BMJ Open

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Journal:	*BMJ Open*
Manuscript ID	bmjopen-2015-010366
Article Type:	Research
Date Submitted by the Author:	24-Oct-2015
Complete List of Authors:	Griffiths, Lucy; UCL Institute of Child Health, Life Course Epidemiology and Biostatistics Sera, Francesco; UCL Institute of Child Health, Life Course Epidemiology and Biostatistics Cortina Borja, Mario; UCL Institute of Child Health, Life Course Epidemiology and Biostatistics Law, Catherine; UCL Institute of Child Health, Life Course Epidemiology and Biostatistics Ness, Andy; University of Bristol, Department of Oral and Dental Science Dezateux, Carol; UCL Institute of Child Health, Life Course Epidemiology and Biostatistics
Primary Subject Heading:	Epidemiology
Secondary Subject Heading:	Sports and exercise medicine, Public health
Keywords:	adiposity, physical activity, sedentary time, children, cohort studies

Objectively measured physical activity and sedentary time: cross-sectional and prospective associations with adiposity in the Millennium Cohort Study

Lucy J Griffiths[1], Francesco Sera[1] (joint first author), Mario Cortina-Borja[1], Catherine Law[1], Andrew Ness[2] and Carol Dezateux[1].

Affiliations: [1]Life Course Epidemiology and Biostatistics, UCL Institute of Child Health, 30 Guilford Street, London, UK; [2]Department of Oral and Dental Science, University of Bristol, Bristol, UK.

Corresponding author: Lucy Griffiths; address as above; lucy.griffiths@ucl.ac.uk

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Word count (excluding title page, abstract, references, figures and tables): 3999

ABSTRACT

Objective: To examine whether physical activity (PA) and sedentary time (ST) in primary school-aged children are associated with adiposity at the start of secondary school, and whether these associations differ by sex or ethnic group.

Design: Nationally representative prospective cohort study.

Setting: Children born across the UK, between 2000 and 2002.

Participants 6497 singleton children.

Outcome measures: Measures of adiposity (body mass index (BMI), fat mass index (FMI) and fat free mass index (FFMI)) - obtained at seven and 11 years of age.

Explanatory measures: Total daily PA (mean counts per minute [cpm]); minutes of moderate-to-vigorous PA (MVPA); and sedentary time (ST). All assessed at seven years of age using accelerometers.

Results: In cross-sectional analyses, total PA was inversely associated with FMI (3.7% (95% confidence interval (CI): 2.7; 4.7) reduction per 150 cpm increase), as was MVPA (4.2% (CI: 3.2; 5.2) reduction per 20 minute/day increase). Associations were stronger in Black and South Asian ethnic groups. Total PA and MVPA were not associated with FFMI. ST was positively associated with FMI (1.3% (CI: 0.2; 2.3) increase per 50 minute/day increase) and inversely associated with FFMI (0.5% (CI: 0.2; 0.7) reduction per 50 minute/day increase). Longitudinally, MVPA at age seven remained inversely associated with FMI at age 11 (1.5% (CI: 2.6; 0.4) reduction per 20 minute/day increase). No association was found between total PA and ST and any of the later adiposity measures.

Conclusions: Seven year old children who are more physically active are less likely to be obese at that age and at age eleven years. This association was particularly evident in children from Black or South Asian ethnicity at age seven and in boys at age eleven. Measurements of fat mass provide valuable insights into ethnic differences in associations between adiposity and activity.

Strengths and limitations of this study

- This study used both cross-sectional and prospective study designs to explore concurrent and causal associations between physical activity / sedentary time and adiposity in primary-school aged children in the UK-wide Millennium Cohort.
- Objective measures of physical activity / sedentary time were obtained using accelerometers - however, these may underestimate activities not involving vertical movement of the trunk and aquatic activities; adiposity measures included fat mass and body mass obtained by trained interviewers using standardised protocols.
- Inclusion of children from different ethnic origins enabled the effect of ethnic origin on associations between activity and adiposity to be explored.
- Information was available on a range of confounding factors, including puberty, but not other potentially important factors, like dietary intake.

INTRODUCTION

Recent evidence suggests that the rising prevalence of childhood obesity may have stabilised in the last decade, especially in younger children;[1] however, the age at onset of obesity is occurring at ever younger ages.[2] Mounting evidence points to the 'potentially devastating'[3] consequences; it has implications in the short term for child health, development and well-being, but also in the longer term for health in young and later adult life. The World Health Organization therefore regards childhood obesity as one of the most serious global public health challenges for the 21st century, reporting that in 2013 there were an estimated 42 million overweight children in under five-year-olds alone.[4]

The notion that insufficient physical activity is a key contributor to obesity is common, and is supported by the logic of the energy-balance equation.[5] Public health authorities therefore aim to increase time spent being physically active, and decrease time spent being sedentary, across all ages. Despite their efforts, many adults, adolescents and children are reported to be insufficiently active.[6-8] We have previously reported that only half of 7-year-old children in the UK achieve recommended levels of physical activity, with significant gender and ethnic variations.[8] Technological advancements in the measurement of physical activity and inactivity over the last decade have not only enabled researchers to assess levels achieved more accurately, but also to investigate associations with a range of diseases, with overweight and obesity the main focus.

The majority of observational studies that have evaluated cross-sectional associations between adiposity and objectively measured physical activity in children suggest that higher activity levels are associated with lower levels of adiposity.[9-13] However, there is limited evidence on how this varies in children of different ethnic groups.[13] Cross-sectional associations with sedentary time are less consistent,[10;12;14;15] although a recent review suggests that sedentary time is usually unrelated to adiposity once activity is taken into account.[16] Few large-scale prospective studies examining both physical activity and sedentary time have been conducted and, to our knowledge, available evidence for UK children is predominantly from white adolescent populations.[17;18]

Our objective was to contribute to this body of research by analysing data from a large UK-wide cohort of primary school-aged children in whom objective measures of activity (total amount of physical activity and moderate-to-vigorous physical activity), sedentary time and adiposity (body mass index, fat mass index and fat free mass index) were obtained at seven years of age. We analysed cross-sectional (age seven) and prospective (activity and sedentary time at age seven and adiposity at age 11) associations, thereby addressing the need for more evidence on longitudinal associations,[19] whilst also exploring if these associations differed by sex or ethnic group.

METHODS

Study participants

We examined data from the Millennium Cohort Study (MCS), a longitudinal study of children born in the United Kingdom between September 2000 and January 2002.[20] Children living in disadvantaged areas, from ethnic minority groups and from Wales, Scotland and Northern Ireland were over-represented by using a stratified clustered sampling design to ensure the cohort was nationally representative. The first study contact (MCS1) with the cohort child was around age 9 months, when information was collected on 72% of those approached, providing information on 18 818 singleton infants. Five further surveys were carried out when children were aged three (MCS2), five (MCS3), seven (MCS4) and eleven (MCS5) years.

Detailed information regarding demographic, social, and health factors relating to the children and their families was obtained through home-based interviews. The MCS received ethical approval from the South West Multi-Centre Research Ethics Committee (MCS1), the London Multi-Centre Research Ethics

Committee (MCS2 and MCS3), Northern and the Yorkshire Research Ethics Committee (MCS4), and the Yorkshire and Humber Research Ethics Committee (MCS5). The study reported here did not require additional ethics approval and used data from MCS1, MCS4 and MCS5 (as detailed below).

Exposure measures: physical activity and sedentary time

Physical activity and sedentary time were measured objectively using the Actigraph GT1M accelerometer (Actigraph, Pensacola, Florida), a small and lightweight, non-waterproof device, which, in this study, was worn on an elastic belt round the child's waist. The Actigraph GT1M has been extensively validated in children and compares favourably against observational techniques [21], heart rate monitoring [22], indirect and room calorimetry [23;24] and doubly labelled water techniques [25]. It has been shown to be robust when used in other large-scale physical activity studies in children.[14;26]

A total of 13 681 singleton children participated in MCS4 interviews when they were invited to participate in an accelerometry study, which took place over a 15-month period between May 2008 and August 2009. Those who consented (12 872; 94.5%) were posted an accelerometer, programmed to collect and aggregate data over 15-second epochs. Participants were instructed to start wearing their accelerometer the morning after they received it and to continue doing so for seven days during waking hours. They were asked to remove the monitor when bathing or swimming. The accelerometer measurements commenced after the MCS4 interviews had been completed, resulting in a median interval of 36 weeks (IQR 29 to 45) between the interview and the date accelerometers were worn.

Accelerometers were returned by 9772 singleton children. Data were downloaded using Actigraph software version 3.8.3 (Actigraph, Pensacola, Florida) and processed using the package `pawacc` [27;28] for the R statistical computing environment [29]. Non-wear time was defined as any time period of consecutive zero-counts lasting 20 minutes or more: these periods were removed from the summation of activity. In addition, we removed moderate-to-vigorous physical activity values ≥11 715 counts per minute (cpm) from the dataset, based on a reliability study that indicated that count values above this threshold were extreme and likely to be spurious.[30] Only days with ten hours or more of recorded time were considered as valid and retained in the dataset, and only participants with at least two such days were included in the analyses.[31] The application of these criteria resulted in a sample size of 6497 singleton children. Reliable accelerometer data were less likely to be acquired from children who were: male; overweight/obese; of white, mixed or 'other' ethnicity; living in disadvantaged areas; had less educated mothers and/or lone mothers.[32] However, overall, small differences were found in the demographic characteristics of the children included in our analyses relative to the whole cohort sample interviewed at age seven years, as detailed previously.[8]

For each child, we derived three exposure variables: average daily minutes of moderate-to-vigorous physical activity (using an accelerometer-defined boundary of ≥ 2240 counts[33]), average daily minutes spent in sedentary time (using the accelerometer-defined boundary of <100 counts[33]), and daily total physical activity, calculated as the average counts per minute (cpm) over the full period of valid recording. Average daily minutes spent in physical activity and sedentary time were adjusted for standardised wear time across the subjects.[34]

Outcome measures: adiposity

At the fourth and fifth survey, weight and body fat measurements were obtained by trained interviewers using the Tanita BF-522W scales (Tanita UK Ltd, Middlesex, UK), which use bioelectrical impedance analysis (BIA). Height was measured using Leicester Height Measure Stadiometers (Seca Ltd, Birmingham, UK). The height and weight measures were used to derive BMI. Fat mass index and fat free mass index were calculated using fat mass and fat free mass measures, respectively (Box).

Box Adiposity formulas

Body Mass Index (BMI): weight (kilograms)/height (metres) squared

Fat mass (kilograms): percent body fat × weight

Fat free mass (kilograms): weight - fat mass

Fat Mass Index (FMI): fat mass/height squared

Fat Free Mass Index (FFMI): fat free mass/height squared

Potential confounding variables

Potential confounding factors were identified a priori from existing literature as factors associated with physical activity and obesity. In order to identify a minimal set of confounders we constructed a direct acyclic graph (DAG)[35] for the cross-sectional analyses and checked that no over-adjustment was present. This set included the child's gender and ethnicity (the latter categorised according to guidelines from the Office for National Statistics[36]) collected at MCS1; maternal weight status (defined using BMI cut-offs), age at birth of the cohort member, social class (National Statistics Socio-economic Classification [NS-SEC][37]) and highest educational attainment; annual household income (quintiles); number of cars or vans in the household that are used regularly; lone parenthood status; number of children in the household; country of residence; index of multiple deprivation; and rural / urban area classification of residence. Unless otherwise stated, information on all of these factors was collected at MCS4. These confounders were also used in prospective analyses.

