Always regular (Reference)	0.0	0.0	0.0	0.0
Usually regular	0.0 (-0.4 to 0.5)	0.0 (-0.3 to 0.4)	0.1 (-0.4 to 0.5)	0.1 (-0.2 to 0.5)
Sometimes regular	1.0 (0.0 to 2.1)	0.1 (-0.8 to 0.9)	0.4 (-0.7 to 1.4)	0.1 (-0.7 to 0.8)
Never regular	1.1 (-0.3 to 2.5)	—	0.9 (-0.4 to 2.1)	—
*P*trend	0.040	0.826	0.184	0.550
Bedtimes (continuous)[a]	1.1 (0.8 to 1.5)	0.8 (0.5 to 1.1)	1.0 (0.6 to 1.4)	0.2 (0.0 to 0.5)
7:30 PM or earlier (Reference)	0.0	—	0.0	—
7:31 PM – 8:00 PM	0.6 (0.1 to 1.1)	—	0.8 (0.2 to 1.4)	—
8:01 PM – 8:30 PM	1.2 (0.6 to 1.8)	—	1.0 (0.3 to 1.7)	—
8:31 PM – 9:00 PM	1.9 (1.1 to 4.6)	—	1.6 (0.7 to 2.5)	—
After 9:00 PM	2.5 (0.6 to 8.8)	—	2.4 (0.6 to 4.2)	—
BFP at 14 years				
Regularity of bedtime				
Always regular (Reference)	0.0	0.0	0.0	0.0

[a]Represents regression coefficient (95% CI) of BFP per hour delay of bedtime

Models IA – Adjusts for age, ethnicity, parental SES, parental education, number of people in household.

Model IB – Adjusts for both baseline age and menarche status at 11 years or age at menarche at 14 years, ethnicity, parental SES, parental education, and number of people in household

Model IVA & IVB – Each model includes both bedtime regularity (categorical) and bedtime (continuous) and adjusts for BFP at 7 years, frequency of TV hours on weekdays, computer hours on weekdays, frequency of physical activity, frequency of bedwetting, in addition to confounders adjusted for in Models IA & IB, respectively

	Boys		Girls	
Usually regular	-0.2 (-0.8 to 0.4)	0.0 (-0.5 to 0.5)	0.2 (-0.3 to 0.6)	0.1 (-0.3 to 0.5)
Sometimes regular	0.2 (-1.1 to 1.5)	-0.6 (-1.8 to 0.5)	1.1 (0.0 to 2.1)	0.5 (-0.3 to 1.4)
Never regular	1.1 (-0.9 to 3.1)	—	0.3 (-1.2 to 1.9)	—
*P*trend	0.504		0.152	0.254
Bedtimes (continuous)[a]	0.8 (0.3 to 1.3)	0.6 (0.1 to 1.1)	0.8 (0.4 to 1.2)	0.3 (-0.1 to 0.6)
7:30 PM or earlier (Reference)	0.0	—	0.0	—
7:31 PM – 8:00 PM	0.3 (-0.3 to 1.0)	—	0.4 (-0.2 to 1.0)	—
8:01 PM – 8:30 PM	0.2 (-0.6 to 1.0)	—	0.9 (0.2 to 1.6)	—
8:31 PM – 9:00 PM	1.7 (0.6 to 2.8)	—	1.3 (0.5 to 2.2)	—
After 9:00 PM	2.3 (0.1 to 4.6)	—	1.9 (-0.1 to 3.8)	—
[a]Represents regression coefficient (95% CI) of BFP per hour delay of bedtime				
Models IA – Adjusts for age, ethnicity, parental SES, parental education, number of people in household.				
Model IB – Adjusts for both baseline age and menarche status at 11 years or age at menarche at 14 years, ethnicity, parental SES, parental education, and number of people in household				
Model IVA & IVB – Each model includes both bedtime regularity (categorical) and bedtime (continuous) and adjusts for BFP at 7 years, frequency of TV hours on weekdays, computer hours on weekdays, frequency of physical activity, frequency of bedwetting, in addition to confounders adjusted for in Models IA & IB, respectively				

Discussion

In this study, we found that increasing frequency of irregular bedtimes at 7 years was associated with increasing risk of obesity at both 11 and 14 years in a dose–response pattern. It was notable that even among children who had some degree of bedtime regularity, similar dose–response relationships were apparent between the time children went to bed and subsequent risk of obesity. Seven-year-olds with bedtimes after 8:30 PM consistently had approximately two- to three-fold higher risk of obesity at 11 and 14 years relative to those with bedtimes at 7:30 PM or earlier; an association which remained consistent

among teenage girls after adjusting for menarche. Every hour delay in bedtime at 7 years associated with approximately 1% increase in BFP at 11 and 14 years for both sexes.

