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PEDIATRIC ORIGINAL ARTICLE

Associations among late chronotype, body mass index and dietary behaviors in young adolescents

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BACKGROUND/OBJECTIVES: Levels of pediatric obesity continue to rise. Previous evidence has linked short sleep duration and/or poor sleep quality to obesity development, although objective data are limited. As adolescents transition through puberty, circadian shifts occur, resulting in sleep loss. However, little is known whether chronotype is associated with body mass index (BMI) or dietary behaviors in adolescents. We hypothesized late chronotype would be positively associated with BMI and poorer dietary behaviors.

SUBJECTS/METHODS: A total of 511 UK young adolescents (11–13 years) from eight secondary schools across the Midlands region (UK) participated in the Midlands Adolescent Schools Sleep Education Study (MASSES), a cross-sectional study to assess potential relationships between chronotype and BMI *z*-score as well as dietary habits. Height (cm) and weight (kg) were objectively measured for BMI calculation and participants completed a questionnaire to assess dietary habits. A subsample of 236 adolescents wore wrist actigraphy for 7 days to estimate average sleep duration (weekday, weekend and combined) and sleep efficiency.

RESULTS: Definitely evening chronotype was positively associated with BMI *z*-score compared to definitely morning chronotypes $\beta = 0.51$, $P < 0.01$, after adjustment. Higher frequency of consuming unhealthy snacks, night-time caffeine consumption and inadequate daily intake of fruit/vegetables were also associated with later chronotype (all $P \leqslant 0.01$). Actigraphy estimated sleep duration was an independent predictor of BMI *z*-score $\beta = -0.36$, $P < 0.001$. Sleep efficiency did not predict BMI *z*-score after adjustment, $\beta = -0.03$, $P = 0.07$.

CONCLUSIONS: Later chronotype young adolescents are at risk of increased BMI and poorer dietary behaviors. Although short sleep duration, but not sleep efficiency, was also an independent risk factor for increased BMI, different mechanisms may be driving the late chronotype and shorter sleep duration associations with BMI in this age group. Sleep hygiene education may help adolescents to better understand the impact of sleeping habits on physical health.

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INTRODUCTION

Obesity currently poses the greatest public health challenge, and is associated with increased morbidity and mortality.[1] Although obesity clearly results because of energy imbalance, the factors that affect food intake and energy expenditure are incompletely understood. A growing body of evidence suggests that sleep duration[2] and quality[3] as well as the circadian system[4] play important roles in metabolic regulation that may predispose to obesity.

Experimentally induced disruptions to the circadian system have been previously associated with alterations in metabolic hormone secretion and eating behaviors.[5–7] Societal behaviors are, to some extent, reflective of experimental sleep investigations, but to a milder degree, with individuals choosing later bed times and waking earlier due to work/school and/or lifestyle demands. These personal or societally imposed sleep/wake behaviors result in ‘circadian misalignment’ and sleep reduction. Interestingly, a recent review of the data suggested that shift workers, with circadian misalignment, had a higher incidence of metabolic disease.[8]

Adolescence is a vulnerable period for obesity, but little is known about the impact of sleep and the circadian system in adolescent obesity. Adolescents commonly experience circadian disruption due to conflict between their biological clocks and social and environmental factors (also termed ‘social jetlag’).[9] Little is known, however, about the relationships between circadian misalignment and metabolic disease in adolescents, who frequently experience circadian disruption, and have become increasingly susceptible to the development of metabolic disease.

