Sleep duration and adiposity in early childhood: evidence for bidirectional associations from the Born in Bradford study

Subtitle: Sleep duration and adiposity in early childhood

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Institution at which the work was performed: Bradford Institute for Health Research

Sources of support: This work has been financially supported by the National Institute for Health Research (NIHR) under its Grants for Applied Research Programme (Grant Reference Number RP-PG-0407-10044). Authors PJC, JWe, SEB, RRCM and JWr are part of the Healthy Children, Healthy Families Theme of the NIHR CLAHRC Yorkshire and Humber.

Disclosure of any off-label or investigational use: N/A

Conflict of interest: The authors declare no conflict of interest.

Clinical trial details: N/A

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No. of figures: Zero

No. of tables: Five

Abbreviations: BiB, Born in Bradford; BMI, Body mass index; CI, Confidence interval; SD, standard deviation; SES, Socioeconomic status; %BF, Percent body fat.

Abstract

Study Objectives: To examine independent associations of sleep duration with total and abdominal adiposity, and the bidirectionality of these associations, in a young bi-ethnic sample of children from a disadvantaged location.

Methods: Child sleep duration (h/day) was parent-reported by questionnaire and indices of total (body weight, body mass index, percent body fat (%BF), sum of skinfolds) and abdominal adiposity (waist circumference) were measured using standard anthropometric procedures at approximately 12, 18, 24, and 36 months of age in 1,338 children (58% South Asian; 42% White). Mixed effects models were used to quantify independent associations (expressed as standardised β-coefficients (95% confidence interval (CI)) of sleep duration with adiposity indices using data from all four time-points. Factors considered for adjustment in models included basic demographics, pregnancy and birth characteristics, and lifestyle behaviours.

Results: With the exception of the sum of skinfolds, sleep duration was inversely and independently associated with indices of total and abdominal adiposity in South Asian children. For example, one standard deviation (SD) higher sleep duration was associated with reduced %BF by -0.029 (95% CI: −0.053, −0.0043) SDs. Higher adiposity was also independently associated with shorter sleep duration in South Asian children (for example, %BF: β= -0.10 (-0.16, -0.028) SDs). There were no significant associations in White children.

Conclusions: Associations between sleep duration and adiposity are bidirectional and independent among South Asian children from a disadvantaged location. The results highlight the importance of considering adiposity as both a determinant of decreased sleep and a potential consequence.

Keywords: Sleep length; Body fat; Obesity; Ethnic Groups; Pediatrics; Poverty

Statement of significance: Few studies have investigated associations between sleep duration and adiposity in young ethnically diverse children from an economically deprived location. Using repeated-measures data collected at four time-points between approximately

12 and 36 months of age, this study found bidirectional inverse associations between parent-reported sleep duration with indicators of total and abdominal adiposity in South Asian children, independent of diverse potential confounding factors. The results highlight that adiposity may be both a determinant and consequence of decreased sleep in a population that is high risk for obesity and cardiometabolic disease. Longitudinal studies of multidimensional sleep constructs (duration, patterns and quality) and their associations with early childhood adiposity are needed, with greater focus on low socioeconomic status and ethnically diverse populations.

Introduction

Meta-analyses suggest that children who sleep less than their peers have an approximate doubling of risk for overweight and obesity, but the data informing this estimate are largely from older children and adolescents.[1,2] As early childhood is considered a critical time-frame for obesity development[3,4], and associations between sleep and adiposity may differ by life stage due to alterations in sleep need and behaviour[5,6], more research in infants and toddlers is warranted to inform obesity prevention.

It is important that any such research acknowledges that there are sociocultural differences in child sleep duration (children of non-White ethnicity sleep less)[7,8] and obesity risk.[9] Childhood obesity prevalence is twice as high in the most compared to the least deprived areas in England, and is higher than the national average in ethnic minority groups[10], including UK resident South Asian children who are higher risk for cardiometabolic disease.[11] Knowledge about sleep duration and its relation with adiposity in disadvantaged high-risk settings and ethnic groups is lacking, however, because most existing studies have incorporated homogenous groups of White young children from predominantly well-educated and high income families.[12–16] Studies have also relied upon BMI as an indicator of total adiposity or weight status, and have not investigated abdominal adiposity, which exhibits ethnic variation[17] and is strongly related to a multitude of cardiovascular and metabolic risk factors more so than BMI.[18,19]

The relation between sleep duration and adiposity has also typically only been considered as unidirectional, although the association may run in both directions.[13,15] Higher adiposity may promote sleep disorders (apnoea or insomnia)[20,21] and may influence intermediary behaviours that could impede or aid sleep (e.g. physical activity).[22,23] Research is needed to identify if adiposity constitutes a novel and potentially modifiable determinant of childhood sleep, given that adequate sleep is essential for normal development and functioning[24], child sleep duration exhibits long-term stability[25], and there has been a prevailing trend of declining childhood sleep in the last 2 decades[26] that may have been most pronounced in the youngest of children.[27]

To address current gaps in the literature, this study examined the associations between sleep duration with total and abdominal adiposity using data from four time-points in early childhood (collected at about age 12, 18, 24 and 36 months) in a bi-ethnic sample of South Asian and White children from a deprived location. Possible bidirectionality of these associations was also scrutinised. Information of this type could help to address health inequalities and the higher prevalence of obesity and cardiometabolic disease in South Asian populations.[28,29]

Methods

Study design and population

All procedures, including equipment details, are described thoroughly elsewhere.[30] Briefly, this investigation entailed data from a sub-study of the 'Born in Bradford' (BiB) cohort[31], named BiB-1000. Expectant mothers (*n*=1916) at 26-28 weeks gestation were approached to participate in the study when attending routine hospital appointments in 2008-09; 1735 accepted (90.6% uptake) and five measurement rounds were carried out when children were about age 6, 12, 18, 24 and 36 months. Attendance at each time-point ranged between 70-77%, 47% of participants attended every time-point, and 17% were formally withdrawn from the study by 36 months. The BiB-1000 cohort is comparable to the larger BiB cohort[30] which is representative of Bradford, the sixth largest and one of the most deprived and ethnically diverse UK cities. At the time of recruitment, 60% of all babies in Bradford were born into the poorest 20% of locations in England and Wales, and approximately half of all new-borns in Bradford are of South Asian origin (mainly Pakistani heritage).[31]

Only children from singleton births (*n*=1707) were included in this investigation as we relied on parent-reports of child behaviours, which may have been compromised for twins. Furthermore, because sleep characteristics and circadian rhythmicity take approximately 12 months to mature, it has been recommended that sleep analyses should be based only on sleeping patterns established after age one year.[12] For this reason the sample was restricted to participants with data for sleep duration, body composition and potential confounders from the 12 month time-point onwards (*n*=1411). For the purposes of this investigation the 12 month time-point is referred to as baseline. Due to small numbers, children with a mother belonging to an ethnic group other than South Asian (Pakistani, Indian, and Bangladeshi) or White (British or Other e.g. White European) were also excluded (remaining *n*=1338).

