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ORIGINAL ARTICLE

Exploring the complex pathways among specific types of technology, self-reported sleep duration and body mass index in UK adolescents

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OBJECTIVE: To examine the independent associations between sleep duration, four technology types (computer use, mobile telephones, TV viewing and video gaming) and body mass index (BMI) *z*-score. We propose a theoretical path model showing direct effects of four technology types on BMI *z*-score and sleep duration as well as the indirect effects of each technology on BMI *z*-score while considering sleep duration as a mediator.
METHODS: Consenting adolescents ($n = 632$; 63.9% girls, aged 11–18 years) were recruited to the Midlands Adolescent Schools sleep Education Study. The School Sleep Habits Survey (SSHS) and Technology Use Questionnaire (TUQ) were administered. Objective measures of height (cm) and weight (kg) were obtained for BMI *z*-score calculation.
RESULTS: Weekday use of all technology types was significantly associated with reduced weekday sleep duration after adjustment (β (computer use) $= -0.38$, $P < 0.01$; β (mobile telephone) $= -0.27$, $P < 0.01$; β (TV viewing) $= -0.35$, $P < 0.01$; and β (video gaming) $= -0.39$, $P < 0.01$). Use of all technology types, with the exception of mobile telephones, was significantly associated with increased BMI *z*-score after adjustment (β (computer use) $= 0.26$, $P < 0.01$; β (TV viewing) $= 0.31$, $P < 0.01$; and β (video gaming) $= 0.40$, $P < 0.01$). Our path model shows that weekday sleep duration was significantly and negatively associated with BMI *z*-score ($\beta = -0.40$, $P < 0.01$).
CONCLUSION: Weekday sleep duration potentially mediates the effects of some technologies on BMI *z*-score. If confirmed, improving sleep through better management of technology use could be an achievable intervention for attenuating obesity.

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Keywords: adolescence; sleep; technology use

INTRODUCTION

Although the importance of sleep to childhood and adolescent growth and development is increasingly appreciated, inadequate sleep duration appears to be common among adolescents. The US National Sleep Foundation (NSF, 2006) recommends an optimal adolescent sleep duration of at least 9 h per night,[1] but their most recent poll showed that 61% of adolescents obtained <8 h of sleep on weekdays.[2] Adolescent sleep loss is, in part, a consequence of societal demands (for example, early school times) superimposed on physiological changes in the adolescent sleep–wake cycle.[3]

Adolescent sleep loss appears to be exacerbated by the use of technology devices.[4] TV viewing,[5] internet use,[6] video gaming[7,8] and mobile telephone use[9,10] have been associated with reduced sleep duration,[5] delayed sleep onset,[5,7] tiredness[9] and/or increased sleep disturbance.[8,10] Technology use before bedtime may affect sleep adversely through several potential mechanisms including light exposure with delayed melatonin release[11] and cognitive processes, resulting in an increased desire for continued use rather than sleep initiation.[12]

Meta-analyses have shown an association between short sleep duration and obesity in all age groups.[13,14] The relationship between short sleep duration and overweight/obesity in adults has been previously related to metabolic hormone alterations associated with hunger and appetite.[15–17] The sleep–obesity relationship in adolescents is less clear with heterogeneous findings. Adolescent sleep–obesity data are either limited to smaller samples[18] or show no longitudinal relationship with self-reported weight and height, used to calculate body mass index (BMI).[19] No sleep–obesity relationship was observed through utilisation of time diaries, although the association was observed with self-reported sleep duration in the same sample.[20] No data are available regarding the sleep–obesity relationship in UK adolescents. We therefore sought to investigate this in a large sample of adolescents in the UK Midlands region, where rates of obesity are the highest in Europe and present a major public health problem.

TV viewing has been consistently associated with overweight in children[21,22] and adolescents.[23] Although one study of 9–14 year olds demonstrated video gaming to be longitudinally associated with increased BMI,[24] the findings remain inconsistent with a recent randomised controlled trial showing beneficial effects of active video gaming on body weight compared with inactive gaming.[25] Interestingly, use of other technologies that may

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promote sedentariness, such as computer use, has shown no relationship with overweight in children.[21] Relationships between obesity and other technology types, however, are lacking, particularly in heavily immersed/high ownership groups such as adolescents. Although both sleep and the use of some technologies have been associated with excess body weight,[13,21] and various technologies have been shown to adversely affect sleep,[7,9] the complex interactions and pathways among these variables have not yet been explored but may be crucial for understanding and tackling obesity. We therefore sought to examine the independent associations between the use of four technology types and sleep duration as well as the relationship between sleep duration and BMI *z*-score in UK adolescents. We hypothesised that technology use (computer use, mobile telephones, TV viewing and video gaming) before bedtime would result in altered sleep duration and that insufficient sleep would alter BMI *z*-score. We also sought to examine the pathways between four technology types and BMI *z*-score while considering sleep duration as a potential mediator.