It is possible that circadian preference (chronotype, usually subjectively reported as: ‘definitely morning’, ‘more morning than evening’, ‘more evening than morning’ or ‘definitely evening’), which may determine sleep-wake timings as well as short sleep duration and/or poor sleep quality, could be independently associated with metabolic disease. Previous work has confirmed the relationship between later self-reported chronotype and type 2 diabetes mellitus in a small patient population.[6] Another group investigated the impact of sleep duration and social jetlag on overweight/obesity in a large sample of adolescents and adults and found that social jetlag was a better predictor of overweight/obesity.[10] To date, however, there are no studies that have assessed the potential association between objectively verified chronotype and body mass index (BMI) as well as dietary behaviors in young adolescents. This group is vulnerable to obesity development and usually has later circadian preferences, which results in sleep deprivation. There is growing evidence to suggest that both short sleep duration and sleep quality, may contribute to various obesity markers and

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obesity development.[2,11–13] Chaput and Tremblay[14] also showed that short sleep duration was significantly associated with increased central adiposity, determined by waist circumference, in a large sample of children. This however, requires confirmation through utilization of objective sleep and obesity measures in adolescents, given that 80% of the 15 sleep–obesity adolescent studies in a recent review used subjective sleep measures.[15] The combination of chronic sleep reduction, poor sleep quality and circadian disruption may be crucial for a comprehensive understanding of the sleep–obesity association and has been recently explored, suggesting that other sleep aspects, aside from sleep duration, may be important for a better understanding of obesity. Buxton *et al.*[5] demonstrated that the combination of chronic sleep restriction (5.6 h per night for 3 weeks) and circadian disruption (recurring 28-h days) resulted in several metabolic alterations including (1) a 32% reduction in insulin secretion leading to inadequate glucose regulation; and (2) an 8% reduction in resting metabolic rate, which the authors claim would translate into ~ 12.5 lb increased weight across a 1-year time frame. Roenneberg *et al.*[10] showed a stronger sleep–obesity effect for weekday sleep duration compared to 'non-work' days and also reported social jetlag as a stronger predictor of overweight/obesity compared to sleep duration. There is further support for a chronotype-BMI link from Culnan *et al.*[16] who reported a small but significant 8-week longitudinal weight gain in those with later chronotypes from a small sample ($n = 54$) of young adults (> 18 years). There are, however, no studies that has specifically focused on adolescents and the studies that are available have not objectively examined sleep timings in a free-living environment.

The primary aim of our study was to assess if chronotype was associated with BMI *z*-score in a large sample of young adolescents. The secondary aims were to investigate if chronotype was associated with poorer dietary behaviors as well as to assess objective measures of sleep duration (weekday, weekend and combined) and sleep efficiency in relation to BMI *z*-score. Finally, we also explored the association between subjective chronotype with objective sleep-wake times through wrist actigraphy. We hypothesized (1) evening chronotype young adolescents would have a higher BMI *z*-score and poorer dietary behaviors; (2) objectively determined sleep duration and sleep efficiency would be negatively associated with BMI *z*-score; and (3) subjective chronotype may be validated with objective sleep-wake timings using wrist actigraphy.

MATERIALS AND METHODS

Study population

Eight schools were randomly selected and recruited to participate in the Midlands Adolescents Schools Sleep Education Study. Parents of registered students were posted a letter regarding study participation. Student participants were only included for study participation if they had parental consent, provided personal written consent, did not have a diagnosed sleep disorder, were not taking sleep medication, or had not travelled to a different time zone 4 weeks prior to data collection. A total of 1113 parents of year 7 and year 8 students from participating schools were contacted. The overall parental response rate was 80% ($n = 890$). A total of 842 (95%) positive parental consents were obtained. Of those eligible, 8% were absent at the time of data collection, 3% were excluded due to exclusion criteria, 9% of students did not consent and 1% was unable to attend due to other curricular activities. The total sample included 664 (79%) participants who provided data in Spring 2012. Complete information on all variables of interest was available in 511 (77%), and was used for subsequent analyses. There were no statistically significant differences between participating and non-participating students for age, gender or ethnicity ($P > 0.05$). All participants were aged between 11 and 13 years and registered in UK education. Information regarding school type (secondary/grammar/independent), ethnicity (Caucasian/south Asian/other) and gender were ascertained. Ethical approval was granted from the University of Birmingham Research Ethics Committee (ERN_08-437).