Sleep assessment

At all time-points the average number of hours usually slept by children between 6am to 6pm, and 6pm to 6am, were reported by parents in response to a single question administered by an interviewer. These data were combined to the average sleep duration in a 24h period, which correlated with concurrent parent-reported sleep diary data that were collected in a sub-sample of children at the 18 and 36 month assessments (n=485; r=0.44, p<0.001). For description, the mean sleep duration over all measurement occasions was calculated and five a priori categories of sleep duration were derived based on recommended ranges (<11, 11-12, 12-13, 13-14 and ≥14 h/day).[32] The middle category (12-13 h/day) reflects the average reported sleep duration of young children from England[8] as well as children globally.[33]

Anthropometric measures

At all visits children's weight and height were assessed by trained researchers. Body mass index (BMI) and *z*-scores were calculated.[34] As in other aetiological studies[35,36] the data were used to generate pooled estimates of body composition[37] by aggregating estimates from published age-appropriate equations that have been validated in both South Asian[38,39] and White[40–42] children. For each equation, predicted total body water was first converted to fat-free mass using age- and sex-specific hydration factors[43,44] and estimates of fat mass (weight minus fat-free mass) and percent body fat (fat mass/weight) were subsequently derived. Every parameter estimate was then mean-averaged to create pooled fat mass and percent body fat variables.[37] At every visit (but with varying amounts of missing data) waist circumferences at the level of the naval and skinfolds of the left triceps, subscapular and thigh were also measured, and the sum of skinfolds was calculated. Reliability metrics calculated for the researchers showed good intra- and inter-observer technical error of measurements for waist circumference and skinfolds.[45]

Covariates

Potential confounders were chosen based on biological plausibility and evidence linking them with sleep duration and adiposity.[8,46–48] Three socioeconomic status (SES) groups were derived from 19 indicators collated during interviews that were typically conducted with mothers.[49] Maternal ethnicity (used as a proxy for child ethnicity), age and smoking in pregnancy were further reported at the point of recruitment and maternal height and weight were first measured; weight was repeated at every subsequent time-point and maternal BMI calculated. Number of previous births (used as a proxy for older siblings), child's season of birth, gender, gestational age, and birth weight were extracted from medical records. Age introduced to solids was collected at the 6 and 12 month time-points, as was the number of weeks children were breast fed, for which information was further available at the 24 month visit. At the 24 month time-point, parents also reported the frequency with which children went to bed at a regular time (dichotomised as every day or not), and using parent responses to validated questions posed at 24 and 36 months, the levels of children's moderate-to-vigorous physical activity were estimated.[50] At all time-points, children's mean daily TV-viewing after 6pm was calculated and was further combined with the hours before 6pm to provide an estimate of total TV-viewing.[51] Infant dietary data were also collected using a validated food frequency questionnaire[52] that was modified for BiB by including ethnic-specific foodstuffs. For this study, diet pattern constructs were formed to reflect unhealthy snacking (i.e. frequency of biscuit, crisps, cakes, sweets, chocolate, sugar-sweetened beverage consumption) and daily intakes of fruit and vegetables. To account for a small proportion of unlikely responses, values were capped at 10 snacks or 10 fruit/vegetable portions daily, which is well above the average reported intakes for UK and European children.[53,54] In the main analyses, maternal BMI, TV-viewing duration, unhealthy snacking, and fruit and vegetable intakes were incorporated as time-varying factors.

Statistics

Descriptive analysis

The characteristics of participants were summarised overall and according to categories of sleep duration for South Asian and White children separately. Trend tests and chi-square tests explored differences in participant characteristics across sleep categories and across time-points. Chi-square, ANOVA and Kruskal-Wallis tests examined differences between ethnic groups and also compared the characteristics of included children against all those excluded from analyses. For included children, logistic regression was performed to investigate predictors of intermittent missing data.

Main analysis

Sleep duration and each adiposity variable were regressed against follow-up time to evaluate the time trend for the whole sample, and for South Asian and White children separately. Models including follow-up time, time-squared and time-cubed were most appropriate to describe trends in adiposity. Mixed effects regression analyses were incorporated to efficiently analyse the repeated-measures data which were characterised by non-standard follow-up durations and missing values. This approach, which has previously been used to investigate bidirectional associations[55,56], allowed inclusion of up to four values of each exposure and outcome per child.[57] The equations used to model associations (detailed in Appendix 1) were mathematically comparable to a former publication[55], and initially involved modelling adiposity indicators as outcomes and sleep duration as a time-varying exposure, before inflecting exposure and outcomes to model the reverse associations; each of the adiposity indicators were included in separate models. To assist comparisons of the effects of sleep duration on different adiposity measures, and vice versa, all exposure and outcome measures were standardised using means and standard deviations (SD) based on values from the mid time-point (24 months of age). The results represent the concurrent change in the outcome (in SDs) associated with a one SD change in the exposure. Our statistics showed significant interactions by ethnicity in both directions between sleep and total adiposity ($p \leq 0.041$) hence all analyses have been stratified by ethnic group. There was no strong evidence for curvature of associations in either direction as identified by non-significant quadratic terms for exposure variables ($p \geq 0.13$).

All models adhered to the same procedure for inclusion of confounders. After running crude models that included only baseline age and follow-up time (and time-squared and cubed when adiposity was the outcome), Model 1 was further adjusted for gender, SES, parity, gestational age, birth weight, birth season, maternal smoking in pregnancy, and maternal follow-up BMI. To elucidate the trajectory of associations over time, an interaction with follow-up time was added to Model 1, and the main effects of sleep duration on adiposity (and vice versa) at 6, 12 and 24 months of follow-up were calculated (Model 1a). In Model 2, TV-viewing duration, unhealthy snacking, and fruit and vegetable intake were added as potential confounders or mediators. Finally, a series of sensitivity analyses were applied to Model 2 that entailed further adjustment for breast feeding history, age introduced to solids, physical activity, and bedtime regularity, all of which had missing data. Maternal follow-up BMI was also exchanged for maternal early-pregnancy BMI as a covariate and total TV-viewing was replaced by the hours of TV watched exclusively after 6pm. In final sensitivity analyses, adjustment for height in all models that involved adiposity indices not already indexed to stature or size (weight, waist circumference, and sum of skinfolds) was performed, fat mass and height were used to generate fat mass index (kg/m^2) which was used as an alternative to %BF[58], and BMI was substituted in models for BMI *z*-score. Stata v13.1 (StataCorp., College Station, TX) was used for all analyses. Two tailed *P*-values of less than 0.05 were considered to be significant.