This study contributes to the expanding literature showing that early bedtime in childhood is associated with lower risk of obesity in adolescence.[18–20] While previous studies had a baseline sample of pre-school age (~5-year-olds) among whom the reference/optimal bedtime was defined as before/at 8:00 PM (25%)[16] or as late as 8:30 PM (27%),[17] our sample were 7-year-olds majority of whom went to bed before 8:00 PM (87%). These differences in baseline sample age distribution and reference bedtime categories did not result in contradictory findings between earlier studies and the present study. Nevertheless, our findings show that even among 7-year-olds, term-time bedtimes at 7:31–8:00 PM relative to 7:30 PM or earlier, was associated with 0.6% and 0.8% increase in BFP at 11 years for boys and girls, respectively. Although these marginal increases in BFP did not necessarily manifest in increased obesity risks for children in this bedtime category, it highlights the potential contributory factor of even minimal delays in children's bedtime on body composition in adolescence. To our knowledge, our study is the first to report such marginal increases in adiposity in adolescence in relation to childhood bedtimes. It is however worth noting that the linear relationship between bedtime and BFP was attenuated for girls after adjusting for baseline BFP and bedtime regularity in sensitivity analysis.

In comparison with bedtimes and obesity in children, there is adequate literature on the relationship consistently showing short sleep duration in childhood as a risk factor for obesity in adolescence.[10,18,27–30] Insufficient age-appropriate sleep duration is hypothesised to be associated with changes in normal metabolic and endocrinal functions including dysregulation of the neuroendocrine control of appetite hormones leptin and ghrelin which increases food consumption and decreased non–insulin-dependent glucose uptake which results increase in fat deposition.[9,31–33] Similar mechanisms are suggested to explain the link between irregular/misaligned sleep patterns and obesity risk.[33,34] Whiles sleep duration is an important factor in relation to obesity risk, fixed wake times likely due to school start time and other social demands for early school-age children implies that the most probable and modifiable risk factor to ensure sufficient sleep duration is early bedtime and a regular bedtime routine.[16,35] Metabolic and endocrinal dysregulation arising from shorter sleep duration and irregular sleep patterns may explain the observed relationships between bedtime irregularity, late bedtimes and increased adiposity in our study. The relationship between late bedtimes and higher obesity risk may also be partially explained by the time available to eat and the likelihood of late night eating.[31,36] Irregular bedtime schedules in children have also been linked poor health and development and may be indicative of unfavourable and poorly-structured home environment beyond the household and socio-economic confounders considered in our analysis.[16,17,37,38]

Attrition is a common problem for prospective cohort studies. In this study, 13% and 22% of the baseline sample were lost to follow-up at 11 and 14 years, respectively. However, sampling and attrition weights were considered for all analyses. Objective bedtime data from actigraphy would have minimised the risk of potential recall bias and exposure misclassification. In addition, the study lacked other sleep-related

parameters such as sleep quality/disturbance and sleep duration to differentiate the relevance of different components of sleep during childhood on the risk obesity and adiposity in adolescence. Also, due to the relatively smaller percentage of children in the never regular and after 9 PM bedtime categories, adjusting for multiple covariates and restricted analysis among girls only resulted in wider confidence intervals for these groups which resulted in nonsignificant differences in some instances.

A major strength of this study is the use of prospective data from a large nationally representative cohort of UK children. While this is insufficient to make causal inference of the relationship between bedtime schedules in childhood and subsequent obesity risk, it provides sufficient evidence of temporality in this relationship considering that none of the children were classified as obese at baseline. Besides the estimation of obesity from anthropometric measurements, we also measured BFP which is a better marker of adiposity in children.[39,40] In this study, mothers who reported that their children never had regular bedtimes were not asked for a bedtime. In the MCS, bedtimes were only collected from mothers who reported *always, usually* or *sometime* regular bedtimes for their children. Exclusion of children with completely irregular bedtimes when investigating the association between the time child went to bed and obesity may have provided less biased results. In addition, confounders identified through DAGs, we also accounted for several covariates in sensitivity analyses, including the age at menarche and baseline overweight status or BFP.

In conclusion, our findings suggest that irregular bedtime schedules and later bedtimes in childhood are independently associated with increased risk of obesity and higher BFP in early- and mid-adolescence. Later bedtimes in childhood, irrespective of bedtime regularity, are associated with marginal increases in BFP in adolescence. The study contributes to the growing body of empirical evidence highlighting the importance of regular and early bedtimes, and sufficient sleep during children as important modifiable risk factor for obesity in adolescence. Further studies are needed to assess whether improvements in bedtime schedules in childhood may reverse potential risk of obesity in adolescence.