Assessments

Participants completed an online survey including the previously validated Cleveland Adolescent Sleepiness Questionnaire comprising 16 items,[17] which were summed to provide a score to indicate the level of daytime sleepiness. Higher scores indicate a higher level of daytime sleepiness. A subsample ($n = 236$) of randomly selected participants (46%) wore wrist actigraphy (GT3X+, Actigraph, Pensacola, FL, USA) on their non-dominant wrist for 7 consecutive days per nights across each 24-h period to acquire average estimates for weekday (calculated by adding sleep duration for Sunday through Thursday/5), weekend (calculated by adding Friday and Saturday/2) and combined sleep duration (calculated by adding Sunday through Saturday/7). The GT3X+ wrist actigraphy has been previously validated against polysomnography.[18,19] A trained researcher obtained objective measures of (1) height using a portable stadiometer where participants were measured without shoes to the nearest 0.5 cm and (2) weight to nearest 0.1 kg using regularly calibrated scales where participants stood without shoes in light indoor clothing. Height and weight were used for subsequent calculation of BMI *z*-score. To determine parental obesity, we asked the question: 'Do either of your parents have a history of overweight/obesity?' (yes/no/don't know). We also asked one question from the previously validated Morningness Eveningness Questionnaire[20] to determine circadian preference (definitely morning/more morning than evening/more evening than morning/definitely evening). As an indicator of depression and anxiety, we asked the following two questions, from the Schools Sleep Habits Survey[21]: 'During the last two weeks, how often were you bothered by the following?' (1) feeling unhappy, sad or depressed; and (2) feeling nervous or tense (a lot/somewhat/not at all). We also asked the following questions concerning dietary behaviors, based on previous studies,[22,23] to assess potential associations with chronotype as well as consideration of these as potential confounders in our regression analyses: (1) How often do you eat unhealthy foods/snacks (crisps, chocolate, biscuits, cake, sweets, etc.)? (daily/almost daily/sometimes/rarely); (2) How many portions of fruit and vegetables do you eat each day? (0/1–2/3–4/5+); and (3) Before you go to bed, do you drink caffeinated beverages such as tea/coffee/fizzy drinks? (never/sometimes/usually/always).

Statistical analyses

Continuous data were checked for distribution and parametric tests were performed on normally distributed data. Non-parametric tests were performed and reported for non-normally distributed data. We performed a one-way analysis of variance to assess mean differences between four chronotype categories and BMI *z*-score. We then performed linear regression analysis to allow for adjustment of potential confounders to assess the same relationship. We also tested for an interaction effect between sleep duration and chronotype. We then conducted chi square analyses to examine potential differences in categorical variables for three dietary behaviors and four chronotype categories. Pearson's bivariate correlations were performed and coefficients reported to assess the association between actigraphy-estimated average sleep duration (weekday, weekend and combined) and sleep efficiency with BMI *z*-score. Further, linear regression was then used for both aspects of sleep to allow for adjustment of potential confounders. Four categories of chronotype were then combined to form a dichotomous variable ((definitely morning/morning more than evening) and (evening more than morning/definitely evening)) to allow independent *t*-test analyses to assess the mean difference between morning/evening types with average actigraphy estimated sleep/wake times. All statistical analyses were performed using IBM SPSS Statistics Version 20 (IBM Corp., Armonk, NY, USA).

RESULTS

Information regarding the study sample characteristics according to chronotype is shown in Table 1. The mean age of the sample was 12.0 ± 0.7 years and there were more females (58.5%) than males. The highest proportion of participants was registered at secondary school, the most common type of school in the UK. The average BMI (kg m^{-2}) *z*-score was 0.03 ± 0.99. Almost 49% of the sample rated themselves as being more evening than morning chronotype and 15.3% considered themselves to be definitely an evening chronotype.