Information on pubertal status was collected at MCS5, using five parentally reported puberty indicators; three were common between boys and girls - growth spurt, body hair, skin changes - while voice change and facial hair were specific for boys and breast growth and age at menarche specific for girls. To reduce the dimensionality of these covariates we built a categorical puberty indicator. Multiple correspondence analyses[38] were performed separately for boys and girls. Using the optimal category scores provided by this, we calculated two quantitative scores; a cluster analysis (complete linkage) was then performed using these two scores and three groups of children were identified after a visual analysis of the dendrogram: those in whom puberty had not started, had barely started or was likely to have started.

Other potential confounding factors explored but, based on the DAG criteria, not included were: presence of a longstanding illness or other illness limiting their everyday activity; diagnosis of asthma; psychological well-being; peer relationship problems; paternal weight status; maternal employment status; housing tenure; and type of residence.

Statistical analysis

Analyses were performed using Stata/SE 13 (Stata Corporation, Texas, USA). Considering the stratified cluster sampling design of MCS study, weights to adjust for attrition between contacts at successive MCS sweeps and for missing accelerometer data were taken into account during the estimation using the Stata command svyset. Gender differences between total physical activity, sedentary time and moderate-to-vigorous physical activity were assessed adjusting by season of measurement and a weekend/weekday contrast.

Multiple linear regression models were fitted to examine cross-sectional associations between total physical activity levels, moderate-to-vigorous physical activity and sedentary time and each of the adiposity measures (body mass index, fat mass index and fat free mass index); the latter variables were log-transformed due their skewed distributions. For each regression coefficient *b*, we calculated the quantity $100\times(e^{b}-1)$; similarly, the lower and upper bounds of *b*'s 95% CI were subject to the same back-transformation. These values can be interpreted as the percentage change between geometric means of the adiposity measure associated with varying levels of the covariates of interest. The *p*-values were calculated using the command nlcom in Stata, which is based on the delta method[39] to approximate nonlinear combinations of parameter estimates. The models were adjusted for child's sex, ethnicity, country of residence and age at measurement; maternal BMI, age, social class, and highest academic qualification; and household annual income, number of cars, lone parenthood status, number of children in the household, urban/rural ward of residence.

Linear regression models were also fitted to evaluate prospective associations between total physical activity levels, moderate-to-vigorous physical activity and sedentary time at age 7 (MCS4) and the three adiposity measures at age 11 (MCS5). Analysis of covariance was used; the baseline value of the adiposity measure was considered as a covariate, alongside the particular exposure variable and confounding variables. Again, adiposity measures were log transformed, and the regression coefficient transformed as described before. A similar strategy was also used to fit the model; adjustment was made for the same variables as in the cross-sectional analyses, in addition to the baseline adiposity measurement and puberty indicator.

In both the cross-sectional and prospective analyses, interactions between exposures and the child's sex, and ethnicity, were explored by considering an interaction term in the regression models. All regression models were initially fitted in the complete case sample. For the prospective analyses, around 500 (8.2%) children had missing data for outcome variables (adiposity measurements) or covariates (particularly for pubertal status). Multiple imputation analysis was performed to mitigate possible bias due to item non-response. For the cross-sectional analyses five imputed datasets were built using the (weighted) iterative chain algorithm, and ten for the prospective analyses; estimates were combined using Rubin's rule.[40]

RESULTS

The majority of children (85%) were white, 51% were boys and 20% overweight or obese at age 7. Almost half of mothers were overweight or obese. Socio-demographic measures at ages 7 and 11 are summarised in Table 1 and showed little change over this interval, with the exception of the increase in prevalence of overweight at age 11.

As reported previously,[8] boys were more active and less sedentary than girls at age seven years. They were also taller and had lower adiposity as assessed by lower mean fat mass and higher fat free mass (Table 2). By age 11 years, the boys were lighter, shorter and still had lower adiposity (lower body mass and fat mass and higher fat free mass) than girls. As expected, marked sex differences in onset of puberty were seen at age 11, with 1 in 5 girls, but less than 1 in 20 boys, having started puberty by this age.

Table 1. Sample characteristics

		MCS4 (*n*=6497)		MCS5 (*n*=6073)	
Variable		***n***	**%***	***n***	**%***
Child's gender	Male	3176	50.9	2950	51.1
	Female	3321	49.1	3123	48.9
Child's ethnicity**	White	5685	85.1	5327	85.0
	Mixed	167	3.3	153	3.1
	South Asian	382	7.1	359	7.3
	Black	141	2.9	119	2.7
	Other	90	1.6	87	1.9
	Missing	32		28	
Obesity (IOTF cut-offs)	Normal	5345	79.8	4522	73.0
	Overweight (not including obese)	836	14.2	1142	21.0
	Obese	289	6.0	290	6.0
	Missing	27		119	
Puberty indicator	Puberty had not started			3498	58.8
	Puberty had barely started			1772	29.3
	Puberty was likely to have started			651	11.9
	Missing			152	
Maternal weight status (BMI-defined groups)	Normal weight	3109	56.1	2929	56.3
	Overweight (not including obese)	1547	28.1	1442	27.9
	Obese	830	15.8	782	15.8
	Missing	1011		920	
Main respondent's age at the birth of the cohort member	14-19	283	8.8	246	8.9
	20-29	2660	45.6	2472	46.4
	30+	3554	45.6	3355	44.7
Maternal socioeconomic circumstances	Managerial and professional occupations	1806	26.1	2082	27.5
	Intermediate occupations	922	18.3	1129	18.2
	Small employers and own account	387	6.9	420	6.8

	workers				
	Lower supervisory and technical occupations	177	5.3	260	5.1
	Semi-routine and routine occupations	1104	34.6	1710	35.5
	Never worked & long-term unemployed	2101	6.8	241	6.9
	Missing	256		231	
Main respondent's highest academic qualification	Degree	1644	18.0	1580	17.4
	Diploma	803	10.0	756	9.7
	A/AS/S levels	677	8.8	645	8.8
	GCSE grades A-G	2536	44.3	2348	45.1
	Other	143	2.7	132	2.9
	None of the above	686	16.2	605	16.1
	Missing	8		7	
Lone parenthood status	Non-lone parent	5485	77.3	5,169	77.3
	Lone parent	989	22.7	884	22.7
	Missing	23		20	
Household annual income (quintiles)	Bottom	960	20.6	859	20.7
	Second	1164	20.2	1071	20.7
	Third	1382	19.8	1293	20.1
	Fourth	1513	20.1	1438	19.9
	Top	1477	19.3	1411	18.6
	Missing	1		1	
Number of cars or vans in the household (regular use)	0	579	14.3	513	14.4
	1	2304	37.1	2133	37.6
	2	3230	42.9	3068	42.3
	3	374	5.7	353	5.7
	Missing	10		6	
Number of children in the	1	719	12.2	670	12.2
	2	3131	46.6	2942	46.0

household	3	1820	27.8	1704	28.2
	4+	812	13.4	744	13.6
	Missing	15		13	
Country of residence	England	4201	81.6	3933	81.5
	Wales	899	5.1	833	5.1
	Scotland	761	9.2	710	9.2
	Northern Ireland	636	4.1	597	4.2
IMD	Least deprived	1499	20.4	1435	20.4
	Second	1255	19.2	1175	18.6
	Third	1255	20.2	1181	20.3
	Fourth	1244	18.7	1147	18.9
	Most deprived	1243	21.5	1134	21.8
	Missing	1		1	
Urban/rural area of residence	Urban	5480	86.8	5110	86.6
	Rural	1016	13.2	962	13.4
	Missing	1		1	

* Weighted estimate.
** Collected at the first MCS survey; all other variables were collected in the fourth (age 7) survey.
Table abbreviations: IOTF: International Obesity Task Force; BMI: body mass index; IMD: index of multiple deprivation.

Table 2. Mean and standard deviation (SD) of the anthropometric and physical activity variables by sex and MCS survey

MCS4	**Girls (*n*=3321)**			**Boys (*n*=3176)**			
	N	**Mean**	**SD**	***n***	**Mean**	**SD**	**p-value**
Weight (Kg)	3315	25.4	5.0	3161	25.7	5.0	0.2
Height (cm)	3319	123.3	5.7	3172	124.1	5.4	<0.001
BMI (kg/m^2)	3312	16.6	2.4	3158	16.6	2.3	0.6
FMI (kg/m^2)	3281	3.8	1.6	3119	3.4	1.6	<0.001
FFMI (kg/m^2)	3281	12.8	1.0	3118	13.1	1.0	<0.001
Total PA (daily cpm)*	3321	573.9	146.4	3176	644.8	155.4	<0.001
Daily sedentary time (min)*	3321	398.7	50.5	3176	382.2	49.4	<0.001
Daily MVPA (min)*	3321	56.4	19.9	3176	69.9	23.0	<0.001
MCS5	**Girls (*n*=3123)**			**Boys (*n*=2950)**			
	n	**Mean**	**SD**	***n***	**Mean**	**SD**	**p-value**
Weight (Kg)	3043	42.1	10.4	2880	40.6	9.8	<0.001
Height (cm)	3080	146.8	7.8	2910	145.8	6.7	<0.001
BMI (kg/m^2)	3056	19.4	3.7	2898	19.0	3.7	0.003
FMI (kg/m^2)	3002	5.0	2.5	2834	4.0	2.5	<0.001
FFMI (kg/m^2)	3002	14.4	1.4	2834	14.9	1.5	<0.001
Puberty indicator:	N	%		n	%		

Puberty had not started	1054	32.9		2444	83.7		
Puberty had barely started	1433	46.4		339	12.8		
Puberty was likely to have started	553	20.7		98	3.5		<0.001

* Adjusted by season of measurement and weekend/weekday
Table abbreviations: SD: standard deviation; BMI: body mass index; FMI: fat mass index; FFMI: Fat free mass index; PA: physical activity; MVPA: moderate-to-vigorous physical activity; min: minutes; cpm: counts per minute.

Children of South Asian ethnic origin were less active and had higher fat mass and lower fat free mass than white children (Table 3). In contrast, black children were more active but also had higher body and fat mass. By age 11 years, these ethnic differences in adiposity persisted though black girls were twice as likely to have started puberty than white or South Asian girls.