Results

Participant characteristics

The final analytical sample comprised 1,338 children (58% South Asian) who provided >2400 observations. Complete data at all time-points were available for 399 participants and for most analyses the mean number of observations per child was 2.8. Table 1 provides a summary of demographic and birth characteristics overall and across sleep duration categories, stratified by ethnicity. Overall, South Asian mothers were on average older, had a lower early-pregnancy BMI, and birthed lighter babies than White mothers. A higher proportion of South Asian than White mothers were multiparous and gave birth in spring, whereas a higher proportion of White mothers gave birth in winter, occupied the least deprived SES category, and smoked in pregnancy. Table 2 summarises children's behaviours (values for sleep duration, TV-viewing, unhealthy snacks, and fruit and vegetable intakes are averages from all time-points); overall there was no ethnic difference in sleep duration but South Asian children on average were breast fed for longer, introduced to solids at an older age, watched more TV after 6pm, consumed more daily portions of fruit and vegetables and more unhealthy snacks, and were more physically active compared to White children. The percentage of children who were reported to sleep <11h and >14h on average over the course of investigation was 7.0% and 12.5% in South Asian children and 5.3% and 8.0% in White children. In South Asians, there was a trend that longer sleep was associated with having a younger mother (Table 1), and as shown in Table 2 also shorter breast feeding duration, less TV-viewing, and more fruit and vegetables. In White children, longer sleep was associated with watching less TV after 6pm and a smaller proportion of winter births (Table 1). In both ethnic groups the proportion of children with regular bedtimes was highest in the longest reported sleep duration category (Table 2).

Table 3 summarises the repeated measures data at each discreet time-point. Parent reported sleep duration declined with age in both ethnic groups; at the 36 month time-point South Asian children were reported to sleep significantly more than White children. There were significant age-related increases in height, weight, fat mass and waist circumference, and significant trends of a decline in all other adiposity measures. South Asian children were taller and consistently less adipose at all ages compared to White children. For time-varying covariates, TV-viewing duration (in total and exclusively after 6pm) and intake of unhealthy snacks increased with age in both ethnic groups, and in South Asians fruit and vegetable intake declined and maternal BMI increased. As per the mean overall data in Table 2, South Asian children were reported to consistently watch more TV, consume more unhealthy snacks and fruit and vegetables than White children.

Missing data comparisons revealed that a greater proportion of excluded children were classified as most deprived (22.4 vs. 15.8%) and were born to a mother that smoked in pregnancy (21.5 vs. 15.8%). Fewer excluded children had regular bedtimes (55.0 vs. 69.1%). With these exceptions, there were no other significant differences in any variables, at any time-point, between children included in the analyses (n=1338) and those that were excluded (n=397) from the original sample. With regards to children who were included, the only predictors of missing data were age and birth season; at each discreet time-point older children and children born in summer/autumn were less likely to have missing data.

Mixed effects regression between sleep duration (exposure) and adiposity as outcomes

Table 4 shows estimated associations from the mixed effects models with sleep duration modelled as the exposure and adiposity indices as outcomes. In South Asian children, sleep duration was inversely and independently associated with all measures of total adiposity except the sum of skinfolds (Model 1). Of the significant associations, standardised β-coefficients ranged from -0.024 (95% confidence interval (CI): -0.047, -0.014) for weight to -0.031 (-0.062, -0.0013) for BMI. For weight and waist circumference the interaction between sleep duration and follow-up time was statistically significant, and the interaction approached statistical significance for BMI and %BF ($p \leq 0.089$), suggesting that the inverse association between sleep duration and adiposity strengthened over time in South Asians. For example, the main effect (β (95% CI)) of sleep duration on waist circumference at 12 months was -

0.028 (-0.064, 0.0081), and -0.070 (-0.14, -0.0038) at 24 months follow-up. This corresponded to a 0.26 (0.014, 0.52) cm reduced waist circumference with 1.4h more sleep at 24 months follow-up. The main effect of sleep duration on %BF was -0.069 (-0.12, -0.017) at 24 months of follow-up, which corresponded to reduced %BF by 0.22 (0.054, 0.38) units for the same amount (1.4h) of sleep. The overall effect of sleep duration on total adiposity indices was robust to further statistical adjustment indicating independence of associations (Model 2). With regards to White children, there were no significant associations between sleep duration and adiposity regardless of the level of adjustment, and no significant interactions between sleep duration and follow-up time. All of the presented results were consistent with crude models and were unchanged in sensitivity analyses.

Mixed effects regression between adiposity (exposures) and sleep duration as the outcome

When sleep duration was modelled as the outcome, inverse independent associations were consistently observed in South Asian children for weight, BMI and %BF (Table 5). The overall effects of adiposity on sleep duration were consistent between Models 1 and 2, and associations were approximately two- to three-fold greater in magnitude compared with reciprocal relations when sleep duration was the exposure. Of the significant associations, adjusted standardised β-coefficients ranged from -0.064 (-0.12, -0.0057) for weight to -0.10 (-0.16, -0.028) for %BF (Model 2). On the original scales, these associations translated to reduced sleep by 5.4 (0.48, 10.1) min/d and 8.4 (2.4, 13.4) min/d for every additional 1.7 kg body weight and 3.2 %BF, respectively. Interactions between adiposity variables and follow-up time were not statistically significant (Model 1a). In South Asian children, no associations were apparent for waist circumference or for the sum of skinfolds, and again no significant associations were observed in White children. All of the presented results were consistent with crude models and sensitivity analyses.

Discussion

This study incorporated repeated data spanning approximately 12 to 36 months of age to investigate associations between parent reported sleep duration and measured adiposity in South Asian and White children from a deprived location. We also evaluated the extent to which these associations changed over time and bidirectionality of associations. We found no significant associations in White children. However, there was evidence of an independent bidirectional relation between sleep duration and adiposity in South Asian children.

Sleep duration as the exposure and adiposity as outcomes

A recent meta-analysis concluded that for every additional hour of daily sleep the annual BMI gain in children and adolescents was lower by 0.05 (0.01, 0.09) kg/m^2, with no appreciable effect modification by age.[2] Our analysis yielded equally modest magnitudes of association: per 1.4 h/day of additional reported sleep the overall main effect in South Asian children was lower BMI by 0.05 (0.0021, 0.10) kg/m^2. We did find, however, that the association strengthened over time, and at 24 months of follow-up the same amount of parent-reported sleep was associated with lower BMI by 0.13 (0.027, 0.24) kg/m^2. The observation that follow-up time modified the association between sleep duration and adiposity may reflect a lag or cumulative effect of short sleep on adiposity.