Table 1. Sample characteristics of 511 young adolescents according to chronotype

	Definitely morning (n = *44*)	*Morning more than evening* (n = *139*)	*Evening more than morning* (n = *250*)	*Definitely evening* (n = *78*)
Age (years)	11.8 ± 0.7	12.0 ± 0.7	12.0 ± 0.7	12.2 ± 0.7
Gender				
Male	23 (52.3)	63 (45.3)	99 (39.6)	27 (34.6)
Female	21 (47.7)	76 (54.7)	151 (60.4)	51 (65.4)
School type				
Secondary	25 (56.8)	63 (45.3)	165 (66.0)	47 (60.3)
Grammar	3 (6.8)	21 (15.1)	28 (11.2)	5 (6.4)
Independent	16 (36.4)	55 (39.6)	57 (22.8)	26 (33.3)
Ethnicity				
Caucasian/European	21 (47.8)	90 (64.7)	135 (54.0)	41 (52.6)
South Asian	17 (38.6)	33 (23.7)	75 (30.0)	20 (25.6)
Other	6 (13.6)	16 (11.6)	40 (16.0)	17 (21.8)
BMI *z*-score	− 0.36 ± 0.81	− 0.11 ± 0.93	0.02 ± 1.01	0.14 ± 1.06
Weekday sleep duration[a]	7.48 ± 0.64	7.39 ± 0.65	7.46 ± 0.74	7.41 ± 0.71
Weekend sleep duration[a]	7.55 ± 0.83	7.34 ± 0.74	7.44 ± 0.93	7.64 ± 1.16
Combined sleep duration[a]	7.51 ± 0.59	7.38 ± 0.59	7.45 ± 0.66	7.47 ± 0.69
Sleep efficiency %[a]	86 (83–89)	84 (79–89)	86 (84–90)	86 (84–90)
CASQ score	29 (21–36)	28 (23–34)	28 (24–34)	29 (24–35)
Unhealthy snack frequency				
Daily	9 (20.5)	19 (13.7)	46 (18.4)	27 (34.6)
Almost daily	11 (25.0)	37 (26.6)	77 (30.8)	18 (23.1)
Sometimes/rarely	24 (54.5)	83 (59.7)	127 (50.8)	33 (42.3)
Daily fruit and vegetable consumption				
0–2	13 (29.5)	36 (25.9)	111 (44.4)	33 (42.3)
3–4	20 (45.5)	75 (54.0)	104 (41.6)	33 (42.3)
⩾5	11 (25.0)	28 (20.1)	35 (14.0)	12 (15.4)
Night-time caffeine consumption				
Never	26 (59.0)	101 (72.7)	146 (58.4)	38 (48.7)
Sometimes	9 (20.5)	27 (19.4)	75 (30.0)	22 (28.2)
Usually/always	9 (20.5)	11 (7.9)	29 (11.6)	18 (23.1)
Family history of obesity				
Yes	2 (4.6)	15 (10.8)	14 (5.6)	8 (10.3)
No	28 (63.6)	84 (60.4)	162 (64.8)	51 (65.3)
Don't know	14 (31.8)	40 (28.8)	74 (29.6)	19 (24.4)
Unhappy/sad/depressed				
A lot	10 (22.8)	11 (7.9)	31 (12.4)	10 (12.8)
Somewhat	13 (29.5)	54 (38.8)	92 (36.8)	30 (38.5)
Not at all	21 (47.7)	74 (53.2)	127 (50.8)	38 (48.7)
Nervous or tense				
A lot	11 (25.0)	14 (10.0)	22 (8.8)	11 (14.1)
Somewhat	18 (40.9)	55 (39.6)	102 (40.8)	31 (39.7)
Not at all	15 (34.1)	70 (50.4)	126 (50.4)	36 (46.2)

Abbreviations: BMI, body mass index; CASQ, Cleveland Adolescent Sleepiness Questionnaire. Data are presented as mean ± s.d., median (interquartile range) or *n* (%), as appropriate. [a]$n = 236$ with data presented in minutes.