Table 3. Description of the anthropometric and physical activity variables at age 7 years by ethnicity

MCS4	**White (*n* = 5685)**		**Mixed (*n* = 167)**			**South Asian (*n* = 382)**			**Black/Black British (*n* = 141)**			**Other (*n* = 90)**		
	Mean	SD	Mean	SD		Mean	SD		Mean	SD		Mean	SD	
Weight (Kg)	25.4	4.7	26.0	5.4	0.3	25.4	5.6	0.95	30.8	6.3	<0.001	24.0	3.6	0.003
Height (cm)	123.5	5.6	124.6	4.9	0.031	124.1	5.1	0.07	127.9	5.0	<0.001	123.3	3.9	0.8
BMI (kg/m^2)	16.6	2.2	16.6	2.6	0.8	16.3	2.7	0.2	18.7	3.3	<0.001	15.8	1.9	0.001
FMI (kg/m^2)	3.5	1.4	3.7	1.8	0.3	3.9	2.0	0.023	5.0	2.3	<0.001	3.4	1.3	0.2
FFMI (kg/m^2)	13.0	1.0	13.0	1.0	0.6	12.4	0.9	<0.001	13.7	1.1	<0.001	12.5	1.0	<0.001
Total PA (daily cpm)	613.9	157.9	584.4	122.6	0.003	570.7	134.3	<0.001	627.9	134.7	0.3	590.7	174.9	0.3
Daily sedentary time (min)	389.6	50.7	406.1	47.0	<0.001	391.8	51.6	0.3	388.0	39.8	0.6	393.2	55.2	0.6
Daily MVPA (min)	63.3	23.0	62.2	17.2	0.3	59.9	19.7	0.009	70.3	22.0	0.012	62.4	23.8	0.7

MCS5	White (*n* = 5327)		Mixed (*n* = 153)			South Asian (*n* = 359)			Black/Black British (*n* = 119)			Other (*n* = 87)		
	Mean	SD	Mean	SD		Mean	SD		Mean	SD		Mean	SD	
Weight (Kg)	41.1	10.0	42.1	11.0	0.4	41.6	9.5	0.5	50.8	10.5	<0.001	38.8	6.6	0.046
Height (cm)	146.2	7.4	147.2	6.2	0.098	146.6	6.3	0.4	151.0	6.1	<0.001	145.5	5.0	0.5
BMI (kg/m^2)	19.1	3.6	19.2	4.0	0.8	19.2	3.6	0.5	22.3	4.3	<0.001	18.3	2.9	0.053
FMI (kg/m^2)	4.4	2.5	4.6	3.0	0.5	4.9	2.3	0.001	7.0	4.0	0.001	4.5	2.2	0.99
FFMI (kg/m^2)	14.7	1.4	14.6	1.4	0.6	14.2	1.4	<0.001	15.3	1.9	0.004	14.0	1.1	<0.001
Puberty indicator:	*n*	%	*n*	%		*n*	%		*n*	%		*n*	%	
Puberty had not started	3127	59.4	76	45.3		182	60.9		46	44.3		51	72.5	
Puberty had barely started	1566	29.2	49	35.0		87	26.4		42	31.3		20	25.4	
Puberty was likely to have started	548	11.4	25	19.7		44	12.7		27	24.4		5	2.1	<0.001

Table abbreviations: BMI: body mass index; FMI: fat mass index; FFMI: Fat free mass index; PA: physical activity; MVPA: moderate-to-vigorous physical activity; min: minutes; cpm: counts per minute.

In adjusted cross-sectional analyses, total physical activity and moderate-to-vigorous physical activity were inversely associated with indices of body mass and fat mass at age seven years (Table 4). Body mass was on average 0.84% (95% CI: 0.45; 1.22) and fat mass 3.68% (95% CI: 2.68; 4.68) lower for each 150 cpm increase in total physical activity, while body mass was 1.05% (95% CI: 0.66; 1.43), and fat mass 4.18% (95% CI: 3.15; 5.21), lower for each additional 20 minute period spent in moderate-to-vigorous physical activity. Fat mass was on average 1.27% (0.21; 2.33) higher for each additional 50 minute period of daily sedentary time.

Table 4. Cross-sectional analysis: adjusted percent change in anthropometric indices measured at 7 years of age for given changes in the summary physical activity or sedentary variables measured at 7 years of age.

	BMI			FMI			FFMI		
Exposures	**% Change**	**95%CI**	***p*-value**	**% Change**	**95%CI**	***p*-value**	**% Change**	**95%CI**	***p*-value**
Total PA (150 counts increase)	-0.84	(-1.22; -0.45)	<0.0001	-3.68	(-4.68; -2.68)	<0.0001	0.06	(-0.17; 0.29)	0.62
Sedentary time(50 min increase)	-0.01	(-0.41; 0.40)	0.97	1.27	(0.21; 2.33)	0.019	-0.46	(-0.71; -0.21)	<0.0001
MVPA (20 min increase)	-1.05	(-1.43; -0.66)	<0.0001	-4.18	(-5.21; -3.15)	<0.0001	-0.04	(-0.27; 0.18)	0.69

Regression models were adjusted for weekend, season, child's sex, age at measurement, child's ethnicity, maternal BMI, main respondent's age at the birth of the cohort member, maternal socioeconomic circumstances, main respondent's education, household annual income, cars or vans (regular use), lone parenthood status, number of children in the household, Country by (index of multiple deprivation) interaction and urban/rural indicators.
Table abbreviations: CI: confidence interval; BMI: body mass index; FMI: fat mass index; FFMI: Fat free mass index; PA: physical activity; MVPA: moderate-to-vigorous physical activity; min: minutes.

Black children and those of South Asian ethnic origin showed the greatest decrease in fat mass index for each increment in time spent in moderate-to-vigorous physical activity across the range of 20-90 minutes. Significant interactions with ethnicity were found in cross-sectional analyses between total physical activity and fat mass (*p*=0.003) and moderate-to-vigorous physical activity and fat mass (*p*=0.020); the latter is shown in Figure 1. Fat mass was, on average, 12.74% (95% CI: 3.97; 21.51) and 7.44% (95% CI: 3.74; 11.15) lower per 150 cpm increase in total physical activity level in black children and those of South Asian ethnic origin respectively and 8.22% (95% CI: 5.05; 11.39) lower for each additional 20 minutes of moderate-to-vigorous physical activity in children of South Asian ethnic origin

Interactions with gender were not significant.

INSERT Figure 1

By 11 years of age, moderate-to-vigorous physical activity but not total physical activity levels at age 7 remained inversely associated with body mass and fat mass (Table 5). The effect sizes were also smaller than those obtained in the cross-sectional analyses; body mass and fat mass at age 11 were on average 0.39% (0.04; 0.74) and 1.5% (0.44; 2.58) lower for each 20 minute increase in daily moderate-to-vigorous physical activity at age 7.

In this longitudinal analysis, we also found a significant interaction for sex (p<0.001), where the association between moderate-to-vigorous physical activity and body mass or fat mass was present only in boys: body mass and fat mass at age 11 were on average 2.53% (0.88; 4.17) and 2.89% (1.34; 4.40) lower for each 20 minute increase in daily moderate-to-vigorous physical activity at age 7. There were no significant interactions with ethnicity.

Table 5. Longitudinal analysis: adjusted percent change in anthropometric indices measured at 11 years of age for given changes in the summary physical activity or sedentary variables measured at 7 years of age

	BMI			FMI			FFMI		
Exposures	**% Change**	**95%CI**	***p*-value**	**% Change**	**95%CI**	***p*-value**	**% Change**	**95%CI**	**p *p*-value**
Total PA (150 counts increase)	-0.15	(-0.50; 0.20)	0.40	-0.94	(-2.10; 0.28)	0.11	0.05	(-0.17; 0.27)	0.64
Sedentary time (50 min increase)	-0.25	(-0.59; 0.09)	0.16	-0.25	(-1.36; 0.85)	0.65	-0.16	(-0.38; 0.05)	0.13
MVPA (20 min increase)	-0.39	(-0.74; -0.04)	0.029	-1.51	(-2.58; -0.44)	0.006	-0.06	(-0.27; 0.14)	0.53

Regression models were adjusted for weekend, season, interaction between child's sex and puberty indicators, baseline anthropometric index, age at measurement, child's ethnicity, maternal BMI, main respondent's age at the birth of the cohort member, maternal socioeconomic circumstances, main respondent's education, household annual income, cars or vans (regular use), lone parenthood status, number of children in the household, Country by (index of multiple deprivation) interaction and urban/rural indicators.
Table abbreviations: CI: confidence interval; BMI: body mass index; FMI: fat mass index; FFMI: Fat free mass index; PA: physical activity; MVPA: moderate-to-vigorous physical activity; min: minutes.

DISCUSSION

Statement of the principal findings

Using data from a large nationally representative sample of primary school-aged children, we found that children who were less active at age seven years has higher levels of adiposity, as assessed using indices of body mass and fat mass. These associations were particularly marked with the measure of fat mass but not body mass for children of Black and South Asian ethnic origin. Children who were more sedentary were also likely to have greater fat mass at seven years. In longitudinal analyses, boys (but not girls) who spent more time in moderate-to-vigorous physical activity at age seven had less body or fat mass - at age 11, but there was no association with overall activity levels or being sedentary at seven years and adiposity at 11 years.

Comparison with the literature

Our findings from cross-sectional analyses are consistent with other large population-based studies.[10-13] Ekelund and colleagues[10] reported an inverse association between total physical activity and fat mass, assessed using the sum of five skinfold measures, in 9-10 year old children across four European centres. Evidence from the Avon Longitudinal Study of Parents and Children (ALSPAC) also suggests an inverse association between total and moderately-to-vigorous physical activity, and fat mass assessed through DXA measurements in 12-year-olds.[11] Other studies also report similar inverse associations in 9-10 year olds.[12;13] These studies acknowledge the limitations of cross sectional analyses, potential reverse causality and the importance of and need for prospective i.e. longitudinal studies.

Within our prospective longitudinal study, moderate or vigorous activity at age seven remained inversely associated with both body mass and fat mass measured four years later. This is to our knowledge the first time this has been reported in a large scale population based study of primary school aged children. Our findings are consistent with those of prospective studies conducted in adolescent populations. Pate and colleagues[41] identified five studies reporting inverse associations between overall activity levels or moderate-to-vigorous physical activity measured at baseline and fat mass at intervals of one to seven years of follow up.[42-46] Within ALSPAC, higher levels of physical activity at age 12 were associated with lower levels of fat mass at age 14.[17] Basterfield et al [47] reported that changes in moderate-to-vigorous physical activity were associated with changes in fat mass over a two year period: interestingly they noted an interaction and that this finding was only present in boys – consistent with our finding. Although our observed effect sizes were small, increasing activity levels in boys may have important implications at the population level in the prevention of excess adiposity. We propose that our finding of a significant association in boys but not girls may reflect differences in tracking of physical activity levels[48] and / or in dietary behaviours by sex which, in turn, could also be affected by differences in age of onset of puberty in boys and girls. However, the data available precluded exploring these hypotheses.

Evidence on associations between physical activity and adiposity by ethnic origin is limited and inconsistent: studies from the United States reports differences between black and white adolescent girls,[49] whilst a cross-sectional study from the UK reports that they are broadly similar across those of South Asian, black African-Caribbean and white European origin.[13] We have observed stronger associations in children of South Asian and black origin; however, interactions between ethnicity and physical activity were only observed within the cross-sectional analyses. Associations with ethnicity, and possible underlying mechanisms, warrant further investigation given established differences in activity levels,[8;50] risk of adiposity and markers of cardiovascular risk[51] in children from different ethnic groups.

A growing body of research has explored associations between sedentary time and adiposity markers, including fat and body mass. We found that sedentary time was positively associated with FMI, but only within the cross-sectional analysis. A positive association between sedentary time and markers of adiposity is supported by some[52;53] but not by other studies;[10;12;14;18;54;55] significant associations are frequently reduced or removed completely following adjustment for levels of physical activity.[16] Due to collinearity, we chose not to adjust for moderate-to-vigorous physical activity levels in the sedentary time analyses.