MATERIALS AND METHODS

Study population

Data were drawn from six schools across the UK Midlands region, all with similar start times (0820–0840 h). We aimed to include a number of schools with students from a variety of socioeconomic groups. A total of 1043 students across the six schools were invited to take part in the study. Of those invited to participate, 177 were excluded because of meeting $\geqslant 1$ exclusion criteria and 107 were either absent or attending curricular/sporting activities during data collection. Students were excluded if they did not provide written consent, had a diagnosed sleep disorder, were taking sleep medication or had travelled to a different time zone 4 weeks before data collection. Of those invited to participate, 759 (72.8%) volunteers met all inclusion criteria and provided survey data in 2009. All participants were aged 11–18 years (mean 13.9 ± 2.0 years) and were registered students in years 7–13 of UK secondary education. School type (secondary, grammar, independent) was used as a potential proxy for socioeconomic background[26] because of the deprivation and geographic diversity across the Midlands region. Of the sample, 56.8% were from secondary schools, the main type of school in England, 24.1% attended grammar school and 19.1% were from an independent school. Information concerning ethnicity (35.0% Caucasian, 47.5% Asian, 9.8% Black, 7.7% other), gender (63.9% girls) and bedroom sharing (73.6% non-bedroom sharing) were collected.

Exposure and outcome measures

Participants completed an online survey combining the validated School Sleep Habits Survey (SSHS)[27] and a Technology Use Questionnaire (TUQ), previously developed for a birth cohort study.[28] We have previously validated the TUQ with 7-day technology use diary information through Pearson's correlation for all four types of technology. A good correlation between diary and questionnaire technology measures was observed (range $r = 0.50$–0.74, all $P < 0.05$). All measures were self-reported; information was gained on weekday sleep duration through the SSHS. Volunteers were asked the question 'Work out how long you USUALLY sleep on a normal school night and fill it in here. Do not include time you spend awake in bed'. Respondents estimated the number of hours and minutes that they slept for on a weekday and sleep duration (hours) was calculated. The association between sleep duration as a predictor and BMI *z*-score as the outcome was assessed. Sleep duration was also considered as an outcome with individual technology types. Sleep duration was then modelled as a mediator of the relationships between technology type and BMI *z*-score. We specifically assessed weekday sleep duration, as this is when sleep restriction is more likely to occur because of compulsory school attendance; thus, sleep loss during the week may exhibit different effects to the weekend, when 'catch-up' sleep is common in adolescents.[29] Stadiometers (Seca 217, Hamburg, Germany) and scales (Seca 761, Hamburg, Germany), calibrated regularly, were used to objectively measure height (to the nearest 0.5 cm) and weight (to the nearest 0.5 kg) immediately before completing the survey. Height and weight measurements were subsequently used for BMI *z*-score calculation. The proportion of overweight/obesity versus normal weight was calculated using Cole's standardised definition.[30] Information on technology use (computer use, mobile telephones, TV viewing, video gaming) at bedtime was obtained (No (never) and Yes (sometimes, usually, always)) for all technology types. The study received ethical approval from the University of Birmingham Research Ethics Committee (ERN_08–437).

Other measures

Napping (yes/no) was assessed through the SSHS. Information on method of travel to school, categorised to provide an estimate of activity level (inactive (public transport or car), active (walk, cycle)), snacking and caffeine consumption before bedtime (never, sometimes, usually, always) was collected. The SSHS identified symptoms of depression by asking volunteers: 'In the past 2 weeks, how often were you bothered by feeling unhappy, sad or depressed?' Although obstructive sleep apnoea (OSA) is uncommon in adolescence, it is not unusual among overweight/obese adolescents, and therefore information on stopping breathing/gasping for air while asleep (yes/no) was sought to highlight participants with potential OSA. These variables, as well as other demographics, were considered potential confounders of the relationships assessed.