We confirmed self-reported chronotype with average actigraphy estimated bed/wake times. Independent *t*-tests verified the average bedtime for morning and evening chronotypes was 2114 hours and 2129 hours ($P = 0.012$), respectively for weekdays. Average wake time for morning and evening chronotypes was 0644 hours and 0653 hours ($P = 0.008$), respectively for weekdays. However, assessment of weekend sleep/wake time, when adolescents have more autonomy and flexibility to select sleep-wake timings, a greater difference was observed. Average bedtime for morning and evening chronotypes was 2159 hours and 2348 hours ($P < 0.001$) and average wake times revealed more than 1-h difference for morning and evening chronotype 0835 hours and 0947 hours ($P < 0.001$), respectively.

Results of the one-way analysis of variance showed a significant mean difference between chronotype and BMI *z*-score F = 3.03 (3), $P = 0.029$. In particular, Bonferroni *post hoc* tests demonstrated significant mean differences between definitely evening chronotypes who had higher average BMI *z*-score compared to definitely morning chronotypes 0.14 ± 1.06 and − 0.36 ± 0.81 ($P = 0.04$), respectively. Our linear regression analyses (Table 2), after adjustment, demonstrated that both evening chronotypes (definitely evening, more evening than morning) had a significant increase in BMI *z*-score compared to those who rated themselves as definitely morning chronotypes $\beta = 0.51$, $P < 0.01$ and $\beta = 0.36$, $P < 0.05$, respectively. A dose-dependent linear relationship was also observed between chronotype and BMI *z*-score $P = 0.02$; however, no interaction effect was found between sleep duration and chronotype ($P > 0.05$).

Chi square analysis revealed a significant association of all dietary behaviors investigated and chronotype. Unhealthy snacking consumption, fruit and vegetable intake and night-time caffeine consumption were all significantly associated with chronotype $\chi^2 = 16.28$ (6), $P = 0.012$, $\chi^2 = 16.45$ (6), $P = 0.012$ and $\chi^2 = 20.87$ (6), $P = 0.002$, respectively. Of those who consumed unhealthy snacks on a daily basis, 45.5% were evening more than morning chronotype, 26.7% were definitely evening chronotype, 18.8% were more morning than evening, and just 8.9% were definitely morning types. Similarly, the majority of the sample who had inadequate daily fruit and vegetable intake were evening more than morning types (57.5%), 17.1% were definitely evening types, 18.7% were more morning than evening types and just 6.7% classified themselves as definitely morning types. Those who usually/always consumed caffeine at night-time 43.9% were evening more than morning types, 26.9% were definitely evening types, 16.4% were more morning than evening types and 13.4% were definitely morning types.

Pearson's bivariate correlations showed a significant negative relationship between all measures of actigraphy estimated average sleep duration and objectively determined BMI *z*-score. The strongest effects were observed in average combined sleep duration ($r = -0.28$, $P < 0.001$) then average weekday sleep duration ($r = -0.27$, $P < 0.001$), followed by average weekend sleep duration ($r = -0.17$, $P = 0.011$). Sleep efficiency was negatively associated with BMI *z*-score ($r = -0.16$, $P = 0.04$). Our linear regression analyses confirmed some of these associations (Table 3). After adjustment, unstandardized beta coefficients for average weekday, weekend and combined actigraphy estimated sleep duration and BMI *z*-score were $\beta = -0.36$, $P < 0.001$; $\beta = -0.11$, $P > 0.05$; and $\beta = -0.36$, $P < 0.001$, respectively. Sleep efficiency was not, however, significantly associated with BMI *z*-score after adjustment.

Table 2. Linear regression analyses to assess the potential association between chronotype and body mass index *z*-score in 511 young adolescents

	Model 1	*Model 2*	*Model 3*
More morning than evening	0.25 (0.17)	0.30 (0.17)	0.33 (0.17)
More evening than morning	0.38 (0.16)*	0.35 (0.16)*	0.36 (0.16)*
Definitely evening	0.52 (0.19)**	0.49 (0.19)**	0.51 (0.19)**

Data are presented as unstandardized beta coefficients (standard error). Model 1: unadjusted. Model 2: adjusted for age, sex, ethnicity and school type. Model 3: further adjusted for dietary behaviors, parental obesity, daytime sleepiness, depression and anxiety. Reference category is definitely morning type. *$P < 0.05$; **$P < 0.01$.