Strengths and weaknesses of the study

This study was carried out using data from a large and contemporary UK cohort, using both cross-sectional and prospective study designs to explore concurrent and causal associations between physical activity / sedentary time and adiposity. Response weights and multiple imputation methods were also used to address attrition and missing data.

We used objective measures of physical activity and sedentary time which, while overcoming the limitations of child or parental report, may underestimate activities not involving vertical movement of the trunk (such as cycling) and aquatic activities. We used strict accelerometer data management criteria, including thresholds used to categorise intensity of activity and minimum required wear time, based on our previously published methodological studies.[30;31;33;34]

We were able to take advantage of measures of fat mass obtained by trained interviewers using standardised protocols. The former are increasingly recognised as more appropriate measures of adiposity than body mass index in young people,[16] although many studies still only examine body mass. The breadth of information recorded in MCS enabled consideration of a wide variety of potential confounding factors, including – importantly – an estimate of pubertal status. Information on dietary intake is limited in this cohort and we were unable to explore how this may confound or mediate associations between physical activity and adiposity. Another strength of the Millennium Cohort Study is its inclusion of children from ethnic minorities who – with the exception of the bi-ethnic Born in Bradford cohort - are largely absent from other UK birth cohort studies. This enabled associations between activity and adiposity to be explored within different ethnic groups.

It is possible that children who are obese at age seven are less active as a consequence, thereby explaining the findings of the cross-sectional analyses.[56] We adjusted for adiposity at age seven in the longitudinal analyses when these smaller but significant associations remained. A reduction in activity levels from seven to 11 years, which we were unable to assess, may partially explain the reduction in effect sizes between the two study analyses.

Implications for policy and practice

More active boys are at lower risk of adiposity. Our findings highlight the importance of promoting higher levels of physical activity, specifically of moderate-to-vigorous intensity level, in primary school-aged boys, as well as in girls who are less active than boys. This is particularly important given evidence that transition to secondary school is associated with even lower activity levels.[57] Increase in activity levels is particularly important for children from those ethnic groups at greater risk of obesity and its complications.[58] However, efforts to increase activity levels in these groups need to reduce cultural and religious barriers, which have been shown to influence involvement.[59]

The case for policies regarding sedentary activities remain unclear: our findings suggest that this may make a less significant contribution to obesity risk however other evidence using proxy measures of sedentariness (e.g. television viewing or screen time) provides some support for interventions aimed at re-allocating time from sedentary to active pursuits.

ACKNOWLEDGEMENTS / FUNDING

The co-operation of the participating Millennium Cohort families is gratefully acknowledged as is the contribution of the management team at the Centre for Longitudinal Studies, UCL Institute of Education. We are grateful to the latter organisation for the use of these data and to the UK Data Archive and Economic and Social Data Service for making them available; however, they bear no responsibility for the analysis or interpretation of these data. The persistent identifiers of the datasets used in this paper are: MCS1: http://dx.doi.org/10.5255/UKDA-SN-46833; MCS4: http://dx.doi.org/10.5255/UKDA-SN-6411-5; MCS5: http://dx.doi.org/10.5255/UKDA-SN-7464-2. The Millennium Cohort Study is funded by grants to former and current directors of the study from the Economic and Social Research Council (Professor Heather Joshi, Professor Lucinda Platt and Professor Emla Fitzsimons) and a consortium of government funders. The accelerometer data collection was funded by the Wellcome Trust (principal investigator Professor Carol Dezateux) [grant 084686/Z/08/A]. These data were collected when the Population, Policy and Practice Programme was known as the Centre for Paediatric Epidemiology and Biostatistics which was supported in part by the Medical Research Council in its capacity as the MRC Centre of Epidemiology for Child Health (Grant reference G0400546). Research at the UCL Institute of Child Health and Great Ormond Street Hospital for Children receives a proportion of the funding from the Department of Health's National Institute for Health Research Biomedical Research Centres funding scheme. The study sponsors played no part in the design, data analysis and interpretation of this study, the writing of the manuscript, or the decision to submit the paper for publication and the authors' work was independent of their funders.

Competing interests None

CONTRIBUTORS

MC-B, LJG, CD, and FS contributed to data processing. FS conducted the data analysis and, with LJG, CD and MC-B, interpreted the data and drafted the article. All authors contributed to the study conception/design, critically revised the article and reviewed the final draft of the article. LJG is the guarantor.

FIGURE CAPTION

Figure 1 Ethnic differences in strength of cross-sectional associations between MVPA and FMI at age seven years

DATA SHARING STATEMENT

The MCS data for surveys 1–5 can be downloaded from:
http://www.esds.ac.uk/findingData/mcs.asp

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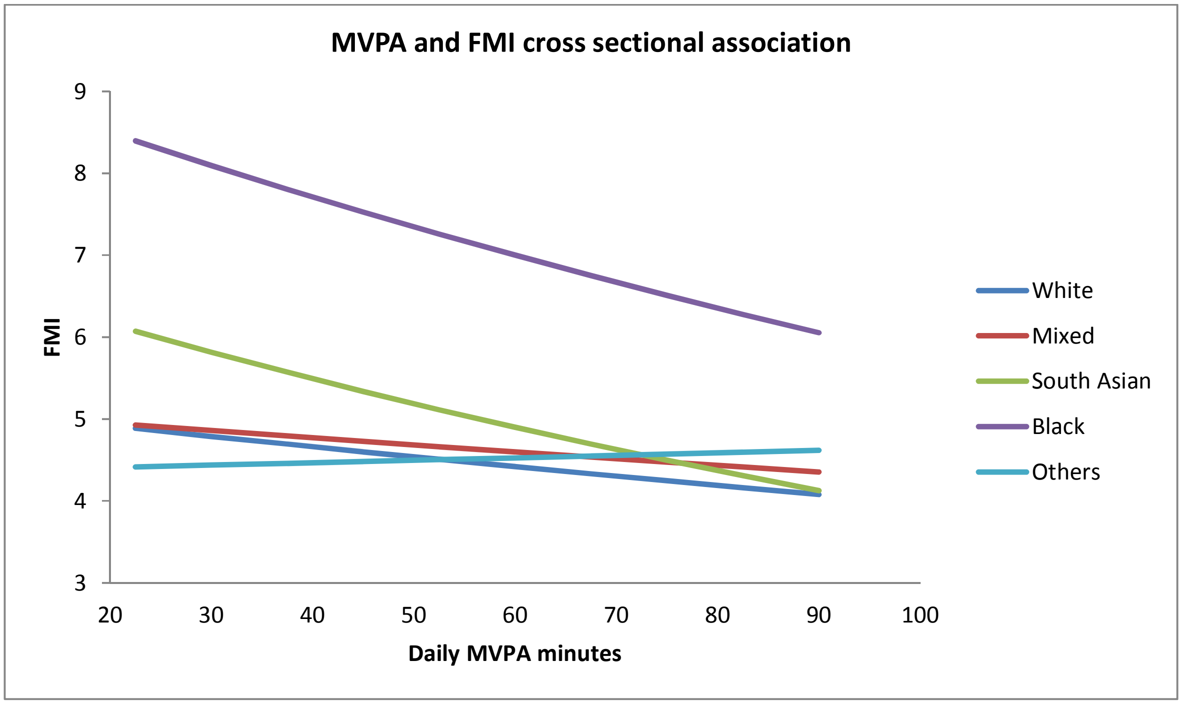
Figure 1 Ethnic differences in strength of cross-sectional associations between MVPA and FMI at age seven years



STROBE 2007 (v4) checklist of items to be included in reports of observational studies in epidemiology*
Checklist for cohort, case-control, and cross-sectional studies (combined)

Section/Topic	Item #	Recommendation	Reported on page #
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	1
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	2
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	3
Objectives	3	State specific objectives, including any pre-specified hypotheses	4
Methods			
Study design	4	Present key elements of study design early in the paper	4
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	4-6
Participants	6	(*a*) *Cohort study*—Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up *Case-control study*—Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls *Cross-sectional study*—Give the eligibility criteria, and the sources and methods of selection of participants	4
		(*b*) *Cohort study*—For matched studies, give matching criteria and number of exposed and unexposed *Case-control study*—For matched studies, give matching criteria and the number of controls per case	N/A
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	5-7
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	5-7
Bias	9	Describe any efforts to address potential sources of bias	8-9
Study size	10	Explain how the study size was arrived at	5
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	8
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	8-9
		(*b*) Describe any methods used to examine subgroups and interactions	9
		(*c*) Explain how missing data were addressed	9
		(*d*) *Cohort study*—If applicable, explain how loss to follow-up was addressed *Case-control study*—If applicable, explain how matching of cases and controls was addressed	8-9

		Cross-sectional study—If applicable, describe analytical methods taking account of sampling strategy	
		(*e*) Describe any sensitivity analyses	N/A
Results			
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	5
		(b) Give reasons for non-participation at each stage	5
		(c) Consider use of a flow diagram	
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	9
		(b) Indicate number of participants with missing data for each variable of interest	10
		(c) *Cohort study*—Summarise follow-up time (eg, average and total amount)	
Outcome data	15*	*Cohort study*—Report numbers of outcome events or summary measures over time	10
		Case-control study—Report numbers in each exposure category, or summary measures of exposure	N/A
		Cross-sectional study—Report numbers of outcome events or summary measures	N/A
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	17-20
		(*b*) Report category boundaries when continuous variables were categorized	
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	19
Discussion			
Key results	18	Summarise key results with reference to study objectives	21
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	23
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	21-24
Generalisability	21	Discuss the generalisability (external validity) of the study results	22
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	24

*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.

BMJ Open

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Journal:	*BMJ Open*
Manuscript ID	bmjopen-2015-010366.R1
Article Type:	Research
Date Submitted by the Author:	12-Feb-2016
Complete List of Authors:	Griffiths, Lucy; UCL Institute of Child Health, Life Course Epidemiology and Biostatistics Sera, Francesco; UCL Institute of Child Health, Life Course Epidemiology and Biostatistics Cortina Borja, Mario; UCL Institute of Child Health, Life Course Epidemiology and Biostatistics Law, Catherine; UCL Institute of Child Health, Life Course Epidemiology and Biostatistics Ness, Andy; University of Bristol, Department of Oral and Dental Science Dezateux, Carol; UCL Institute of Child Health, Life Course Epidemiology and Biostatistics
Primary Subject Heading:	Epidemiology
Secondary Subject Heading:	Sports and exercise medicine, Public health
Keywords:	adiposity, physical activity, sedentary time, children, cohort studies

Objectively measured physical activity and sedentary time: cross-sectional and prospective associations with adiposity in the Millennium Cohort Study

Lucy J Griffiths[1], Francesco Sera[1] (joint first author), Mario Cortina-Borja[1], Catherine Law[1], Andrew Ness[2] and Carol Dezateux[1].

Affiliations: [1]Life Course Epidemiology and Biostatistics, UCL Institute of Child Health, 30 Guilford Street, London, UK; [2]Department of Oral and Dental Science, University of Bristol, Bristol, UK.

Corresponding author: Lucy Griffiths; address as above; lucy.griffiths@ucl.ac.uk

Key words: adiposity, physical activity, sedentary time, children, cohort studies

Word count (excluding title page, abstract, references, figures and tables): 4413

ABSTRACT

Objective: To examine whether physical activity (PA) and sedentary time (ST) in primary school-aged children are associated with adiposity at the start of secondary school, and whether these associations differ by sex or ethnic group.