Abbreviations

BFP – Body Fat Percentage

CI – Confidence Intervals

MCS – Millennium Cohort Study

MD – Mean Difference

NS-SEC – National Statistics Socioeconomic Classification

RR – Risk Ratio

SES – Socioeconomic Status

Declaration

Source of Funding: The authors received no funds for this article. However, the Millennium Cohort Study is funded by grants from the Economic and Social Research Council and a consortium of government funders. The funders of the Millennium Cohort Study had no role in the study design, data analysis and results interpretation, article writing or the decision to submit the article for publication.

Competing Interests: The authors have no competing interests relevant to this article to disclose.

Availability of data and material: Data used in this paper are publicly available on the UK Data Service portal https://ukdataservice.ac.uk/ for registered users.

Code availability: Stata software SE/13.1 (Stata Corp, College Station, TX) was used for data analysis

Author's contribution: Conceptualisation/design (MOM, LF), Methodology (MOM, LF), Drafting Initial Manuscript (MOM, LF), Reviewing Manuscript (MOM), Supervision (MOM), Data Curation (MOM), Formal Analysis (MOM).

Ethics approval: Ethical approval for the MCS was provided by the UK National Health Service (NHS) and regional Research Ethics Committees (07/MRE03/32, 11/YH/0203, 13/LO/1786) in line with the Declaration of Helsinki.

Consent to participate: Parents/guardians of children participating in the MCS provided consent to participate in the study.