Statistical analysis

Data analyses were performed using Statistical Package for the Social Sciences (SPSS, version 18.0, Chicago, IL, USA). Internal consistency of the TUQ was derived through calculation of Cronbach's α-score. Mean differences in sample characteristics for weekday sleep duration (hours) were calculated using either independent *t*-tests or one-way analysis of variance. Linear regression was used to examine the associations of technology types upon weekday sleep duration (hours) and BMI *z*-score. Three models are presented in Tables 2 and 3. Model 1 is the base model, model 2 is adjusted for age, sex, ethnicity and school type and model 3 is further adjusted for snacking, potential OSA, depression, method of travel to school, bedroom sharing, napping and BMI *z*-score and weekday sleep duration (hours), as appropriate. Data on sleep duration (hours) and BMI *z*-score were plotted (not shown) to explore the type of relationship between these variables. Linear regression analysis was then performed to examine the associations between weekday sleep duration (hours) on BMI *z*-score, based on the models above but with additional adjustment for all four technology types in model 3. All potential confounders were selected *a priori,* based on scientific evidence. Based on the findings of the regression analyses, we then performed path analysis to assess the possibility of weekday sleep duration as a mediator of the relationship between each technology type on BMI *z*-score. Path analysis was used to concurrently examine the direct effects of all four types of technology on the two outcome variables: weekday sleep duration (hours) and BMI *z*-score. We also explored the indirect effects of technology type on BMI *z*-score, considering sleep duration as a mediating factor. Path analysis was conducted using the statistical software package Mplus, version 6 (Muthen & Muthen, Los Angeles, CA, USA). We analysed the model using standard goodness-of-fit statistics: χ^2, comparative fit index (>0.95), standardised root mean square residual (<0.05) and mean square error of approximation (<0.05) with a *P*-value for the test of closeness of fit >0.50.

RESULTS

Of the 759 volunteers who participated in the study, 127 were excluded because of incomplete data, leaving a total of 632 (83%) available for subsequent analyses. The TUQ showed good internal consistency for the four technology types with a Cronbach's α of 0.68. Technology use was highly prevalent with 85.1% using at least one type: 13.9% used one type, 21.7% used two, 17.2% used three and 32.3% used all four types. Sample characteristics are presented as mean (s.d.) in Table 1. Briefly, older adolescents (15–18 years) had significantly shorter sleep duration (7.79 ± 1.17 h) compared with younger (11–14 years) adolescents (8.76 ± 1.35 h). Students registered at secondary schools achieved longer sleep duration compared with those attending grammar or independent schools. Overweight/obesity was significantly associated with shorter sleep duration (7.92 ± 1.57 h) compared with those who were underweight/normal weight (8.53 ± 1.24 h), $P < 0.001$. Those who did not watch TV, play video games and use computers or mobile telephones at bedtime on weekdays had a significantly longer weekday sleep duration compared with those who used these technologies (all $P \leqslant 0.01$; see Table 1).

Table 2 shows the associations between weekday use of each type of technology and weekday sleep duration (hours), assessed by linear regression. After adjustment for a range of potential confounders (model 3), use of all technology types at bedtime on weekdays was significantly associated with decreased sleep duration compared with those who did not use the technology. The greatest significant negative direct effects on weekday sleep duration was observed in those who used a computer ($\beta = -0.39$, $P < 0.01$) or played video games ($\beta = -0.39$, $P < 0.01$) at bedtime on weekdays.

The associations between the four technologies and BMI *z*-score are presented in Table 3. Positive and significant associations were found in users of all types of technology in the unadjusted model (model 1). The greatest positive association on BMI *z*-score was observed in those who watched TV or played video games at bedtime on weekdays (β (TV viewing) = 0.51, $P < 0.01$; β (video gaming) = 0.52, $P < 0.01$). This association remained, although slightly attenuated after adjustment (model 3; β (TV viewing) = 0.31, $P < 0.01$; β (video gaming) = 0.40, $P < 0.01$).

The linear relationship between weekday sleep duration (hours) and BMI *z*-score was examined through linear regression, subsequent to plotting the data. The base model showed a significant association (β (weekday sleep duration) = −0.44, $P < 0.01$). After adjustment, the association remained, although slightly attenuated (β (weekday sleep duration) = −0.35, $P < 0.01$), demonstrating a negative linear relationship between weekday sleep duration and BMI *z*-score.