Design: Nationally representative prospective cohort study.

Setting: Children born across the UK, between 2000 and 2002.

Participants 6497 singleton children.

Outcome measures: Measures of adiposity (body mass index (BMI), fat mass index (FMI) and fat free mass index (FFMI)) - obtained at seven and 11 years of age.

Explanatory measures: Total daily PA (mean counts per minute (cpm)); minutes of moderate-to-vigorous PA (MVPA); and sedentary time (ST). All assessed at seven years of age using accelerometers.

Results: In cross-sectional analyses, total PA was inversely associated with FMI (3.7% (95% confidence interval (CI): 2.7; 4.7) reduction per 150 cpm increase), as was MVPA (4.2% (CI: 3.2; 5.2) reduction per 20 minute/day increase). Associations were stronger in Black and South Asian ethnic groups. Total PA and MVPA were not associated with FFMI. ST was positively associated with FMI (1.3% (CI: 0.2; 2.3) increase per 50 minute/day increase) and inversely associated with FFMI (0.5% (CI: 0.2; 0.7) reduction per 50 minute/day increase). Longitudinally, MVPA at age seven remained inversely associated with FMI at age 11 (1.5% (CI: 2.6; 0.4) reduction per 20 minute/day increase). No association was found between total PA and ST and any of the later adiposity measures.

Conclusions: Seven year old children who are more physically active are less likely to be obese at that age and at age eleven years. These associations were particularly evident in children from Black or South Asian ethnicity at age seven and in boys at age eleven. Measurements of fat mass provide valuable insights into ethnic differences in associations between adiposity and activity.

Strengths and limitations of this study

- This study used both cross-sectional and prospective study designs to explore concurrent and causal associations between physical activity / sedentary time and adiposity in primary-school aged children in the UK-wide Millennium Cohort.
- Objective measures of physical activity / sedentary time were obtained using accelerometers - however, these may underestimate activities not involving vertical movement of the trunk and aquatic activities; adiposity measures included fat mass and body mass obtained by trained interviewers using standardised protocols.
- Inclusion of children from different ethnic origins enabled associations between activity and adiposity to be explored in these groups.
- Information was available on a range of confounding factors, including puberty, but not other potentially important factors, such as dietary intake.

INTRODUCTION

Recent evidence suggests that the prevalence of childhood obesity is rising around the world, although rates may have stabilised in the last decade in some countries.[1-4] Furthermore, the onset of obesity is occurring at ever younger ages.[5] Mounting evidence points to the 'potentially devastating'[6] consequences of this increase; in the short term it has implications for children's health, development and well-being, and - in the longer term - for health in young and later adult life. The World Health Organization therefore regards childhood obesity as one of the most serious global public health challenges for the 21st century, reporting that in 2014 there were an estimated 41 million overweight children aged under five-years alone.[4]

The notion that insufficient physical activity is a one of the key contributors to obesity is common, and is supported by the logic of the energy-balance equation.[7] Public health authorities therefore target obesity prevention as a high priority and endeavour to increase time spent being physically active, and decrease time spent being sedentary, across all ages; however, many adults, adolescents and children are reported to be insufficiently active worldwide.[8-10] We have previously reported that only half of 7-year-old children in the UK achieve recommended levels of physical activity, with significant gender and ethnic variations.[10] Technological advancements in the assessment of physical activity and inactivity over the last decade have enabled researchers to estimate levels achieved more accurately, and to investigate associations with a range of outcomes, with overweight and obesity the main focus.

The majority of observational studies that have evaluated cross-sectional associations between adiposity and objectively assessed physical activity in children suggest that higher activity levels are associated with lower levels of adiposity.[11-15] However, there is limited evidence on how this varies in children of different ethnic groups.[15] Cross-sectional associations with sedentary time are less consistent,[12;14;16;17] although a recent review suggests that sedentary time is usually unrelated to adiposity once activity is taken into account.[18] Evidence from intervention studies is inconsistent but generally shows no or modest effects of physical activity programmes on childhood obesity prevention.[19;20] This may in part reflect the difficulty in changing activity behaviours in childhood.[21] Few large-scale prospective studies examining both physical activity and sedentary time have been conducted and, to our knowledge, available evidence for UK children is predominantly from white adolescent populations.[22-24]

The main pathway linking physical activity and sedentary behaviours to overweight and obesity is energy imbalance, resulting from greater energy intake than energy expenditure over time: from a life course perspective one hypothesis relates to a temporal pathway whereby lower energy expenditure related to inactivity leads to greater weight gain. Psychosocial or physical difficulties or socioeconomic disadvantage in childhood may contribute to future risk of increased adiposity via inactivity. Alternatively these factors may confound associations between childhood obesity and physical activity, by reducing involvement in active pursuits and/or increasing dietary and energy intake.

Our objective was to contribute to this body of research by analysing data from a large UK-wide cohort of primary school-aged children in whom objective assessments of activity (total amount of physical activity and moderate-to-vigorous physical activity), sedentary time and adiposity (body mass index, fat mass index and fat free mass index) were obtained at seven years of age. We analysed cross-sectional (age seven) and prospective (activity and sedentary time at age seven and adiposity at age 11) associations, thereby addressing the need for more evidence on longitudinal associations,[25;26] whilst also exploring if these associations differed by sex or ethnic group.

METHODS

Study participants

We analysed data from the Millennium Cohort Study (MCS), a longitudinal study of children born in the United Kingdom between September 2000 and January 2002.[27] Children living in disadvantaged areas, from ethnic minority groups and from Wales, Scotland and Northern Ireland were over-represented by using a stratified clustered sampling design to ensure the cohort was nationally representative. The first study contact (MCS1) with the cohort child was around age 9 months, when information was collected on 72% of those approached, providing information on 18 818 singleton infants. Five further surveys were carried out when children were aged three (MCS2), five (MCS3), seven (MCS4) and eleven (MCS5) years.

Detailed information regarding demographic, social, and health factors relating to the children and their families was obtained through home-based interviews. The MCS received ethical approval from the South West Multi-Centre Research Ethics Committee (MCS1), the London Multi-Centre Research Ethics Committee (MCS2 and MCS3), Northern and the Yorkshire Research Ethics Committee (MCS4), and the Yorkshire and Humber Research Ethics Committee (MCS5). The study reported here did not require additional ethics approval and used data from MCS1, MCS4 and MCS5 (as detailed below).

Exposure measures: physical activity and sedentary time

Physical activity and sedentary time were assessed objectively using the Actigraph GT1M accelerometer (Actigraph, Pensacola, Florida), a small and lightweight, non-waterproof device, which, in this study, was worn on an elastic belt round the child's waist. The Actigraph GT1M has been extensively validated in children and compares favourably against observational techniques [28], heart rate monitoring [29], indirect and room calorimetry [30;31] and doubly labelled water techniques [32]. It has been shown to be robust when used in other large-scale physical activity studies in children.[16;33]

A total of 13 681 singleton children participated in MCS4 interviews when they were invited to participate in an accelerometry study, which took place over a 15-month period between May 2008 and August 2009. Those who consented (12 872; 94.5%) were posted an accelerometer, programmed to collect and aggregate data over 15-second epochs. Participants were instructed to start wearing their accelerometer the morning after they received it and to continue doing so for seven days during waking hours. They were asked to remove the monitor when bathing or swimming. The accelerometer assessments commenced after the MCS4 interviews had been completed, resulting in a median interval of 36 weeks (IQR 29 to 45) between the interview and the date accelerometers were worn.

Accelerometers were returned by 9772 singleton children. Data were downloaded using Actigraph software version 3.8.3 (Actigraph, Pensacola, Florida) and processed using the package `pawacc` [34;35] for the R statistical computing environment.[36] Non-wear time was defined as any time period of consecutive zero-counts lasting 20 minutes or more:[15] these periods were removed from the summation of activity. Data were summarised as counts per minute (cpm) and values for moderate-to-vigorous physical activity ≥11 715 removed from the dataset, based on a reliability study that indicated that count values above this threshold were extreme and likely to be spurious.[37] Only days with ten hours or more of recorded time were considered as valid and retained in the dataset, and only participants with at least two such days were included in the analyses.[38] We have previously shown high reliability (r=0.86) of this criteria in the MCS cohort.[38] The application of these criteria resulted in a sample size of 6497 singleton children. Reliable accelerometer data were less likely to be acquired from children who were: male; overweight/obese; of white, mixed or 'other' ethnicity; living in disadvantaged areas; had less educated mothers and/or lone mothers.[39] However, overall, small differences were found in the demographic characteristics of the children included in our analyses relative to the whole cohort sample interviewed at age seven years, as detailed previously.[10]

For each child, we derived three exposure variables: average daily minutes of moderate-to-vigorous physical activity (using an accelerometer-defined boundary of ≥ 2240 counts[40]), average daily minutes spent in sedentary time (using the accelerometer-defined boundary of <100 counts[40]), and total physical activity, calculated as the average cpm over the full period of valid recording. As average daily minutes spent in physical activity and sedentary time are related to observed or wear time, these variables were adjusted for standardised wear time across the subjects.[41]

Outcome measures: adiposity

At the fourth and fifth surveys, measures of body composition were taken by trained interviewers. Body fat measurements were obtained using the Tanita BF-522W scales (Tanita UK Ltd, Middlesex, UK); children were asked to stand bare-footed and without outdoor clothing on the metal sole-plates of the scales, which incorporate electrodes and measure foot-to-foot bioelectrical impedance. Bioelectrical impedance analysis (BIA) assesses body fat by passing a very small current through the body and assessing differences in impedance caused by the fact that fat and lean tissues have different electrical properties. The interviewers entered information on each child's age, sex and height into the scales, and recorded the resultant calculated estimate of body fat percentage for that child. Height was measured using Leicester Height Measure Stadiometers (Seca Ltd, Birmingham, UK) and recorded to the nearest millimetre with the head in the Frankfort plane. Weight was measured in kilograms to one decimal place using the Tanita BF-522W scales. The height and weight measures were used to derive BMI. Fat mass index and fat free mass index were calculated using fat mass and fat free mass measures, respectively (Box).

Box Adiposity formulas

Body Mass Index (BMI): weight (kilograms)/height (metres) squared

Fat mass (kilograms): percent body fat × weight

Fat free mass (kilograms): weight - fat mass

Fat Mass Index (FMI): fat mass/height squared

Fat Free Mass Index (FFMI): fat free mass/height squared

Potential confounding variables

Potential confounding factors were identified a priori from existing literature as factors associated with physical activity and obesity. In order to identify a minimal set of confounders we constructed a direct acyclic graph (DAG)[42] for the cross-sectional analyses and checked that no over-adjustment was present. This set included the child's gender and ethnicity (the latter categorised according to guidelines from the Office for National Statistics[43]) collected at MCS1; maternal weight status (defined using BMI cut-offs), age at birth of the cohort member, social class (National Statistics Socio-economic Classification [NS-SEC][44]) and highest educational attainment; annual household income (quintiles); number of cars or vans in the household that are used regularly; lone parenthood status; number of children in the household; country of residence; index of multiple deprivation; and rural / urban area classification of residence. Unless otherwise stated, information on all of these factors was collected at MCS4. These confounders were also used in prospective analyses.