Consent for publication: Not applicable

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Figures

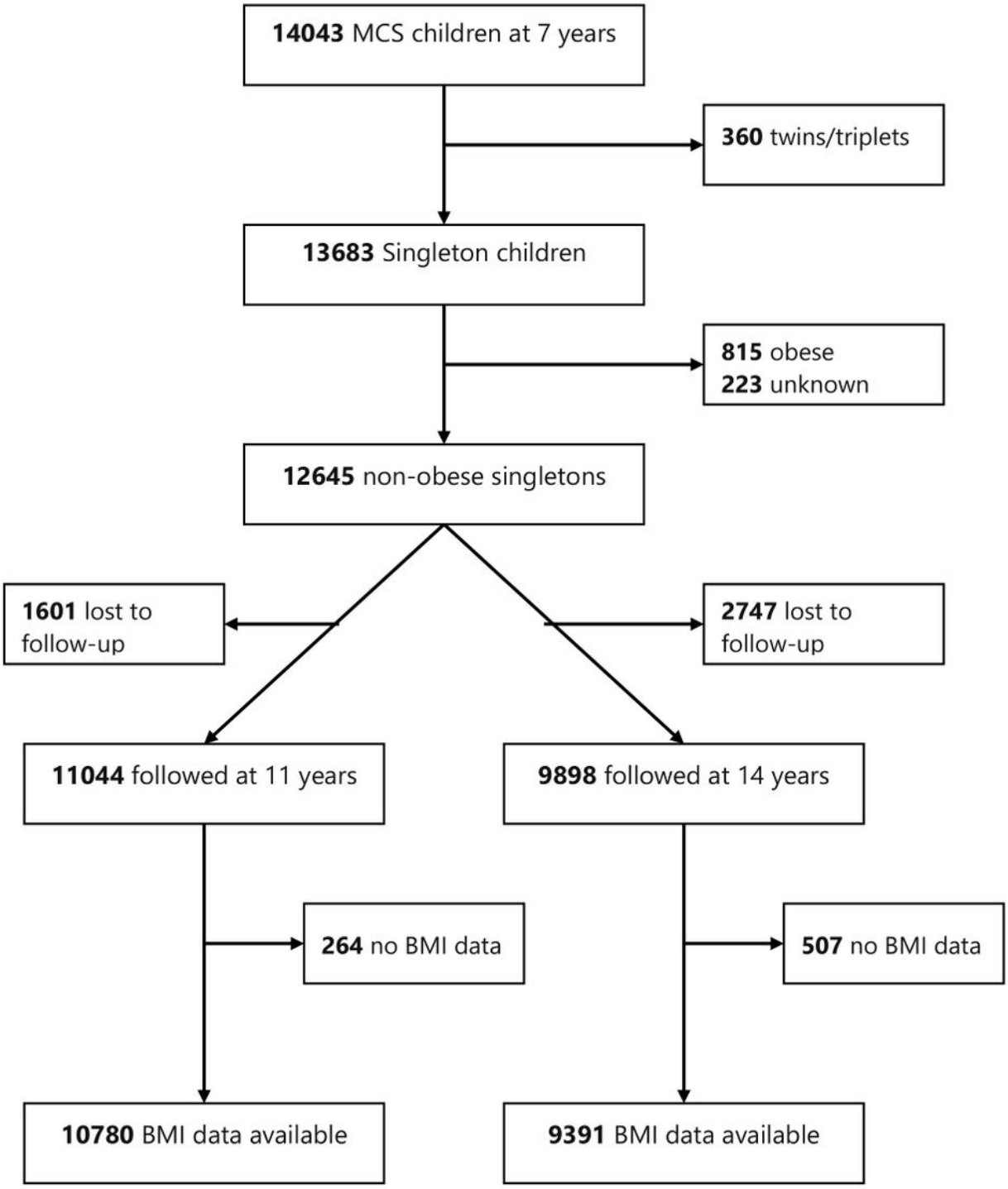

Figure 1

Participant follow-up flowchart

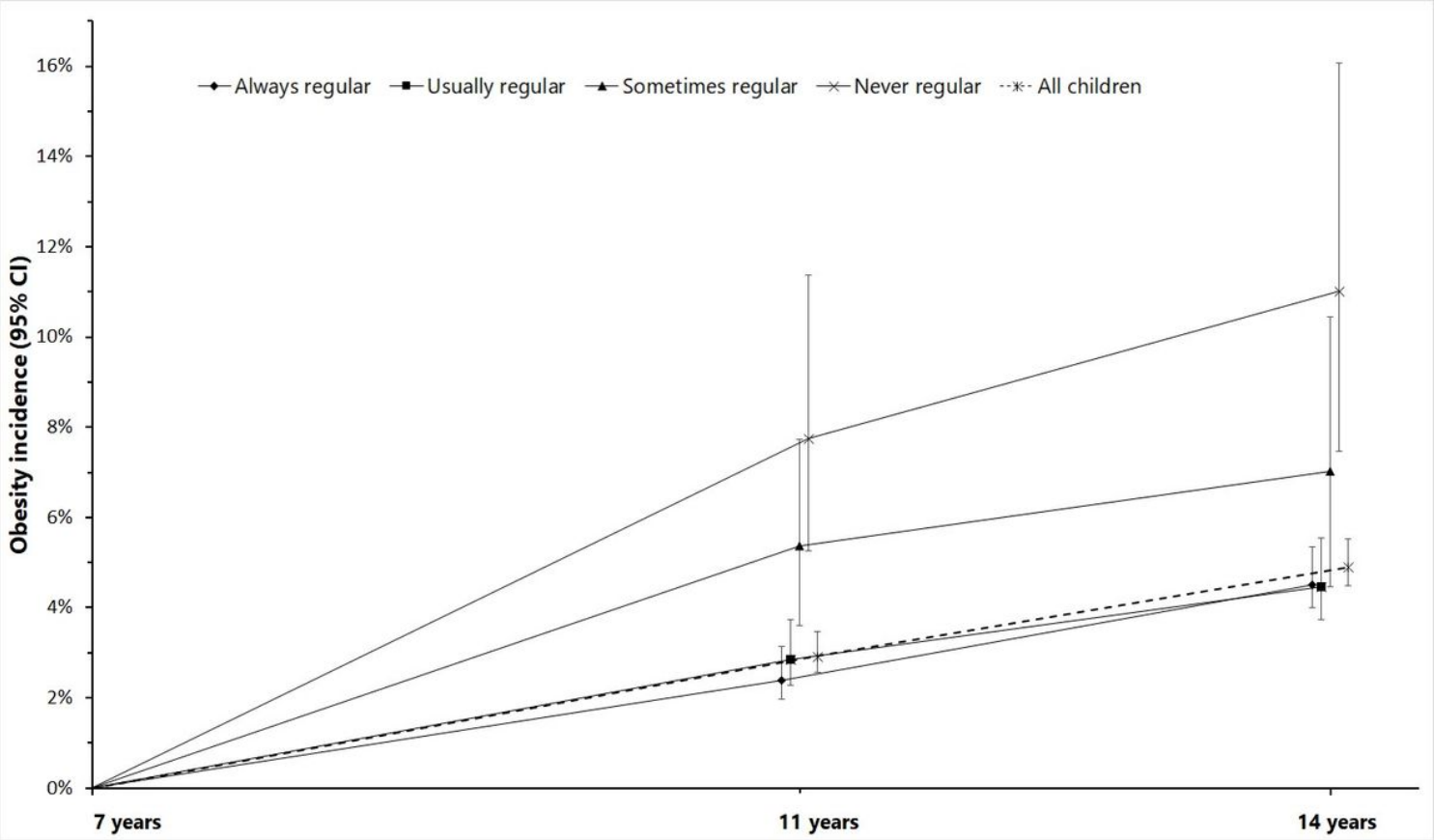

Figure 2

Trajectory of obesity incidence at 11 and 14 years by bedtime regularity among non–obese 7-year-olds