The path diagram is shown in Figure 1. The results from the path analysis showed that the model had a good fit to the data (χ^2 (2, $n = 632$) = 1.31, $P = 0.52$, comparative fit index = 1.00, mean square error of approximation = 0.00, standardised root mean square residual = 0.01). Mobile telephones and computer use had significant negative direct effects on sleep duration. There was no direct relationship between TV viewing or video gaming on sleep duration. Positive and significant direct effects were found for those who watched TV, engaged in video gaming or used a computer on BMI *z*-score. A significant negative direct effect was observed for sleep duration on BMI *z*-score. When sleep duration was considered as a mediator of the relationship between technology types and BMI *z*-score, the indirect effects of computer use and mobile telephones were statistically significant and positive. The standardised and unstandardised coefficients along with standard errors for direct, indirect and total effects of technology types, weekday sleep duration and BMI *z*-score are presented in Table 4.

Table 1. The characteristics of 632 contemporary UK adolescents according to weekday sleep duration

Characteristics	*Weekday sleep duration*	P-*value*
Sex, n *(%)*		
Boys, 228 (36.1)	8.43 ± 1.48	0.43
Girls, 404 (63.9)	8.34 ± 1.29	
Age, n *(%)*		
Younger adolescent, 381 (60.3)	8.76 ± 1.35	< 0.001
Older adolescent, 251 (39.7)	7.79 ± 1.17	
Ethnicity, n *(%)*		
White, 221 (35.0)	8.19 ± 1.12	0.001
Asian, 300 (47.5)	8.53 ± 1.41	
Black, 62 (9.8)	8.66 ± 1.47	
Other, 49 (7.7)	7.92 ± 1.71	
School, n *(%)*		
Secondary, 359 (56.8)	8.65 ± 1.44	< 0.001
Grammar, 152 (24.1)	7.85 ± 1.14	
Independent, 121 (19.1)	8.21 ± 1.16	
BMI[a], n *(%)*		
Underweight/normal weight, 469 (74.2)	8.53 ± 1.24	< 0.001
Overweight/obese, 163 (25.8)	7.92 ± 1.57	
Technology use, n *(%)*		
Weekday computer use		< 0.001
Yes, 403 (63.8)	8.16 ± 1.38	
No, 229 (36.2)	8.75 ± 1.24	
Weekday mobile telephone use		< 0.001
Yes, 474 (75.0)	8.22 ± 1.32	
No, 158 (25.0)	8.83 ± 1.39	
Weekday TV viewing		< 0.001
Yes, 407 (64.4)	8.22 ± 1.40	
No, 225 (35.6)	8.66 ± 1.24	
Weekday video gaming		0.01
Yes, 296 (46.8)	8.23 ± 1.50	
No, 336 (53.2)	8.50 ± 1.22	

[a]Body mass index (BMI) categories calculated using standard definition.[30] Data are presented as mean ± s.d. Younger adolescent (11–14 years); older adolescent (15–18 years).

DISCUSSION

Sleep and technology

The potential negative effects of technology use, such as TV viewing, on the health and well-being of adolescents have been previously highlighted.[21] Evidence suggests that TV viewing,[5] internet use,[6] video gaming[8] and mobile telephones[9] can reduce sleep duration[6] and/or impair sleep quality,[8,10] but modern and interactive technology types have not been examined collectively

Table 2. The linear relationships between weekday use of specific technologies at bedtime and weekday sleep duration (hours) in 632 contemporary UK adolescents

	Model 1	*Model 2*	*Model 3*
	Unst (s.e.) St	*Unst (s.e.) St*	*Unst (s.e.) St*
Computer use	−0.59** (0.11) −0.21	−0.63** (0.10) −0.22	−0.39** (0.10) −0.14
Mobile telephone	−0.60** (0.12) −0.19	−0.38** (0.12) −0.12	−0.28** (0.11) −0.09
TV viewing	−0.45** (0.11) −0.16	−0.62** (0.10) −0.22	−0.35** (0.10) −0.12
Video gaming	−0.27** (0.11) −0.10	−0.71** (0.10) −0.26	−0.39** (0.10) −0.15

Abbreviations: St, standardised coefficient; s.e., standard error; Unst, unstandardised coefficient. Model 1: unadjusted. Model 2: adjusted for age, sex, ethnicity and school. Model 3: further adjusted for snacking, caffeine consumption, depression, method of travel to school, potential obstructive sleep apnoea (OSA), bedroom sharing, napping and body mass index (BMI) *z*-score. *$P < 0.05$; **$P < 0.01$.