Information on pubertal status was collected at MCS5, using five parentally reported puberty indicators; three were common between boys and girls - growth spurt, body hair, skin changes - while voice change and facial hair were specific for boys and breast growth and age at menarche specific for girls. To reduce the dimensionality of these covariates we built a categorical puberty indicator. Multiple correspondence analyses[45] were performed separately for boys and girls. Using the optimal category scores provided by this, we calculated two quantitative scores; a cluster analysis (complete linkage) was then performed using these two scores and three groups of children were identified after a visual analysis of the dendrogram: those in whom puberty had not started, had barely started or was likely to have started.

Other potential confounding factors explored but, based on the DAG criteria, not included were: presence of a longstanding illness or other illness limiting their everyday activity; diagnosis of asthma; psychological well-being; peer relationship problems; paternal weight status; maternal employment status; housing tenure; and type of residence.

Statistical analysis

Analyses were performed using Stata/SE 13 (Stata Corporation, Texas, USA). Considering the stratified cluster sampling design of MCS study, weights to adjust for attrition between contacts at successive MCS sweeps and for missing accelerometer data were taken into account during the estimation using the Stata command `svyset`. Gender and ethnic differences between total physical activity, sedentary time and moderate-to-vigorous physical activity were assessed adjusting by season of measurement and a weekend/weekday contrast.

Multiple linear regression models were fitted to examine cross-sectional associations between total physical activity levels, moderate-to-vigorous physical activity and sedentary time and each of the adiposity measures (body mass index, fat mass index and fat free mass index); the latter variables were log-transformed due to their skewed distributions. For each regression coefficient *b*, we calculated the quantity $100\times(e^{b}-1)$; similarly, the lower and upper bounds of *b*'s 95% CI were subject to the same back-transformation. These values can be interpreted as the percentage change between geometric means of the adiposity measure associated with varying levels of the covariates of interest. The *p*-values were calculated using the command `nlcom` in Stata, which is based on the delta method[46] to approximate the distribution of nonlinear combinations of parameter estimates. The models were adjusted for child's sex, ethnicity, country of residence and age at measurement; maternal BMI, age, social class, and highest academic qualification; and household annual income, number of cars, lone parenthood status, number of children in the household, urban/rural ward of residence.

Linear regression models were also fitted to evaluate prospective associations between total physical activity levels, moderate-to-vigorous physical activity and sedentary time at age 7 (MCS4) and the three adiposity measures at age 11 (MCS5). Analysis of covariance was used; the baseline value of the adiposity measure was considered as a covariate, alongside the particular exposure variable and confounding variables. Again, adiposity measures were log transformed, and the regression coefficient transformed as described before. A similar strategy was also used to fit the model; adjustment was made for the same variables as in the cross-sectional analyses, in addition to the baseline adiposity measurement and puberty indicator.

In both the cross-sectional and prospective analyses, the effects of joint variation between exposures and the child's sex, and ethnicity, were explored by considering an interaction term in the regression models. All regression models were initially fitted in the complete case sample. For the prospective analyses, around 500 (8.2%) children had missing data for outcome variables (adiposity measurements) or covariates (particularly for pubertal status). Multiple imputation analysis was performed to mitigate possible bias due to item non-response. For the cross-sectional analyses five imputed datasets were built using the (weighted) iterative chain algorithm, and ten for the prospective analyses; estimates were combined using Rubin's rule.[47]

RESULTS

The majority of children (85%) were white, 51% were boys and 20% overweight or obese at age 7. Almost half of mothers were overweight or obese. Socio-demographic measures at ages 7 and 11 are summarised in Table 1 and showed little change over this interval, with the exception of an increase in the prevalence of overweight at age 11.

As reported previously,[10] boys were more active and less sedentary than girls at age seven years. They were also taller and had lower adiposity as assessed by lower mean fat mass and higher fat free mass (Table 2). By age 11 years, the boys were lighter, shorter and still had lower adiposity (lower body mass and fat mass and higher fat free mass) than girls. As expected, marked sex differences in onset of puberty were seen at age 11, with 1 in 5 girls, but less than 1 in 20 boys, having started puberty by this age.

Table 1. Sample characteristics

		MCS4 (*n*=6497)		MCS5 (*n*=6073)	
Variable		***n***	**%***	***n***	**%***
Child's gender	Male	3176	50.9	2950	51.1
	Female	3321	49.1	3123	48.9
Child's ethnicity**	White	5685	85.1	5327	85.0
	Mixed	167	3.3	153	3.1
	South Asian	382	7.1	359	7.3
	Black	141	2.9	119	2.7
	Other	90	1.6	87	1.9
	Missing	32		28	
Obesity (IOTF cut-offs)	Normal	5345	79.8	4522	73.0
	Overweight (not including obese)	836	14.2	1142	21.0
	Obese	289	6.0	290	6.0
	Missing	27		119	
Puberty indicator	Puberty had not started			3498	58.8
	Puberty had barely started			1772	29.3
	Puberty was likely to have started			651	11.9
	Missing			152	
Maternal weight status (BMI-defined groups)	Normal weight	3109	56.1	2929	56.3
	Overweight (not including obese)	1547	28.1	1442	27.9
	Obese	830	15.8	782	15.8
	Missing	1011		920	
Main respondent's age at the birth of the cohort member	14-19	283	8.8	246	8.9
	20-29	2660	45.6	2472	46.4
	30+	3554	45.6	3355	44.7
Maternal socioeconomic circumstances	Managerial and professional occupations	1806	26.1	2082	27.5
	Intermediate occupations	922	18.3	1129	18.2
	Small employers and own account workers	387	6.9	420	6.8
	Lower supervisory and technical occupations	177	5.3	260	5.1
	Semi-routine and routine occupations	1104	34.6	1710	35.5
	Never worked & long-term unemployed	2101	6.8	241	6.9
	Missing	256		231	
Main respondent's highest academic qualification	Degree	1644	18.0	1580	17.4
	Diploma	803	10.0	756	9.7
	A/AS/S levels	677	8.8	645	8.8
	GCSE grades A-G	2536	44.3	2348	45.1
	Other	143	2.7	132	2.9
	None of the above	686	16.2	605	16.1
	Missing	8		7	
Lone parenthood	Non-lone parent	5485	77.3	5,169	77.3

status	Lone parent	989	22.7	884	22.7
	Missing	23		20	
Household annual income (quintiles)	Bottom	960	20.6	859	20.7
	Second	1164	20.2	1071	20.7
	Third	1382	19.8	1293	20.1
	Fourth	1513	20.1	1438	19.9
	Top	1477	19.3	1411	18.6
	Missing	1		1	
Number of cars or vans in the household (regular use)	0	579	14.3	513	14.4
	1	2304	37.1	2133	37.6
	2	3230	42.9	3068	42.3
	3	374	5.7	353	5.7
	Missing	10		6	
Number of children in the household	1	719	12.2	670	12.2
	2	3131	46.6	2942	46.0
	3	1820	27.8	1704	28.2
	4+	812	13.4	744	13.6
	Missing	15		13	
Country of residence	England	4201	81.6	3933	81.5
	Wales	899	5.1	833	5.1
	Scotland	761	9.2	710	9.2
	Northern Ireland	636	4.1	597	4.2
IMD	Least deprived	1499	20.4	1435	20.4
	Second	1255	19.2	1175	18.6
	Third	1255	20.2	1181	20.3
	Fourth	1244	18.7	1147	18.9
	Most deprived	1243	21.5	1134	21.8
	Missing	1		1	
Urban/rural area of residence	Urban	5480	86.8	5110	86.6
	Rural	1016	13.2	962	13.4
	Missing	1		1	

* Weighted estimate.
** Collected at the first MCS survey; all other variables were collected in the fourth (age 7) survey.
Table abbreviations: IOTF: International Obesity Task Force; BMI: body mass index; IMD: index of multiple deprivation.

Table 2. Mean and standard deviation (SD) of the anthropometric and physical activity variables by sex and MCS survey

MCS4	**Girls (*n*=3321)**			**Boys (*n*=3176)**			
	N	**Mean**	**SD**	***n***	**Mean**	**SD**	***p*-value****
Weight (Kg)	3315	25.4	5.0	3161	25.7	5.0	0.2
Height (cm)	3319	123.3	5.7	3172	124.1	5.4	<0.001
BMI (kg/m^2)	3312	16.6	2.4	3158	16.6	2.3	0.6
FMI (kg/m^2)	3281	3.8	1.6	3119	3.4	1.6	<0.001
FFMI (kg/m^2)	3281	12.8	1.0	3118	13.1	1.0	<0.001
Total PA (daily cpm)*	3321	573.9	146.4	3176	644.8	155.4	<0.001
Daily sedentary time (min)*	3321	398.7	50.5	3176	382.2	49.4	<0.001
Daily MVPA (min)*	3321	56.4	19.9	3176	69.9	23.0	<0.001
MCS5	**Girls (*n*=3123)**			**Boys (*n*=2950)**			
	n	**Mean**	**SD**	***n***	**Mean**	**SD**	***p*-value**
Weight (Kg)	3043	42.1	10.4	2880	40.6	9.8	<0.001
Height (cm)	3080	146.8	7.8	2910	145.8	6.7	<0.001
BMI (kg/m^2)	3056	19.4	3.7	2898	19.0	3.7	0.003
FMI (kg/m^2)	3002	5.0	2.5	2834	4.0	2.5	<0.001
FFMI (kg/m^2)	3002	14.4	1.4	2834	14.9	1.5	<0.001
Puberty indicator:	N	%		n	%		
Puberty had not started	1054	32.9		2444	83.7		
Puberty had barely started	1433	46.4		339	12.8		
Puberty was likely to have started	553	20.7		98	3.5		<0.001

* Adjusted by season of measurement and weekend/weekday
** The *p*-values indicate differences between genders; obtained from an adjusted Wald test with girls as the referent.
Table abbreviations: SD: standard deviation; BMI: body mass index; FMI: fat mass index; FFMI: Fat free mass index; PA: physical activity; MVPA: moderate-to-vigorous physical activity; min: minutes; cpm: counts per minute.

Children of South Asian ethnic origin were less active and had higher fat mass and lower fat free mass than white children (Table 3). In contrast, black children were more active but also had higher body and fat mass. By age 11 years, these ethnic differences in adiposity persisted. Black girls were twice as likely to have started puberty than white or South Asian girls.