DISCUSSION

Our study is the first to assess the potential association between objectively verified chronotype and BMI in a large sample of young adolescents. We demonstrate that evening chronotypes had a small and significantly higher BMI compared to definitely morning types. Furthermore, we observed significant associations between three poor dietary behaviors and evening chronotype in our sample. We were also able to objectively show that each additional hour of weekday sleep was associated with a small but significant reduction in BMI. Finally, we also validated subjective chronotype through objectively determined sleep-wake timings using wrist actigraphy and while weekday timings were statistically significant the difference was weak in magnitude with stronger observations for weekend timings.

Metabolic and hormonal dysfunction, as a result of circadian disruption, has been previously demonstrated. A recent study, conducted in a small sample of healthy individuals, experimentally induced circadian disruption combined with sleep restriction for 21 days/nights. Exposure to this protocol resulted in decreased resting metabolic rate and increased plasma glucose concentrations after a standardized meal as a consequence of insufficient pancreatic insulin production.[5] Scheer *et al.*[24] also demonstrated the effects of experimental circadian misalignment following a 10-day laboratory protocol. Circadian misalignment was associated with significantly decreased leptin, increased glucose despite an increase in the production of insulin. Furthermore, cardiovascular effects were also observed with an increase in mean arterial pressure reported.[24] One recent study, conducted in a patient population of those with type 2 diabetes mellitus, also supports these experimental findings.[6] Reutrakul *et al.*[6] showed that later chronotype as well as larger dinner portions were associated with poorer glycemic control, independent of sleep disturbance. Our findings, from a young adolescent population, also provide support for an association between evening chronotype and increased BMI, which may have clinical implications for overweight and/or obese individuals. Health advice/campaigns may need to target sleep habits through suggestions of earlier sleep timings in young, obese adolescents. This may, in turn, regulate appetite and improve eating behaviors, although our findings are tentative and require further longitudinal investigation.

Our findings also show that poor dietary behaviors such as higher frequency of night-time caffeine consumption, inadequate daily fruit and vegetable intake as well as higher consumption of unhealthy snacks were related to evening chronotypes. It is possible that young adolescents with evening chronotype preferences have unhealthier eating habits, which undoubtedly play a crucial role in development of obesity as a consequence of energy imbalance. Although it is unclear why those with evening preferences may be more likely to have increased BMI, mechanistically, it is possible that young adolescents with later bed times, forced to rise early for school commitments, are also sleep deprived as a result. In turn, alterations in appetite regulating hormones such as leptin and ghrelin may occur[2] and result in unhealthy eating behaviors and later obesity, although this needs

Table 3. Linear regression analyses to assess the potential association between sleep duration (hours), sleep efficiency and body mass index *z*-score in 236 young adolescents

	Model 1	*Model 2*	*Model 3*
Weekday sleep duration	−0.38 (0.09)***	−0.40 (0.09)***	−0.36 (0.09)***
Weekend sleep duration	−0.18 (0.07)*	−0.14 (0.07)*	−0.11 (0.07)
Combined sleep duration	−0.43 (0.10)***	−0.41 (0.10)***	−0.36 (0.10)***
Sleep efficiency	−0.03 (0.02)*	−0.03 (0.02)	−0.03 (0.02)

Data are presented as unstandardized beta coefficients (standard error).Model 1: unadjusted. Model 2: adjusted for age, sex, ethnicity and school type. Model 3: further adjusted for dietary behaviors, parental obesity, daytime sleepiness, depression and anxiety. *$P < 0.05$; ***$P < 0.001$.

to be verified, particularly in adolescent populations. However, we observed no interaction effect between sleep duration and chronotype in our study, suggesting there are different mechanisms at play for body weight regulation, which need to be separately investigated.