Few studies have investigated outcomes other than BMI, but similar to this study an investigation of Danish children failed to find an association between infant sleep duration (at 9 and 18 months) and the sum of skinfolds at 36 months. In contrast to our results, however, which may in part be explained by skinfolds representing a different measure of adiposity to height-for-weight indices and circumferences, that small study also reported null associations for fat mass and %BF.[14] In another study, German children who slept more at 18 and 24 months exhibited progressively lower fat mass index levels up to age 7 years compared to children that slept less.[12] Likewise, in a sample of predominantly White Americans, greater sleep curtailment from age 6 months to 7 years was associated with higher total and truncal fat mass index, waist and hip circumference.[16] The current study is the first to be performed in a deprived, bi-ethnic population, and the first from the UK. We uniquely found inverse associations between sleep duration with total and abdominal adiposity in South Asian, but not White children.

Our null results for White children contrast meta-analysed data, but there is considerable inconsistency in the literature, with half of all studies that have investigated sleep duration with continuous BMI as an outcome reporting null results.[1,2] With regards to our observed inverse associations between sleep duration and adiposity in South Asian children, although they are modest in size, it is important to consider that they might be underestimated due to error in parent-reported sleep. It is also conceivable that any positive influence on adiposity levels this early in life may be important, given that adiposity levels rise over the remainder of childhood[59], overweight and obesity track over time[60], and South Asian populations have an increased risk of obesity and metabolic disease.[61]

Adiposity as exposures and sleep duration as the outcome

To our knowledge, just two studies, both conducted with Australian children, have investigated the influence of adiposity on sleep duration. The first reported that BMI measured before 18 months of age was not associated with sleep duration at age 2-3y; an association of sleep predicting BMI was also not found. The same study reported null results in both directions for preschool children from the same cohort (aged 4-5y at baseline and 6-7y at follow-up).[13] Subsequent investigation of the same pre-schoolers found no evidence for an association between baseline BMI and sleep duration at 8-9y in the whole sample, but a significant inverse association was observed when analyses were restricted to children from disadvantaged homes.[15] This supports results from our study, but we uniquely found that indicators of adiposity were inversely associated with reported sleep duration in South Asian children from a deprived location but not White children; for every additional 3.2 %BF sleep was reduced by 8.4 (2.4, 13.4) min/d in South Asians. This may seem clinically insignificant, but concerns have been raised regarding a global 0.75 min/d annual decline in childhood sleep over the 20th century[26], which lower adiposity could seemingly help to counteract. Of note is that the relative magnitude of association between adiposity and sleep duration was greater than the reciprocal association. However, we issue a note of caution before interpreting this to mean that adiposity exerts a greater influence on sleep duration than vice versa. Habitual behaviours like sleep are often subject to greater measurement imprecision than anthropometric data, and this could explain the greater magnitudes of association (and wider CIs) when sleep was the outcome as opposed to the exposure.[62] Despite this measurement conundrum, we have highlighted for the first time that adiposity is both a potential determinant of decreased sleep and a consequence in early childhood.

There are many plausible biological and behavioural explanations to account for the observed inverse associations between sleep duration and adiposity, they have been described comprehensively by others.[63,64] It is noteworthy that the associations reported in this paper were independent of TV-viewing, diet, and physical activity levels, all of which have been proposed as mediating factors.[15,35,65] The associations between adiposity and curtailed sleep may be mediated by poorer general health and physiological disorders such as sleep apnoea.[20,21] But the puzzling question emerging from our results is why were associations observed in South Asian but not White children? Reported sleep durations were largely similar between ethnic groups, and for this reason our first suggestion is that there may be ethnic differences in sleep requirement[66], with South Asians potentially having a greater sleep need than White children. Ethnic differences in the prevalence of paediatric sleep apnoea have also been reported[20], so it may be that South Asian children are more susceptible to obesity-driven sleep apnoea, but this has not been investigated. Another possibility is confounding or residual mediating effects, maybe by factors that are associated with sleep and adiposity in South Asians more so than in Whites, and which we either controlled for inadequately (e.g. parent-reported physical activity) or were unable to control for (e.g. sleep pattern or quality). With regard sleeping patterns, our diary data from a sub-sample highlighted that South Asian children had later bedtimes (median (interquartile range): 9:25pm (80 min) vs. 7:46 pm (55 min)) and were later to rise (8:17am (85min) vs. 7:10am (55 min)) than White children. Others have similarly reported later sleeping in non-White children[7,8] which is a pattern that seems to be associated with higher adiposity.[64] There may have also been ethnic differences in the proportion of total sleep time accumulated overnight. We were unable to differentiate between daytime and nocturnal sleep from the questionnaire reports, but in line with observations that non-White children nap less frequently[7,8] our diary data indicated that South Asian children slept more during the day (1.5 (2.0) h/day vs. 1.0 (1.3) h/day in White children). It has been suggested that daytime sleep is an inadequate substitute for nocturnal sleep[6], and therefore further investigation is needed to establish if these types of sleeping pattern may have confounded our results. Another suggested possibility is differential bias in parent-reported sleep. Co-sleeping is more prevalent in South Asian families[67] meaning that South Asian parents may have reported children's sleep with greater accuracy.

Strengths and weaknesses

This investigation benefited from comprehensive data collection in an ethnically diverse and economically deprived cohort that was followed from birth to 36 months with relatively low attrition.[30] This is an important population to study to improve our understanding of health inequalities and in particular to address the high risk of obesity and cardiometabolic disease in adult South Asian populations[28,29], to which rapid infant growth might contribute. Rapid post-natal growth has been positively associated with child health in low income countries[68], and particularly in preterm and small for gestational age infants is needed to achieve appropriate developmental goals[69], but only 5% of our UK-resident South Asian children were born pre-term (<37 weeks). We accept that proxy reported sleep estimates are subject to measurement error and bias, but objective methods that have been successfully used in older children suffer in this age group from low specificity in identifying night waking. As such, diaries may currently be the optimal method for assessing sleep duration in young children[70], and reassuringly our questionnaire data were correlated with parent-reported diaries that accounted for both daytime napping and broken sleep. We advantageously investigated multiple indicators of total and abdominal adiposity, and although alternative lab-based imaging methods (e.g. DXA) may have provided more accurate measurement of adiposity, a previous study showed consistency in associations regardless of whether DXA-derived outcomes or more feasible anthropometric indices were used.[16] Inevitably there were missing data, which were also found to be patterned by birth season, but our results were unchanged whether or not they were adjusted for this factor. In fact, our results were robust to adjustment for diverse covariates including dietary components and bedtime regularity, which are uncommonly controlled for. It is possible, nevertheless, that confounding still existed in models due to measurement inaccuracy and factors that we were unable to include (e.g. gestational weight gain, sleep patterns and quality). Our analyses focussed on concurrent associations to minimise susceptibility to bias and maximise statistical power. To strengthen claims regarding causality, analyses which manipulate sub-selections of exposure and outcome to investigate early change in exposure with late change in outcome are needed.