Table 3. The linear relationships between weekday use of specific technologies at bedtime and BMI z-score in 632 contemporary UK adolescents

	Model 1 Unst (s.e.) St	Model 2 Unst (s.e.) St	Model 3 Unst (s.e.) St
Computer use	0.47** (0.08) 0.22	0.44** (0.09) 0.21	0.26** (0.08) 0.12
Mobile telephone	0.22* (0.09) 0.09	0.14 (0.09) 0.06	0.01 (0.09) 0.00
TV viewing	0.51** (0.08) 0.24	0.50** (0.08) 0.24	0.31** (0.08) 0.15
Video gaming	0.52** (0.08) 0.26	0.61** (0.08) 0.30	0.40** (0.08) 0.20

Abbreviations: s.e., standard error; St, standardised coefficient; Unst, unstandardised coefficient. Model 1: unadjusted. Model 2: adjusted for age, sex, ethnicity and school. Model 3: further adjusted for snacking, caffeine consumption, depression, method of travel to school, potential obstructive sleep apnoea (OSA), bedroom sharing, napping, weekday sleep duration (hours). *$P<0.05$; **$P<0.01$.

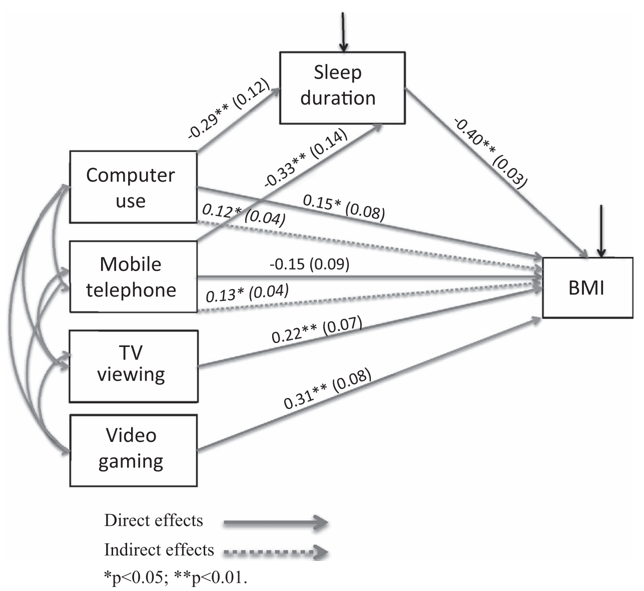

Figure 1. Path analysis theoretical model. *$P<0.05$; **$P<0.01$. Data are presented as standardised coefficients (standard errors).

in the same adolescents, or specifically at bedtime on weekdays. Furthermore, our study contributes to the existing literature by assessing sleep duration as a potential mediator of the relationships between specific technology types and BMI.

The results of our study confirm the association between the weekday use of technology types at bedtime and reduced weekday sleep duration in UK adolescents. In contrast to a structured leisure activity with a defined beginning and end, unstructured activities, such as technology use, may defer bedtimes and result in less time spent in bed. Our findings from adjusted regression analysis showed that video gaming and computer use at bedtime during the week were the strongest predictors of reduced weekday sleep duration. Arguably, TV viewing is more passive compared with video gaming and computer use, which may be more mentally stimulating and potentially delay bedtime and/or sleep onset through mental excitation. Our theoretical path model showed that mobile telephones have the strongest negative effect on weekday sleep duration. This may be because of the multiple facilities that mobile telephones now offer (calling, texting, internet access, gaming, photographs, calendars, videos, social networking and other applications), which sometimes require interaction with others, thus resulting in mental excitation and stimulation. Mobile telephones are small and portable, giving immediate access across all hours of the day and night. They have been incorporated into everyday living and mobiles are frequently used after lights out at bedtime. Computer use was also shown to reduce weekday sleep duration in our path model. This may be because of the type of task that the user is completing before bedtime, but further investigation is required to assess this possibility. Interestingly, our path model found no significant effects of TV viewing or video gaming on sleep duration. It is possible that incorporation of TV viewing, from a young age, into our daily lifestyles has allowed adaptation to the passive and noninteractive nature with fewer negative consequences on sleep duration, but longitudinal or retrospective studies are required to investigate this.