Adolescent sleep–obesity studies are inconsistent[25–30] and have mostly relied upon self-reported sleep information[25,26,28–30] and sometimes even height and weight for BMI calculation.[26] Our study showed a significant negative association between objectively estimated sleep duration and objectively determined BMI. The strongest effect was observed for weekday sleep duration, which is when adolescents are most likely to experience sleep loss. Alterations in metabolic hormones (leptin and ghrelin), commonly observed in those who sleep less, are likely to play an important role in this relationship, as demonstrated by large population studies.[2,12] Laboratory studies are also consistent with these findings.[11,31] Adolescent sleep and dietary intake in a free-living environment was comprehensively examined by Weiss *et al.*[32] who reported those sleeping <8 h consumed a significantly higher proportion of calories from fats compared to those with a nocturnal sleep of >8 h. Recent experimental work in a small sample ($n=41$) of older adolescents (14–16 years) participated in a crossover design, which included five nights of sleep restriction and five nights of 10 h of sleep opportunity with a 24-h food recall. Beebe *et al.*[33] reported significantly elevated glycemic index, carbohydrates, calories and sweet food types in those with sleep restriction compared to those with a healthy sleep opportunity. Further recent work in older adolescents ($n=21$, mean age 16.8 years) in a randomized crossover study incorporated three nights of 4-h sleep opportunity and three nights of 9-h sleep opportunity in the laboratory. The authors demonstrated increased levels of fasting insulin (59%, $P=0.001$), and insulin resistance (65%, $P=0.002$) and 24% reduced epinephrine ($P=0.013$) following sleep restriction compared to adequate sleep duration opportunity.[34] Although the literature surrounding a link between short sleep duration and metabolic disruption continues to grow, it is likely that other mechanisms and factors are driving the relationship between metabolic disruption and sleep timing although this is yet to be explored in detail. It is plausible to hypothesize that the cyclic variability in sleep/wake timings across weekdays and weekends in adolescents may play a crucial role with a disrupted and challenged circadian regime potentially driving metabolic alteration and later metabolic disease.

Our study examined the potential relationship between chronotype and BMI in young adolescents, vulnerable to obesity development and circadian disruption. Benefits of the study include the large sample size, actigraphy validated chronotype along with objectively determined sleep duration and BMI. We also acknowledge that our study has some limitations including the cross-sectional nature, which does not allow for us to determine temporal relationships. Our sample of young adolescents had a relatively low rate of overweight/obesity prevalence (8.6%) compared to average UK obesity rates in those aged 11–13 years, where the prevalence is ~13.9%.[35] We acknowledge that measures of chronotype, depression and anxiety were derived from single questions. However, our study is the first to verify chronotype with objective sleep-wake timings through wrist actigraphy. We did not exclude individuals with attention deficit hyperactivity disorder from our sample although from the consented students, only nine had this diagnosis (based on school records), of which we are unable to determine how many participated due to data protection laws within the schools. However, in our analyses we did adjust for the potential of psychological illness such as depression and anxiety, which are known to effect sleep and may also be associated with attention deficit hyperactivity disorder. Future studies could incorporate blood samples to determine differences and/or alterations in appetite regulating hormones, allowing comparisons between those with morning versus evening circadian preferences. For example, it is plausible that levels of hunger-promoting hormones may be elevated in those with later circadian preference and/or chronic sleep loss although this is currently unknown, particularly in adolescents, and warrants investigation.

In conclusion, our study demonstrates that later chronotype preferences in young adolescents are associated with higher BMI and poorer dietary behaviors. Our data also support the negative relationship between sleep duration and BMI in young adolescents, using objective measures. There is a need for the investigation of the role of circadian regulatory systems in the regulation of body weight and metabolism. Understanding the contributions of sleep duration and circadian regulation to body weight regulation will inform future interventions for tackling the rising levels of obesity.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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