Table 3. Description of the anthropometric and physical activity variables at age 7 years by ethnicity

MCS4	**White (*n* = 5685)**		**Mixed (*n* = 167)**			**South Asian (*n* = 382)**			**Black/Black British (*n* = 141)**			**Other (*n* = 90)**		
	Mean	SD	Mean	SD	*p*-value **	Mean	SD	*p*-value	Mean	SD	*p*-value	Mean	SD	*p*-value
Weight (Kg)	25.4	4.7	26.0	5.4	0.3	25.4	5.6	0.95	30.8	6.3	<0.001	24.0	3.6	0.003
Height (cm)	123.5	5.6	124.6	4.9	0.031	124.1	5.1	0.07	127.9	5.0	<0.001	123.3	3.9	0.8
BMI (kg/m^2)	16.6	2.2	16.6	2.6	0.8	16.3	2.7	0.2	18.7	3.3	<0.001	15.8	1.9	0.001
FMI (kg/m^2)	3.5	1.4	3.7	1.8	0.3	3.9	2.0	0.023	5.0	2.3	<0.001	3.4	1.3	0.2
FFMI (kg/m^2)	13.0	1.0	13.0	1.0	0.6	12.4	0.9	<0.001	13.7	1.1	<0.001	12.5	1.0	<0.001
Total PA (daily cpm)*	613.9	157.9	584.4	122.6	0.003	570.7	134.3	<0.001	627.9	134.7	0.3	590.7	174.9	0.3
Daily sedentary time (min)*	389.6	50.7	406.1	47.0	<0.001	391.8	51.6	0.3	388.0	39.8	0.6	393.2	55.2	0.6
Daily MVPA (min)*	63.3	23.0	62.2	17.2	0.3	59.9	19.7	0.009	70.3	22.0	0.012	62.4	23.8	0.7
MCS5	**White (*n* = 5327)**		**Mixed (*n* = 153)**			**South Asian (*n* = 359)**			**Black/Black British (*n* = 119)**			**Other (*n* = 87)**		
	Mean	SD	Mean	SD	*p*-value	Mean	SD	*p*-value	Mean	SD	*p*-value	Mean	SD	*p*-value
Weight (Kg)	41.1	10.0	42.1	11.0	0.4	41.6	9.5	0.5	50.8	10.5	<0.001	38.8	6.6	0.046
Height (cm)	146.2	7.4	147.2	6.2	0.098	146.6	6.3	0.4	151.0	6.1	<0.001	145.5	5.0	0.5
BMI (kg/m^2)	19.1	3.6	19.2	4.0	0.8	19.2	3.6	0.5	22.3	4.3	<0.001	18.3	2.9	0.053

FMI (kg/m^2)	4.4	2.5	4.6	3.0	0.5	4.9	2.3	0.001	7.0	4.0	0.001	4.5	2.2	0.99
FFMI (kg/m^2)	14.7	1.4	14.6	1.4	0.6	14.2	1.4	<0.001	15.3	1.9	0.004	14.0	1.1	<0.001
Puberty indicator:	*n*	%	*n*	%		*N*	%		*n*	%		*n*	%	
Puberty had not started	3127	59.4	76	45.3		182	60.9		46	44.3		51	72.5	
Puberty had barely started	1566	29.2	49	35.0		87	26.4		42	31.3		20	25.4	
Puberty was likely to have started	548	11.4	25	19.7		44	12.7		27	24.4		5	2.1	<0.001

* Adjusted by season of measurement and weekend/weekday
** The *p*-values indicate differences between ethnic groups; obtained from an adjusted Wald test with White children as the referent.
Table abbreviations: BMI: body mass index; FMI: fat mass index; FFMI: Fat free mass index; PA: physical activity; MVPA: moderate-to-vigorous physical activity; min: minutes; cpm: counts per minute.

In adjusted cross-sectional analyses, total physical activity and moderate-to-vigorous physical activity were inversely associated with indices of body mass and fat mass at age seven years (Table 4). Body mass was on average 0.84% (95% CI: 0.45; 1.22) and fat mass 3.68% (95% CI: 2.68; 4.68) lower for each 150 cpm increase in total physical activity, while body mass was 1.05% (95% CI: 0.66; 1.43), and fat mass 4.18% (95% CI: 3.15; 5.21), lower for each additional 20 minute period spent in moderate-to-vigorous physical activity. Fat mass was on average 1.27% (0.21; 2.33) higher for each additional 50 minute period of daily sedentary time.

Table 4. Cross-sectional analysis: adjusted percent change in anthropometric indices measured at 7 years of age for given changes in the summary physical activity or sedentary variables assessed at 7 years of age.

	BMI			FMI			FFMI		
Exposures	**% Change**	**95%CI**	***p*-value**	**% Change**	**95%CI**	***p*-value**	**% Change**	**95%CI**	***p*-value**
Total PA (150 counts increase*)	-0.84	(-1.22; -0.45)	<0.0001	-3.68	(-4.68; -2.68)	<0.0001	0.06	(-0.17; 0.29)	0.62
Sedentary time (50 min increase*)	-0.01	(-0.41; 0.40)	0.97	1.27	(0.21; 2.33)	0.019	-0.46	(-0.71; -0.21)	<0.0001
MVPA (20 min increase*)	-1.05	(-1.43; -0.66)	<0.0001	-4.18	(-5.21; -3.15)	<0.0001	-0.04	(-0.27; 0.18)	0.69

Regression models were adjusted for weekend, season, child's sex, age at measurement, child's ethnicity, maternal BMI, main respondent's age at the birth of the cohort member, maternal socioeconomic circumstances, main respondent's education, household annual income, cars or vans (regular use), lone parenthood status, number of children in the household, Country by (index of multiple deprivation) interaction and urban/rural indicators.
*These values/increments approximate to one standard deviation of these measures.
Table abbreviations: CI: confidence interval; BMI: body mass index; FMI: fat mass index; FFMI: Fat free mass index; PA: physical activity; MVPA: moderate-to-vigorous physical activity; min: minutes.

Black children and those of South Asian ethnic origin showed the greatest decrease in fat mass index for each increment in time spent in moderate-to-vigorous physical activity across the range of 20-90 minutes. Significant interactions with ethnicity were found in cross-sectional analyses between total physical activity and fat mass (p=0.003) and moderate-to-vigorous physical activity and fat mass (p=0.020); the latter is shown in Figure 1. Fat mass was, on average, 12.74% (95% CI: 3.97; 21.51) and 7.44% (95% CI: 3.74; 11.15) lower per 150 cpm increase in total physical activity level in black children and those of South Asian ethnic origin respectively and 8.22% (95% CI: 5.05; 11.39) lower for each additional 20 minutes of moderate-to-vigorous physical activity in children of South Asian ethnic origin. Interactions with gender were not significant.

INSERT Figure 1

By 11 years of age, moderate-to-vigorous physical activity but not total physical activity levels at age 7 remained inversely associated with body mass and fat mass (Table 5). The effect sizes were also smaller than those obtained in the cross-sectional analyses; body mass and fat mass at age 11 were on average 0.39% (0.04; 0.74) and 1.5% (0.44; 2.58) lower for each 20 minute increase in daily moderate-to-vigorous physical activity at age 7.

In this longitudinal analysis, we also found a significant interaction for sex (p<0.001), where the association between moderate-to-vigorous physical activity and body mass or fat mass was present only in boys: body mass and fat mass at age 11 were on average 2.53% (0.88; 4.17) and 2.89% (1.34; 4.40) lower for each 20 minute increase in daily moderate-to-vigorous physical activity at age 7. There were no significant interactions with ethnicity.

Table 5. Longitudinal analysis: adjusted percent change in anthropometric indices measured at 11 years of age for given changes in the summary physical activity or sedentary variables assessed at 7 years of age

	BMI			FMI			FFMI		
Exposures	**% Change**	**95%CI**	***p*-value**	**% Change**	**95%CI**	***p*-value**	**% Change**	**95%CI**	***p*-value**
Total PA (150 counts increase*)	-0.15	(-0.50; 0.20)	0.40	-0.94	(-2.10; 0.28)	0.11	0.05	(-0.17; 0.27)	0.64
Sedentary time (50 min increase*)	-0.25	(-0.59; 0.09)	0.16	-0.25	(-1.36; 0.85)	0.65	-0.16	(-0.38; 0.05)	0.13
MVPA (20 min increase*)	-0.39	(-0.74; -0.04)	0.029	-1.51	(-2.58; -0.44)	0.006	-0.06	(-0.27; 0.14)	0.53

Regression models were adjusted for weekend, season, interaction between child's sex and puberty indicators, baseline anthropometric index, age at measurement, child's ethnicity, maternal BMI, main respondent's age at the birth of the cohort member, maternal socioeconomic circumstances, main respondent's education, household annual income, cars or vans (regular use), lone parenthood status, number of children in the household, Country by (index of multiple deprivation) interaction and urban/rural indicators.
*These values/increments approximate one standard deviation of these measures.
Table abbreviations: CI: confidence interval; BMI: body mass index; FMI: fat mass index; FFMI: Fat free mass index; PA: physical activity; MVPA: moderate-to-vigorous physical activity; min: minutes.

DISCUSSION

Statement of the principal findings

Using data from a large nationally representative sample of primary school-aged children, we found that children who were less active at age seven years have higher levels of adiposity, as assessed using indices of body mass and fat mass. These associations were particularly marked with the measure of fat mass but not body mass for children of Black and South Asian ethnic origin. Children who were more sedentary were also likely to have greater fat mass at seven years. In longitudinal analyses, boys (but not girls) who spent more time in moderate-to-vigorous physical activity at age seven had less body or fat mass - at age 11, but there was no association with total activity levels or being sedentary at seven years and adiposity at 11 years.

Comparison with the literature

Our findings from cross-sectional analyses are consistent with other large population-based studies.[12-15] Ekelund and colleagues[12] reported an inverse association between total physical activity and fat mass, assessed using the sum of five skinfold measures, in 9-10 year old children across four European centres. Evidence from the Avon Longitudinal Study of Parents and Children (ALSPAC) also suggests an inverse association between total and moderately-to-vigorous physical activity, and fat mass assessed through DXA measurements in 12-year-olds.[13] Other studies also report similar inverse associations in 9-10 year olds.[14;15] These studies acknowledge the limitations of cross sectional analyses, potential reverse causality and the importance of and need for prospective i.e. longitudinal studies.

Within our prospective longitudinal study, in boys moderate or vigorous activity at age seven remained inversely associated with both body mass and fat mass measured four years later. This is to our knowledge the first time this has been reported in a large scale population based study of primary school aged children.

In our study, associations between total physical activity levels and sedentary time with subsequent adiposity were not significant in the prospective analyses but a longitudinal effect was still evident for moderate-to-vigorous physical activity. Findings from other studies also suggest that activity of vigorous intensity may be more strongly associated with adiposity outcomes than activity or lower intensity or total physical activity,[14;48] although the mechanisms underlying more beneficial effects of more vigorous activity remain unknown. for example, Fisher and colleagues[48] reported that activity of moderate-to-vigorous intensity was significantly associated with follow up FMI independent of total PA or sedentary time in a smaller study of 280 9-10 year old children. By contrast, other published studies in this age group have reported no prospective associations between activity and adiposity.[24;49]

Our findings are however also consistent with those of prospective studies conducted in adolescent populations. Pate and colleagues[50] identified five studies reporting inverse associations between total activity levels or moderate-to-vigorous physical activity measured at baseline and fat mass at intervals of one to seven years of follow up. Within ALSPAC, higher levels of physical activity at age 12 were associated with lower levels of fat mass at age 14.[22] Basterfield et al [51] reported that changes in moderate-to-vigorous physical activity were associated with changes in fat mass over a two year period: interestingly they noted an interaction and that this finding was only present in boys – consistent with our finding. Although our observed effect sizes were small, increasing activity levels in boys may have important implications at the population level in the prevention of excess adiposity. We propose that our finding of a significant association in boys but not girls may reflect differences in tracking of physical activity levels[52] and / or in dietary behaviours by sex which, in turn, could also be affected by differences in age of onset of puberty in boys and girls. However, the data available precluded exploring these hypotheses.