Table 4. The standardised and unstandardised coefficients of the direct, indirect and total effects of the path analysis model in 632 contemporary UK adolescents

Causal variable	Sleep duration (hours) Unst s.e. St	BMI z-score Unst s.e. St
Computer use		
Direct effect	− 0.395** (0.119) − 0.289	0.147* (0.075) 0.147
Indirect effect	—	0.117* (0.038) 0.116
Total effect		0.264* (0.010) 0.263
Mobile telephone use		
Direct effect	− 0.446** (0.138) − 0.326	− 0.151 (0.086) − 0.150
Indirect effect	—	0.132* (0.042) 0.131
Total effect		0.019 (0.013) − 0.019
TV viewing		
Direct effect	—	0.221** (0.073) 0.220
Indirect effect	—	—
Video gaming		
Direct effect	—	0.315** (0.079) 0.313
Indirect effect	—	—
Weekday sleep duration		
Direct effect		− 0.296** (0.031) − 0.403
Intercept	9.943** (0.243) 7.277	1.740** (0.318) 1.730

Abbreviations: BMI, body mass index; s.e., standard error; St, standardised coefficient; Unst, unstandardised coefficient *$P<0.05$; **$P<0.01$.

Although some adolescent studies have found a negative effect of video gaming on sleep quality[7] and alterations in sleep architecture,[31] another study found no relationship.[32] The only study to specifically examine video gaming and sleep duration reported a negative association, but only in those classified as video game dependent.[8] It is therefore possible that video gaming may alter some sleep parameters, although sleep duration remains unaffected. One study showed that addicted online video gamers reported higher levels of daytime somnolence compared with nonaddicted. Furthermore, addicted gamers experienced more sleep deprivation through play, known to affect mood state and emotional changes.[12] Apart from the mechanisms discussed above, technology use could result in sleep loss through artificial light exposure from devices, previously shown to delay the release of melatonin, and hence, sleep initiation.[11] Although our theoretical model highlights the potential pathways of technology on sleep duration and BMI, our findings do not establish causality. It is therefore possible that those having more difficulty with sleep may be more inclined to use technology, serving as a distraction and time-filler before sleep.

Sleep and obesity

Studies have shown that technology use is independently associated with short sleep duration[4] and overweight.[21] Parallel with this is evidence linking short sleep duration with obesity across all age groups.[13,14] Adolescent sleep–obesity findings have shown inconsistencies in recent prospective[19] and cross-sectional studies.[20] Our multivariate regression, after adjustment for a range of potential confounders, demonstrated a significant negative linear relationship between weekday sleep duration and BMI *z*-score. This was reinforced by a significant causal sleep–obesity pathway, observed in the path model. Evidence suggests that short sleep duration in adults is associated with alterations in the metabolic hormones ghrelin and/or leptin.[15–17] Studies reporting metabolic hormone alterations as a consequence of reduced sleep duration have also shown increases in subjective hunger and appetite for unhealthy foods.[17]

An animal model attempting to mimic accrued human sleep deprivation by subjecting rodents to a 4-week protocol, cycling 5 days of sleep restriction (SR) followed by 2 days of sleep allowance,[33] showed a substantial increase in food intake during the first week of SR, and subsequent weight gain during sleep opportunity. This suggests that weekday sleep curtailment promotes increased energy intake and subsequent weight gain. Human experimental studies also support this notion. One study demonstrated a 22% increase in energy intake following one 4-h sleep opportunity in a small sample of young men (22 ± 1.83 years; $n = 12$).[34] This is further supported by a more prolonged (14 nights) SR study with a 5.5-h sleep opportunity.[35] Currently, there are no adolescent experimental SR data available. Mechanistic evidence has shown disruptions in metabolic hormones associated with hunger and appetite. A relationship has been reported between subjective sleep duration and ghrelin[36] as well as leptin[37] in adolescent girls. Thus, SR in adolescents, potentially as a result of bedtime technology use, may promote metabolic perturbation and increased energy intake with subsequent obesity, as indicated in our path model. However, this was only evident for contemporary technologies (mobiles and laptop/personal computer); thus, the effects of specific technology types may produce different effects in relation to sleep, energy intake and BMI.

Chaput and Tremblay[38] found increased energy intake following a cognitive task compared with sitting at rest. This increased energy intake was not compensated by elevated energy expenditure. These authors, using similar methodology, also demonstrated increased cortisol and unstable increases in plasma glucose and insulin following a cognitive computer task.[39] In a randomised crossover study, despite increased energy expenditure during video game play, energy intake in adolescents after video game play was observed to be higher compared with the resting state, resulting in an overall energy excess.[40] Combined, these studies, and our path analysis, demonstrate that video gaming and television viewing may promote obesity, independent of their potential effects on sleep.