Conclusion

Our results provide evidence for bidirectional associations between sleep duration and adiposity in young children, specifically young South Asian children living in the UK. Further investigations are needed to determine whether cyclical episodes of shortened sleep and adiposity gain may cast negative health effects upon South Asian children from an early age.

Acknowledgements

Born in Bradford (BiB) is only possible because of the enthusiasm and commitment of the participating families. We are grateful to all the participants, health professionals and researchers who have contributed to BiB. This paper presents independent research commissioned by the National Institute for Health Research (NIHR) under its Grants for Applied Research Programme (Grant Reference Number RP-PG-0407-10044). The views expressed are those of the author(s) and not necessarily those of the NHS, the NIHR or the Department of Health.

Authors' contributions: PJC conceived this investigation, planned and executed analyses, and wrote the manuscript; GS assisted data management. JWr, SB, RRCM and JWe designed and implemented the cohort. All authors critically revised the manuscript for intellectual content, helped interpret study findings, and read and approved the final manuscript.

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Table 1. Participant demographic and birth characteristics according to ethnic group and categories of sleep duration.

			Sleep duration (h/day)				
South Asian	*N*	Overall	<11 (*N*=54)	11 to <12 (*N*=159)	12 to <13 (*N*=274)	13 to <14 (*N*=192)	>14 (*N*=97)
Gender (*N* (%) boys)	776	389 (50.1)	33 (61.1)	71 (44.7)	147 (53.7)	91 (47.0)	45 (46.4)
Socioeconomic status (*N* (%))							
Least deprived	776	227 (29.3)†††	14 (25.9)	50 (31.5)	85 (31.0)	54 (28.1)	24 (24.7)
Moderately deprived		452 (58.3)	31 (57.4)	81 (50.9)	165 (60.2)	115 (59.9)	60 (61.9)
Most deprived		97 (12.5)	9 (16.7)	28 (17.6)	24 (8.8)	23 (12.0)	13 (13.4)
Maternal pregnancy age (y)	776	27.6 ± 5.2†††	27.8 ± 5.9	28.3 ± 5.4	27.8 ± 5.5	26.8 ± 4.6	27.1 ± 4.6*
Smoked in pregnancy (*N* (%))	776	27 (3.5)†††	1 (1.9)	6 (3.8)	10 (3.7)	9 (4.7)	1 (1.0)
Previous births (*N* (%) multiparous)	776	531 (68.4)†††	37 (31.5)	54 (34.0)	81 (30.0)	69 (36.0)	24 (24.7)
Birth season (*N* (%))							
Spring	776	343 (44.2)†	23 (42.6)	78 (49.1)	127 (46.4)	72 (37.5)	43 (44.3)
Summer/Autumn		148 (19.1)	13 (24.1)	31 (19.5)	58 (21.2)	34 (17.7)	12 (12.4)
Winter		285 (36.7)	18 (33.3)	50 (31.5)	89 (32.5)	86 (44.8)	42 (43.3)
Gestational age (weeks)	776	39.6 ± 1.5	39.4 ± 1.7	39.7 ± 1.5	39.6 ± 1.4	39.5 ± 1.7	39.5 ± 1.4
Birth weight (g)	776	3125 ± 510†††	3132 ± 561	3143 ± 543	3140 ± 459	3067 ± 513	3166 ± 551
Maternal early-pregnancy BMI (kg/m^2)	760	24.2 (6.9)†††	23.5 (6.8)	25.1 (7.2)	24.1 (7.1)	23.5 (6.3)	25.1 (7.5)

			Sleep duration (h/day)				
White	*N*	Overall	<11 (*N*=30)	11 to <12 (*N*=112)	12 to <13 (*N*=250)	13 to <14 (*N*=125)	>14 (*N*=45)
Gender (*N* (%) boys)	562	265 (47.2)	14 (46.7)	53 (47.3)	117 (46.8)	57 (45.6)	24 (53.3)
Socioeconomic status (*N* (%))							
Least deprived	562	279 (49.6)	11 (36.7)	53 (47.3)	134 (53.6)	63 (50.4)	18 (40.0)
Moderately deprived		168 (29.9)	9 (30.0)	36 (32.1)	73 (29.2)	33 (26.4)	17 (37.8)
Most deprived		115 (20.5)	10 (33.3)	23 (20.5)	43 (17.2)	29 (23.2)	10 (22.2)
Maternal pregnancy age (y)	562	26.5 ± 6.0	26.6 ± 6.2	25.9 ± 5.7	26.9 ± 5.8	26.4 ± 6.4	25.9 ± 7.3

Smoked in pregnancy (*N* (%))	562	185 (32.9)	13 (43.3)	30 (26.8)	79 (31.6)	44 (35.2)	19 (42.2)
Previous births (*N* (%) multiparous)	562	289 (51.4)	13 (43.3)	56 (50.0)	128 (51.2)	71 (56.8)	21 (46.8)
Birth season (*N* (%))							
Spring	562	214 (38.1)	6 (20.0)	47 (42.0)	95 (38.0)	48 (38.4)	18 (40.0)
Summer/Autumn		107 (19.0)	11 (36.7)	18 (16.1)	40 (16.0)	24 (19.2)	14 (31.1)
Winter		241 (42.9)	13 (43.3)	47 (42.0)	115 (46.0)	53 (42.4)	13 (28.9)*
Gestational age (weeks)	562	39.6 ± 1.8	39.0 ± 2.2	39.9 ± 1.4	39.6 ± 1.9	39.5 ± 2.0	39.6 ± 1.5
Birth weight (g)	562	3325 ± 564	2989 ± 675	3422 ± 455	3355 ± 569	3300 ± 578	3209 ± 583
Maternal early-pregnancy BMI (kg/m^2)	543	25.5 (7.7)	24.0 (8.1)	25.0 (7.7)	25.6 (7.4)	25.8 (8.2)	24.8 (8.2)

South Asian ethnicity includes Pakistani (*n*=668), Indian (*n*=60), and Bangladeshi (*n*=28); White ethnicity includes British (*n*=535) and Other White (*n*=27). Socioeconomic status groups correspond with Fairley et al.[38] as follows: Least deprived (least socioeconomically deprived and most educated + employed, not materially deprived); Moderately deprived (employed, no access to money + benefits and not materially deprived); Most deprived (most economically deprived). For continuous variables, values are mean ± standard deviation or median (interquartile range) given skewness. $^{\dagger}P\leq0.05$, $^{\dagger\dagger\dagger}P\leq0.001$ for the difference between ethnic groups (chi-square, ANOVA or Kruskal-Wallis test). *$P\leq0.05$ for trend in the variable of interest across sleep categories (regression, skewed variables natural log transformed).