Evidence on associations between physical activity and adiposity by ethnic origin is limited and inconsistent: studies from the United States report differences between black and white adolescent girls,[53] whilst a cross-sectional study from the UK reports that they are broadly similar across those of South Asian, black African-Caribbean and white European origin.[15] In contrast, we observed stronger associations between activity and adiposity in children of South Asian and black origin; however, interactions between ethnicity and physical activity were only observed within the cross-sectional analyses. Associations with ethnicity, and possible underlying mechanisms, warrant further investigation given the established differences in activity levels,[10;54] risk of adiposity and markers of cardiovascular risk[55] in children from different ethnic groups.

A growing body of research has explored associations between sedentary time and adiposity markers, including fat and body mass. We found that sedentary time was positively associated with FMI, but only within the cross-sectional analysis. A positive association between sedentary time and markers of adiposity is supported by some[56;57] but not by other studies;[12;14;16;23;24;58;59] significant associations are frequently reduced or removed completely following adjustment for levels of physical activity.[18] We did not adjust for moderate-to-vigorous physical activity levels in the sedentary time analyses as suggested by Page and colleagues,[60] and given that in our study these measures were assessed simultaneously.

Strengths and weaknesses of the study

This study was carried out using data from a large and contemporary UK cohort, using both cross-sectional and prospective study designs to explore concurrent and causal associations between physical activity / sedentary time and adiposity. Response weights and multiple imputation methods were also used to address attrition and missing data.

We used objective assessments of physical activity and sedentary time which, while overcoming the limitations of child or parental report, may underestimate activities not involving vertical movement of the trunk (such as cycling) and aquatic activities. We applied strict accelerometer data management criteria, including thresholds used to categorise intensity of activity and minimum required wear time, based on our previously published methodological studies.[37;38;40;41] As there was an interval between the interview at MCS4 and accelerometer assessments, the associations reported here are not truly cross-sectional. However in the longitudinal analyses the exposure (activity) and confounding factors were always measured before the outcome (adiposity), thus providing some support for a causal association.

We were able to take advantage of measures of fat mass obtained by trained interviewers using standardised protocols. The former are increasingly recognised as more appropriate measures of adiposity than body mass index in young people,[18] although many studies still only report body mass index. The breadth of information recorded in MCS enabled consideration of a wide variety of potential confounding factors, including – importantly – an estimate of pubertal status. Unfortunately, information on dietary intake is limited in this cohort, reflecting in part the difficulties inherent in measuring energy intake and dietary quality reliably at this age. Ambrosini et al[61] found longitudinal associations between dietary intakes characterised by energy density, % total energy from fat and fibre density and fat mass in children aged between seven to 15 years, which they reported were independent of physical activity. However, this does not exclude an effect of moderate and/or vigorous physical activity since adjustment was for total physical activity only. We were unable to explore how this important factor may confound or mediate associations between physical activity and adiposity in our study. Further studies are needed that provide concurrent information on diet and objective assessment of physical activity.

Another strength of the Millennium Cohort Study is its inclusion of children from ethnic minorities who – with the exception of the bi-ethnic Born in Bradford cohort [62] - are largely absent from other UK birth cohort studies. This enabled associations between activity and adiposity to be explored within different ethnic groups.

It is possible that children who are obese at age seven are less active as a consequence, thereby explaining the findings of the cross-sectional analyses.[63] We adjusted for adiposity at age seven in the longitudinal analyses when these smaller but significant associations remained. A reduction in activity levels from seven to 11 years, which we were unable to assess, may partially explain the reduction in effect sizes between the two study analyses. The lack of a second subsequent assessment of physical activity or sedentary time at or before age 11 years limits the extent to which physical activity trajectories could be taken into account in assessing the changes in adiposity. Objective assessments of activity are being repeated currently in cohort members at age 14 years and this will enable future analyses to examine changes in activity levels from childhood to adolescence and associations with subsequent adiposity.

Implications for policy and practice

Our findings suggest that more active boys are at lower risk of subsequent adiposity. While Our findings highlight the importance of promoting higher levels of physical activity, specifically of moderate-to-vigorous intensity level, in primary school-aged boys, as well as in girls who are known to be less active than boys. This is particularly important given evidence that transition to secondary school is associated with even lower activity levels.[64] While increased physical activity is recognised to have a number of benefits, greater activity is generally promoted as part of a multifactorial approach to tackling childhood obesity, as evidenced by the recent WHO 2016 report which emphasises the global dimensions of childhood obesity.[4] An increase in activity levels is likely to be particularly important for children from those ethnic groups at greater risk of obesity and its complications.[65] However, efforts to increase activity levels in these groups need to reduce cultural and religious barriers, which have been shown to influence involvement.[66]

The case for policies regarding sedentary activities remain unclear: our findings suggest that this may make a less significant contribution to obesity risk however other evidence using proxy measures of sedentariness (e.g. television viewing or screen time) provides some support for interventions aimed at re-allocating time from sedentary to active pursuits.

ACKNOWLEDGEMENTS / FUNDING

The co-operation of the participating Millennium Cohort families is gratefully acknowledged as is the contribution of the management team at the Centre for Longitudinal Studies, UCL

Institute of Education. We are grateful to the latter organisation for the use of these data and to the UK Data Archive and Economic and Social Data Service for making them available; however, they bear no responsibility for the analysis or interpretation of these data. The persistent identifiers of the datasets used in this paper are: MCS1: http://dx.doi.org/10.5255/UKDA-SN-46833; MCS4: http://dx.doi.org/10.5255/UKDA-SN-6411-5; MCS5: http://dx.doi.org/10.5255/UKDA-SN-7464-2. The Millennium Cohort Study is funded by grants to former and current directors of the study from the Economic and Social Research Council (Professor Heather Joshi, Professor Lucinda Platt and Professor Emla Fitzsimons) and a consortium of government funders. The accelerometer data collection was funded by the Wellcome Trust (principal investigator Professor Carol Dezateux) [grant 084686/Z/08/A]. These data were collected when the Population, Policy and Practice Programme was known as the Centre for Paediatric Epidemiology and Biostatistics which was supported in part by the Medical Research Council in its capacity as the MRC Centre of Epidemiology for Child Health (Grant reference G0400546). Research at the UCL Institute of Child Health and Great Ormond Street Hospital for Children receives a proportion of the funding from the Department of Health's National Institute for Health Research Biomedical Research Centres funding scheme. The study sponsors played no part in the design, data analysis and interpretation of this study, the writing of the manuscript, or the decision to submit the paper for publication and the authors' work was independent of their funders.

Competing interests None

CONTRIBUTORS

MC-B, LJG, CD, and FS contributed to data processing. FS conducted the data analysis and, with LJG, CD and MC-B, interpreted the data and drafted the article. All authors contributed to the study conception/design, critically revised the article and reviewed the final draft of the article. LJG is the guarantor.

FIGURE CAPTION

Figure 1 Ethnic differences in strength of cross-sectional associations between MVPA and FMI at age seven years

DATA SHARING

No additional data available.

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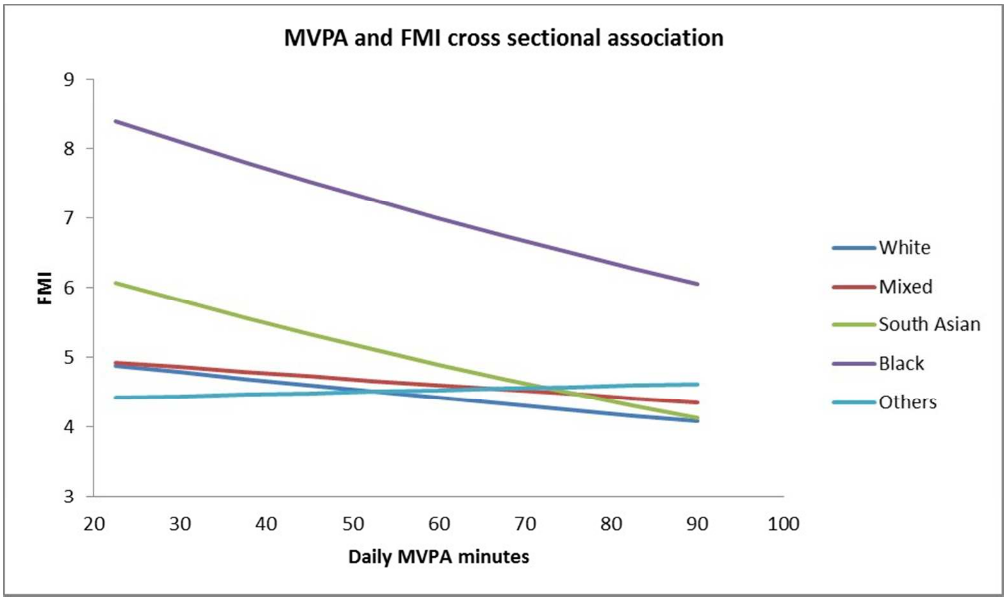

Ethnic differences in strength of cross-sectional associations between MVPA and FMI at age seven years
165x98mm (150 x 150 DPI)

STROBE 2007 (v4) checklist of items to be included in reports of observational studies in epidemiology*
Checklist for cohort, case-control, and cross-sectional studies (combined)

Section/Topic	Item #	Recommendation	Reported on page #
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	1
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	2
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	4-5
Objectives	3	State specific objectives, including any pre-specified hypotheses	5
Methods			
Study design	4	Present key elements of study design early in the paper	5
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	5-9
Participants	6	(*a*) *Cohort study*—Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up *Case-control study*—Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls *Cross-sectional study*—Give the eligibility criteria, and the sources and methods of selection of participants	5
		(*b*) *Cohort study*—For matched studies, give matching criteria and number of exposed and unexposed *Case-control study*—For matched studies, give matching criteria and the number of controls per case	N/A
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	6-9
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	6-9
Bias	9	Describe any efforts to address potential sources of bias	10
Study size	10	Explain how the study size was arrived at	7
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	10-11
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	10-11
		(*b*) Describe any methods used to examine subgroups and interactions	10
		(*c*) Explain how missing data were addressed	10
		(*d*) *Cohort study*—If applicable, explain how loss to follow-up was addressed *Case-control study*—If applicable, explain how matching of cases and controls was addressed	10-11

		Cross-sectional study—If applicable, describe analytical methods taking account of sampling strategy	
		(*e*) Describe any sensitivity analyses	N/A
Results			
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	5-7
		(b) Give reasons for non-participation at each stage	5-7
		(c) Consider use of a flow diagram	
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	11-17
		(b) Indicate number of participants with missing data for each variable of interest	11-17
		(c) *Cohort study*—Summarise follow-up time (eg, average and total amount)	6
Outcome data	15*	*Cohort study*—Report numbers of outcome events or summary measures over time	14
		Case-control study—Report numbers in each exposure category, or summary measures of exposure	N/A
		Cross-sectional study—Report numbers of outcome events or summary measures	N/A
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	18-21
		(*b*) Report category boundaries when continuous variables were categorized	
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	18-21
Discussion			
Key results	18	Summarise key results with reference to study objectives	22
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	24-26
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	22-26
Generalisability	21	Discuss the generalisability (external validity) of the study results	22-26
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	26-27

*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.
Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.