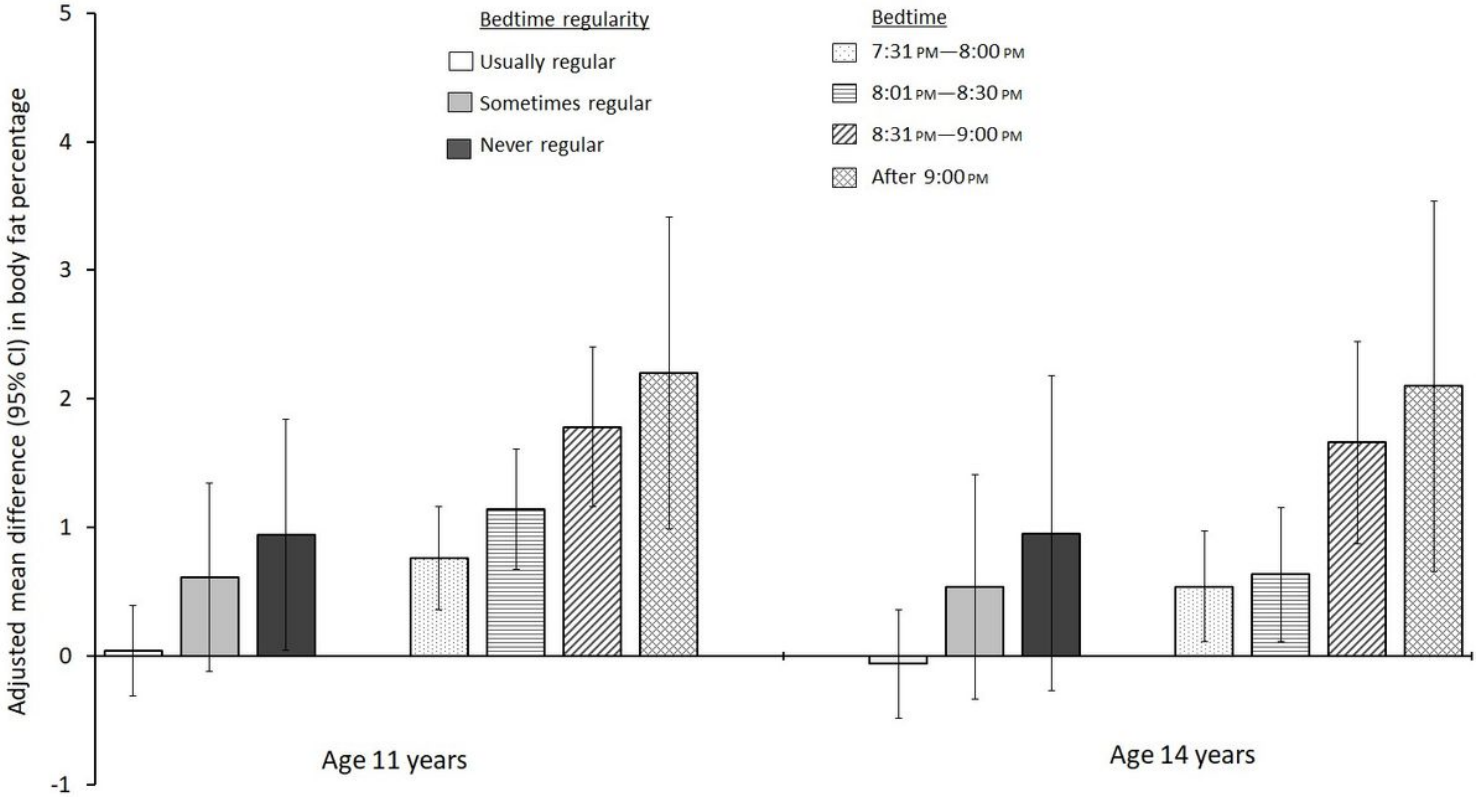

Figure 3

Adjusted mean difference in body fat percentage at 11 and 14 years by bedtime regularity and bedtimes at 7 years. Reference for bedtime regularity is always regular. Reference category for bedtime is 7:30 PM or earlier. Models were adjusted for sex, age, ethnicity, parental SES, parental education, and number of persons in household.

Supplementary Files

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