Table 2. Participant behavioural characteristics according to ethnic group and categories of sleep duration.

			Sleep duration (h/day)				
South Asian	*N*	Overall	<11 (*N*=54)	11 to <12 (*N*=159)	12 to <13 (*N*=274)	13 to <14 (*N*=192)	>14 (*N*=97)
Sleep duration (h/day)	776	12.6 ± 1.2	10.1 ± 1.0	11.5 ± 0.3	12.4 ± 0.3	13.3 ± 0.3	14.6 ± 0.8
TV-viewing duration (h/day)							
After 6pm	776	0.38 (0.58)†††	0.25 (0.64)	0.25 (0.38)	0.25 (0.41)	0.25 (0.50)	0.17 (0.36)*
Total	776	1.4 (1.3)†††	1.4 (1.3)	1.6 (1.5)	1.4 (1.3)	1.3 (1.2)	1.2 (1.3)***
Unhealthy snacks (*N*, daily)	776	1.8 (1.6)†††	1.8 (1.8)	1.9 (1.8)	1.7 (1.6)	1.9 (1.6)	1.7 (1.5)
Fruit & veg (daily portions)	776	4.9 ± 1.9†††	4.4 ± 1.8	4.5 ± 1.6	4.7 ± 1.8	5.5 ± 1.9	5.2 ± 2.3***
Solid foods (weeks since birth)	744	21.2 ± 4.4†††	20.9 ± 4.2	21.6 ± 4.1	20.9 ± 4.4	21.0 ± 4.0	21.9 ± 5.1
Breast feeding (weeks since birth)	722	6 (21.4)†††	6 (23.4)	8.7 (32.0)	6 (21.6)	4 (12.0)	6 (19.9)*
Regular bedtime (*N* (%) every day)	653	438 (67.1)	26 (59.1)	80 (57.1)	171 (69.5)	107 (67.7)	54 (83.1)**
Physical activity (h/day)	642	2.9 (1.9)†	2.4 (2.8)	2.7 (2.0)	2.7 (2.6)	2.5 (1.8)	2.4 (2.5)
			Sleep duration (h/day)				
White	*N*	Overall	<11 (*N*=30)	11 to <12 (*N*=112)	12 to <13 (*N*=250)	13 to <14 (*N*=125)	>14 (*N*=45)
Sleep duration (h/day)	562	12.5 ± 1.0	10.3 ± 0.7	11.5 ± 0.3	12.4 ± 0.3	13.2 ± 0.2	14.5 ± 0.6
TV-viewing duration (h/day)							
After 6pm	562	0.25 (0.45)	0.50 (0.54)	0.50 (0.62)	0.35 (0.54)	0.38 (0.60)	0.38 (0.61)*
Total	562	1.1 (1.0)	1.1 (1.1)	1.3 (0.9)	1.1 (0.9)	1.1 (1.1)	1.0 (1.3)
Unhealthy snacks (*N*, daily)	562	1.5 (1.1)	1.7 (1.4)	1.6 (1.0)	1.5 (1.1)	1.6 (1.2)	1.3 (1.1)
Fruit & veg (daily portions)	562	4.5 ± 1.8	4.6 ± 1.5	4.5 ± 1.7	4.5 ± 1.9	4.4 ± 1.8	4.7 ± 2.2
Solid foods (weeks since birth)	537	18.9 ± 4.6	18.9 ± 4.2	19.2 ± 4.1	18.6 ± 4.6	19.2 ± 5.1	18.5 ± 5.0
Breast feeding (weeks since birth)	544	1 (10.5)	0.7 (4.0)	2 (12.5)	1.4 (11.0)	0.4 (8.0)	0.3 (16.0)
Regular bedtime (*N* (%) every day)	457	329 (72.0)	14 (56.0)	63 (65.0)	157 (72.4)	72 (79.1)	23 (85.2)*
Physical activity (h/day)	465	2.6 (2.2)	2.9 (2.1)	2.8 (2.2)	3.0 (1.7)	2.5 (1.7)	3.3 (2.0)

South Asian ethnicity includes Pakistani, Indian, and Bangladeshi; White ethnicity includes British and Other White. For continuous variables, values are mean ± standard deviation or median (interquartile range) given skewness. For sleep duration, TV-viewing, unhealthy snacks, and fruit and vegetables, the values are averages from all time-points. ††† *P*≤0.001 for the difference between ethnic groups (chi-square, ANOVA or Kruskal-Wallis test). **P*≤0.05, ***P*≤0.01, ****P*≤0.001 for trend in the variable of interest across sleep categories (regression, skewed variables natural log transformed).

Table 3. Participant characteristics at each measurement time-point according to ethnic group.

South Asian	*N*	12 months (baseline)	*N*	18 months	*N*	24 months	*N*	36 months
Age (months)	682	12.6 (1.5)	670	18.4 (1.3)	648	25.0 (1.2)	637	36.8 (1.1)
Sleep duration (h/day)	679	13.0 ± 1.9	670	12.6 ± 1.6	646	12.5 ± 1.4	637	11.9 ± 1.2†††,**
TV-viewing (h/day)								
After 6pm	681	0 (0.5)†††	668	0.1 (0.5)†	648	0.5 (0.8)†††	636	0.5 (1.5)†††,***
Total	681	0.5 (0.6)††	668	1.0 (1.5)	648	1.5 (2.1)†††	636	2.0 (2.5)†††,***
Unhealthy snacks (*N*, daily)	682	0.7 (0.9)	670	1.0 (1.2)	648	1.3 (1.6)†††	637	1.8 (2.2)†††,***
Fruit & veg (daily portions)	682	5.1 ± 2.6†††	670	5.1 ± 2.4†††	647	3.6 ± 2.0†††	637	5.1 ± 3.0†††,**
Maternal BMI (kg/m^2)	658	25.8 (7.1)	645	25.4 (6.9)	604	25.8 (7.0)	576	26.5 (6.8)***
Weight (kg)	653	9.7 ± 1.3††	639	11.0 ± 1.5	590	12.4 ± 1.7	591	14.8 ± 2.2***
Height (cm)	647	76.2 ± 3.6††	604	82.4 ± 3.7†	446	87.0 ± 3.6†††	524	95.9 ± 4.1†††,***
BMI (kg/m^2)	639	16.6 ± 1.8†††	596	16.1 ± 1.6†††	360	16.4 ± 1.6††	522	16.1 ± 1.6†††,***
BMI *z*-score (kg/m^2)	639	-0.74 ± 1.4†††	596	-0.71 ± 1.3†††	360	0.17 ± 1.1†††	522	-0.013 ± 1.2†††,***
Fat mass (kg)	639	2.2 ± 0.5†††	596	2.4 ± 0.6††	441	2.7 ± 0.7	522	3.2 ± 1.0***
Fat mass index (kg/m^2)	639	3.8 ± 0.9†††	596	3.5 ± 0.8†††	441	3.6 ± 0.8††	522	3.4 ± 0.9†††,***
Percent body fat	639	22.8 ± 2.8†††	596	21.8 ± 2.8†††	441	21.4 ± 3.2††	522	21.0 ± 3.4†,***
Waist circumference (cm)	572	43.4 ± 3.1†††	529	44.7 ± 3.3†††	400	47.7 ± 3.7††	484	49.9 ± 4.1†††,***
Sum of skinfolds (mm)	475	36.6 (11.2)†††	430	33.4 (8.5)†††	241	31.8 (8.8)	305	28.0 (9.9)†††,***