Technology and obesity

All types of technology examined were significantly and positively related to BMI *z*-score, except for mobile telephones. The portable nature of a mobile telephone does not require the user to remain in one place during use, thus allowing movement, which may account for the nonsignificant finding with BMI in our study. Our theoretical path model, however, suggests that the most powerful effects of technology on BMI *z*-score, mediated through weekday sleep duration, occur from the use of computers and mobile telephones. Interestingly, despite mobile telephones showing a negative direct effect on BMI *z*-score (nonsignificant), sleep duration appears to mediate this relationship. The use of mobile telephones in adolescents therefore has a powerful negative effect on sleep duration, in line with other findings.[9,10] Although mobile telephone use was not directly related to BMI, the strong negative association that mobile use has with sleep duration appears to contribute to the pathway of increased BMI. The impact of adolescent use of mobile telephones needs to be further investigated, given these devices can now be used for a multitude of tasks, and can be used as replacements for other technologies. Computer use had a significant and positive indirect effect on BMI *z*-score. If confirmed by other studies, our results suggest that restricting computer and mobile telephone usage at bedtime could help to avoid sleep reduction in adolescents and the downstream possibility of increased BMI. TV viewing and video gaming were significantly and directly associated with BMI but not with weekday sleep duration. Indeed, TV viewing has been linked with a positive energy balance, independent of sleep.[41] Also, as discussed above, video game play is associated with excess energy intake that could translate to obesity over time.[35] Our findings suggest that the pathways among more modern and interactive technology types, sleep duration and BMI are crucial to our understanding for implementing future strategies to tackle inadequate sleep obesity in adolescents.

Strengths and limitations

Our study has several strengths and potential limitations. Although objectively measured weight and height allowed accurate calculation of BMI, the sleep and technology use data collected were self-reported. Although it can be argued that self-reported data may be unreliable, the Cronbach's α-score (0.68) showed good internal consistency for the TUQ, and the SSHS has been previously validated in adolescents. Self-reported sleep duration in the SSHS is comparable with more objective measures of sleep duration such as actigraphy, inclusive of weekdays and weekends, when assessed over 8 days/nights with corresponding sleep diary data.[27] Although we specifically asked participants about bedtime technology use, adolescent technology use is common after 'lights out'.[9] Therefore, our findings may be an underestimate. Furthermore, inadequate sleep duration was unlikely to be a consequence of either diagnosed or undiagnosed sleep disorder(s) in our study, as those with diagnosed sleep disorder(s) were excluded and symptoms of OSA were adjusted for in our analyses. Further data on potential OSA from parental report would have been useful, but data from parents were not collected in our study. Our study would have also been strengthened by more detailed socioeconomic data collection.

Previous adolescent sleep–obesity studies[18,20] did not adjust for technology as a confounder, with the exception of one, which controlled for TV viewing only.[42] Technology in this age group is easily accessible and use is highly prevalent, and hence future sleep–obesity studies should attempt to control for this interrelated factor. Our study benefitted from information on four technology types, which we were therefore able to adjust for in our final regression model when assessing the association between sleep duration and BMI. The limitations of our study include data collected on physical activity and diet that provide only a snapshot and are unlikely to be fully representative of these aspects. The measure of physical activity was derived from the adolescents' daily commute to and from school and the diet measure originated from weekday snacking at bedtime only. Future studies should utilise objective measures of physical activity, although this would be difficult from a logistic and financial perspective for population studies. Food diaries and other approaches could also be incorporated into future studies for a more comprehensive assessment of diet. Also, our study did not obtain duration of technology use before bedtime; this should be collected in future studies to determine potential dose-dependent relationships.

The present findings, if confirmed by others and experimentally, could have significant public health implications. Advances in available technology promote media use that is easily accessible/available at any time of the day for all age groups, displacing activities such as sleep and physical activity, both associated with obesity. Increasing numbers of technology devices are utilised by adolescents before bedtime, which may result in shortened sleep duration and increased BMI. Should our results be confirmed through longitudinal and experimental studies, technology use, particularly modern types, may need to be better managed in adolescents, encouraging daytime rather than bedtime usage. This may enhance sleep duration with potential positive effects on health and well-being.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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