White	*N*	12 months (baseline)	*N*	18 months	*N*	24 months	*N*	36 months
Age (months)	483	12.7 (1.2)	478	18.4 (1.3)	445	25.0 (1.2)	454	36.8 (1.1)
Sleep duration (h/day)	481	12.9 ± 1.4	477	12.7 ± 1.3	438	12.3 ± 1.4	454	11.7 ± 1.2***

TV-viewing (h/day)								
After 6pm	483	0 (0.5)	477	0 (0.5)	445	0.1 (0.5)	454	0.4 (0.5)***
Total	483	0.5 (1.0)	477	0.9 (1.0)	445	1.0 (1.5)	454	1.5 (1.4)***
Unhealthy snacks (*N*, daily)	483	0.7 (0.8)	478	1.0 (0.9)	445	1.0 (9.5)	454	1.3 (1.2)***
Fruit & veg (daily portions)	483	4.3 ± 2.4	478	4.6 ± 2.2	445	4.9 ± 2.2	454	4.5 ± 2.6
Maternal BMI (kg/m^2)	466	25.6 (9.0)	451	25.5 (9.1)	406	26.1 (9.0)	365	25.5 (7.7)
Weight (kg)	473	9.9 ± 1.2	458	11.2 ± 1.3	423	12.5 ± 1.6	425	14.8 ± 1.9***
Height (cm)	465	75.6 ± 3.5	446	82.0 ± 3.4	364	86.1 ± 3.5	392	94.6 ± 4.1***
BMI (kg/m^2)	463	17.3 ± 1.5	440	16.6 ± 1.4	441	16.8 ± 1.5	387	16.5 ± 1.3***
BMI *z*-score (kg/m^2)	463	-0.15 ± 1.1	440	-0.30 ± 1.0	441	-0.11 ± 1.2	387	0.33 ± 0.9***
Fat mass (kg)	463	2.4 ± 0.5	440	2.5 ± 0.5	360	2.8 ± 0.6	387	3.2 ± 0.7***
Fat mass index (kg/m^2)	463	4.2 ± 0.7	440	3.8 ± 0.7	360	3.7 ± 0.8	387	3.6 ± 0.7***
Percent body fat	463	24.0 ± 2.3	440	22.5 ± 2.4	360	22.0 ± 3.0	387	21.7 ± 3.4***
Waist circumference (cm)	572	44.1 ± 3.0	391	46.0 ± 3.3	330	48.2 ± 3.2	361	50.7 ± 3.4***
Sum of skinfolds (mm)	296	41.4 (13.8)	306	36.0 (9.4)	224	31.8 (8.3)	223	31.8 (8.4)***

South Asian ethnicity includes Pakistani, Indian, and Bangladeshi; White ethnicity includes British and Other White; Values are mean ± standard deviation or median (interquartile range) given skewness. $^{\dagger}P\leq0.05$, $^{\dagger\dagger}P\leq0.01$, $^{\dagger\dagger\dagger}P\leq0.001$ for the difference between ethnic groups at each time-point (ANOVA or Kruskal-Wallis test). $^{**}P\leq0.01$, $^{***}P\leq0.001$ for trend in the variable of interest across time-points (regression, skewed variables natural log transformed). BMI, Body mass index. BMI *z*-scores based on UK reference data from Cole et al. 1995.

Table 4. Associations of sleep duration (exposure) with total and abdominal adiposity (outcomes) from mixed effects models using data at all time-points.

South Asian

Exposure	Outcome	*N* (Observations)	Overall main effect (Model 1)	Interaction effect with follow-up time (Model 1a)	Main effect at 6m follow-up (Model 1a)	Main effect at 12m follow-up (Model 1a)	Main effect at 24m follow-up (Model 1a)	Overall main effect (Model 2)
Sleep duration	Weight	775 (2406)	**-0.024 (-0.047, -0.014)***	**-0.0039 (-0.0063; -0.0016)*****	-0.022 (-0.045, 0.0012)	**-0.045 (-0.071, -0.019)*****	**-0.093 (-0.14, -0.046)*****	**-0.024 (-0.047, -0.0015)***
	BMI	765 (2135)	**-0.031 (-0.062, -0.0013)***	-0.0028 (--0.0061; 0.00039)	**-0.030 (-0.061, -0.00036)***	**-0.047 (-0.083, -0.012)****	**-0.081 (-0.15, -0.017)***	**-0.030 (-0.061, -0.00016)***
	%BF	765 (2135)	**-0.029 (-0.053, -0.0043)***	-0.0022 (-0.0049; 0.00034)	**-0.028 (-0.053, -0.0036)***	**-0.042 (-0.070, -0.013)****	**-0.069 (-0.12, -0.017)****	**-0.029 (-0.053, -0.0042)***
	WC	748 (1923)	-0.0073 (-0.038, 0.023)	**-0.0035 (-0.0068; -0.00022)***	-0.0071 (-0.038, 0.023)	-0.028 (-0.064, 0.0081)	**-0.070 (-0.14, -0.0038)***	-0.0072 (-0.038, 0.023)
	SSF	688 (1418)	-0.016 (-0.062, 0.030)	-0.0028 (-0.0084; 0.0026)	-0.018 (-0.064, 0.027)	-0.036 (-0.095, 0.023)	-0.071 (-0.18, 0.043)	-0.013 (-0.059, 0.033)

White

Exposure	Outcome	*N* (Observations)	Overall main effect (Model 1)	Interaction effect with follow-up time (Model 1a)	Main effect at 6m follow-up (Model 1a)	Main effect at 12m follow-up (Model 1a)	Main effect at 24m follow-up (Model 1a)	Overall main effect (Model 2)
Sleep duration	Weight	562 (1654)	0.0053 (-0.020, 0.031)	0.00022 (-0.0024; 0.0029)	0.0049 (-0.021, 0.031)	0.0062 (-0.022, 0.034)	0.0089 (-0.041, 0.059)	0.0069 (-0.019, 0.033)
	BMI	559 (1534)	-0.0043 (-0.042, 0.033)	-0.0022 (-0.0062; 0.0018)	-0.00056 (-0.039, 0.037)	-0.014 (-0.055, 0.027)	-0.041 (-0.12, 0.034)	-0.0047 (-0.042, 0.033)
	%BF	559 (1534)	-0.00018 (-0.031, 0.031)	-0.0024 (-0.0057; 0.00085)	0.0038 (-0.027, 0.035)	-0.011 (-0.045, 0.023)	-0.040 (-0.10, 0.022)	0.00018 (-0.031, 0.031)
	WC	543 (1384)	0.0023 (-0.044, 0.048)	0.000093 (-0.0049; 0.0051)	0.0022 (-0.044, 0.049)	0.0027 (-0.048, 0.054)	0.0039 (-0.090, 0.098)	0.0035 (-0.042, 0.050)
	SSF	485 (991)	0.011 (-0.063, 0.085)	0.0012 (-0.0074; 0.0098)	0.0098 (-0.065, 0.084)	0.017 (-0.069, 0.10)	-0.032 (-0.13, 0.20)	0.012 (-0.063, 0.086)

Abbreviations: %BF, Percentage body fat, BMI, Body mass index, WC, Waist circumference, SSF, Sum of skinfolds (triceps, subscapular and thigh). South Asian ethnicity includes Pakistani, Indian, and Bangladeshi; White ethnicity includes British and Other White. Results are standardised regression coefficients (95% confidence interval) and should be interpreted as the change in outcome (in SD units) per 1 SD higher value of the exposure. Model 1 is adjusted for baseline age and follow-up time, gender, socio-economic status, parity, gestational age, birth weight, season of birth, maternal pregnancy age, maternal smoking in pregnancy, and maternal follow-up BMI. Model 1a: Model 1 with an interaction term between sleep duration and follow-up time. Model 2: As model 1 but further adjusted for TV-viewing duration, unhealthy snacking, and fruit and vegetable intake. *$P \leq 0.05$, **$P \leq 0.01$, ***$P \leq 0.001$. Significant results are highlighted bold.

Table 5. Associations of total and abdominal adiposity (exposures) with sleep duration (outcome) from mixed effects models using data at all time-points.

South Asian

Outcome	Exposure	*N* (Observations)	Overall main effect (Model 1)	Interaction effect with follow-up time (Model 1a)	Main effect at 6m follow-up (Model 1a)	Main effect at 12m follow-up (Model 1a)	Main effect at 24m follow-up (Model 1a)	Overall main effect (Model 2)
Sleep duration	Weight	775 (2406)	**-0.067 (-0.13; -0.0089)***	0.0011 (-0.0020; 0.0043)	**-0.078 (-0.14; -0.012)***	**-0.071 (-0.13; -0.011)***	-0.057 (-0.12; 0.0076)	**-0.064 (-0.12; -0.0057)***
	BMI	765 (2135)	**-0.072 (-0.13; -0.018)****	-0.00070 (-0.0052; 0.0038)	**-0.070 (-0.13; -0.015)***	**-0.074 (-0.13; -0.018)****	-0.083 (-0.17; -0.0062)	**-0.067 (-0.12; -0.013)***
	%BF	765 (2135)	**-0.097 (-0.16; -0.031)****	-0.00092 (-0.0057; 0.0039)	**-0.094 (-0.16; -0.024)***	**-0.099 (-0.17; -0.032)***	**-0.11 (-0.20; -0.016)***	**-0.10 (-0.16; -0.028)****
	WC	748 (1923)	-0.027 (-0.087; 0.034)	0.00020 (-0.0043; 0.0047)	-0.028 (-0.093; 0.037)	-0.026 (-0.087; 0.035)	-0.024 (-0.11; 0.060)	-0.021 (-0.082; 0.039)
	SSF	688 (1418)	-0.022 (-0.081; 0.038)	-0.0042 (-0.0096; 0.0012)	-0.017 (-0.077; 0.043)	-0.042 (-0.11; 0.023)	-0.092 (-0.20; 0.017)	-0.018 (-0.077; 0.041)

White

Outcome	Exposure	*N* (Observations)	Overall main effect (Model 1)	Interaction effect with follow-up time (Model 1a)	Main effect at 6m follow-up (Model 1a)	Main effect at 12m follow-up (Model 1a)	Main effect at 24m follow-up (Model 1a)	Overall main effect (Model 2)
Sleep duration	Weight	562 (1654)	0.030 (-0.041; 0.10)	-0.0021 (-0.0055; 0.0014)	0.047 (-0.029; 0.12)	0.035 (-0.036; 0.11)	0.0099 (-0.068; 0.088)	0.031 (-0.040; 0.10)
	BMI	559 (1534)	0.0046 (-0.056; 0.065)	-0.0029 (-0.0082; 0.0023)	0.010 (-0.051; 0.071)	-0.0075 (-0.072; 0.057)	-0.043 (-0.15; 0.062)	0.0047 (-0.056; 0.065)
	%BF	559 (1534)	0.0060 (-0.070; 0.081)	-0.0030 (-0.0084; 0.0023)	0.017 (-0.061; 0.095)	-0.0013 (-0.078; 0.075)	-0.038 (-0.15; 0.070)	0.0079 (-0.068; 0.084)
	WC	543 (1384)	0.013 (-0.045; 0.071)	-0.00060 (-0.0048; 0.0036)	0.015 (-0.045; 0.075)	0.012 (-0.047; 0.071)	0.0046 (-0.080; 0.089)	0.014 (-0.045; 0.072)
	SSF	485 (991)	0.0034 (-0.048; 0.055)	0.0020 (-0.0038; 0.0078)	0.0058 (-0.046; 0.058)	0.018 (-0.049; 0.084)	0.042 (-0.081; 0.16)	0.0043 (-0.047; 0.056)

Abbreviations: %BF, Percentage body fat, BMI, Body mass index, WC, Waist circumference, SSF, Sum of skinfolds (triceps, subscapular and thigh). South Asian ethnicity includes Pakistani, Indian, and Bangladeshi; White ethnicity includes British and Other White. Results are standardised regression coefficients (95% confidence interval) and should be interpreted as the change in outcome (in SD units) per 1 SD higher value of the exposure. Each adiposity parameter was included in a separate model. Model 1 is adjusted for baseline age and follow-up time, gender, socio-economic status, parity, gestational age, birth weight, season of birth, maternal pregnancy age, maternal smoking in pregnancy, and maternal follow-up BMI. Model 1a: Model 1 with an interaction term between adiposity and follow-up time. Model 2: As model 1 but further adjusted for TV-viewing duration, unhealthy snacking, and fruit and vegetable intake. *$P \leq 0.05$, **$P \leq 0.01$. Significant results are highlighted bold.