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Sleep and adiposity in pre-adolescent children: the importance of social jetlag

Running Title: social jetlag and adiposity in children

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Keywords: obesity; circadian clock; chronobiology; sleep; behavior; pediatric

CONTRIBUTORS STATEMENT

Lee Stoner: conceptualized and designed the study, carried out the initial analysis, drafted the initial manuscript, and approved the final manuscript as submitted.

Nicholas Castro: assisted with the initial analysis, coordinated and supervised data collection at each site, and approved the final manuscript as submitted

Leigh Signal: assisted with study design, assisted with drafting the initial manuscript, critically reviewed the manuscript, and approved the final manuscript as submitted.

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ABSTRACT

Background: While short and poor quality sleep has been associated with childhood obesity, no known studies have examined social jetlag. Social jetlag is the discrepancy between an individual's circadian clock and social rhythms, and is measured as the difference in hours between the midpoint of sleep during work/school days and on free (weekend) days. The current study investigated the independent associations between sleep duration, sleep disturbances and social jetlag with adiposity in children.

Methods: A cross-sectional study, including 341 children (50% F) aged 8–10 years. Five dependent variables: body fat (%), fat mass (kg), fat mass index (FMI, kg/m^2), waist to hip ratio (WHR), body mass index (BMI, kg/m^2). Three independent variables: average sleep duration, sleep disturbances, social jetlag.

Results: Following adjustment for confounders, sleep duration was not associated with any sleep variable, and sleep disturbances were associated with FMI ($\beta = 0.047$, 95%CI: 0.002, 0.093 kg/m^2), while social jetlag was associated with all five adiposity variables, including an absolute 3% greater body fat ($\beta = 2.963$, 95%CI: 0.40, 5.53 %) per one hour of social jetlag.

Conclusions: Social jetlag may be an important and measurable public health target in children.

Keywords: obesity; circadian clock; chronobiology; sleep; behavior; pediatric

INTRODUCTION

Short and poor quality sleep, along with physical inactivity and poor diet, has been associated with childhood obesity.[1-3] Several aspects of sleep may be important, including sleep disturbances, sleep duration, and social jetlag. Social jetlag is the discrepancy between an individual's circadian clock and social rhythms, and is measured as the difference in hours between the midpoint of sleep during work/school days and on weekend free days.[4] Studies have reported an association between sleep disturbances and obesity in children.[2, 5] Similarly, a recent meta-analysis of 11 longitudinal studies (total n = 24,821 participants) reported that children sleeping for a short duration, defined as 30-60 min less than a 'long' duration, had twice the risk of being overweight/obese (OR: 2.15, 95%CI: 1.64-2.81)[1]. However, the importance of social jetlag in children is unknown. In adults, social jetlag has been associated with obesity,[6, 7] with one longitudinal cohort study, including 815 non-shift workers, reporting that each hour of social jetlag was associated with a 0.10 kg (SE: 0.48) increase in fat mass and 0.12 kg/m^2 (SE: 0.24) increase in body mass index (BMI).[6] Similarly, at least one study of 77 adolescents has reported an association between social jetlag with BMI and waist:hip ratio (WHR).[8] However, while previous studies have investigated the association between sleep timing and adiposity among children,[9-11] no known studies have specifically examined social jetlag, nor has any study simultaneously examined the importance of sleep duration, sleep disturbances and social jetlag.

Sleep–wake and metabolism cycles are regulated by the circadian clock.[12] In modern society, the rhythmicity of the circadian clock is often disrupted by social obligations, including work and school schedules.[13] Social jetlag is simple to measure, and may be a simple target for public health policy. However, while national guidelines in New Zealand[14] and Canada[15] recommend that children aged 6 – 13 years sleep for 9-11 hours, and that bed and wake-up times should be consistent, the evidence for regulating the sleep-wake cycle is limited. The current study investigated whether sleep duration, sleep disturbances and social jetlag are independently associated with adiposity in pre-adolescent children.

METHODS

Study design

This cross-sectional study was carried out in accordance with STROBE (Strengthening the Reporting of Observational Studies in Epidemiology) guidelines.[16] Details of the wider study, Pre-Adolescent Cardio-Metabolic Associations and Correlates (PACMAC), have been previously published.[17] Adiposity was assessed in the schools between the hours of 9:00 and 12:00. Participants were asked to ensure adequate hydration, but fast for at least 3 h, and refrain from exercise for 24 h. Within 7 days of the adiposity assessments, sleep habits and demographic data were collected using a questionnaire completed at home by the primary caregiver. Only children with complete adiposity and sleep data were included in the analyses.

Participants

Children aged 8–10 years were recruited from schools in three major cities across New Zealand (Wellington, Christchurch and Dunedin), between April 2015 - April 2016 (**Figure 1**). For each region, schools were stratified by socioeconomic status and randomly invited to participate. All children were eligible to participate unless they had an orthopedic injury/surgery that prohibited full function within the previous four weeks, or were prescribed any cardiovascular medications. Parental or guardian consent and child assent were obtained prior to participation, in accordance with the requirements of the New Zealand Health and Disability Ethics Committees (HDEC:14/CEN/83).

Demographics

Demographic data collected included date of birth, sex, ethnicity, and school address. The school address was used to determine school decile rating, a socio-economic status (SES) indicator of the school. The decile is based on the proportion of students at the school with low SES as defined by the student's residential address. Decile 1 includes the 10% of schools with the highest proportion of students from low SES communities; decile 10 the lowest proportion. School decile was divided into 'Low (Deciles 1 to 5) and 'High' (Deciles 6 to 10).

Sleep Behaviors

Three variables were measured: average sleep duration, sleep disturbances, and social jetlag. To determine average sleep duration, and social jetlag, the participant's primary caregiver was asked to report what time their child usually went to bed and what time they usually got up on both school days and free (weekend) days. Single items of habitual school/weekday sleep shows reasonable concurrent validity with actigraphy and diary data.[18] Average sleep duration was calculated using a ratio of five weekdays to two weekend days. Social jetlag was calculated as the absolute difference between the midpoints of sleep on weekdays versus weekend days.[7]

Sleep disturbances were estimated by having parents complete the Children's Sleep Habits Questionnaire (CSHQ). The CSHQ demonstrates adequate internal consistency, acceptable test–retest reliability, and discriminant validity.[19] The 33 questions were answered on a 7-point Likert scale from Always (1) to Never (7), with higher scores indicative of greater sleep disturbances. The CSHQ includes eight subscales that align with the key sleep complaints relevant for this age group: bedtime resistance, sleep onset delay, sleep duration, sleep anxiety, night waking, parasomnias, sleep-disordered breathing, and daytime sleepiness. A Total Sleep Disturbance score was calculated as the sum of all 33 scored CSHQ questions, with a potential range of 33 to 99. A Total Sleep Disturbances score >41 was used to indicate disturbed sleep, as this cut-off has been shown to accurately identify 80% of children with a clinically diagnosed sleep disorder. For the current study, only the Total Sleep Disturbance score was used.[19]

Adiposity

Five dependent variables were recorded: body fat (%), fat mass (kg), fat mass index (FMI, kg/m^2), WHR, and body mass index (BMI, kg/m^2). Body fat (%) and fat mass (kg) were measured using multi-frequency bio-impedance analysis (BodyStat Quadscan 4000, Isle of Man, UK). The instrument was calibrated in accordance with the manufacturer's instructions, and measurements were conducted according to standardized procedures.[20] Participants were studied in the supine position on a non-conductive surface, with arms and legs abducted at a 30°–45° angle from the trunk to avoid medial body contact by upper and lower extremities. FMI was calculated by dividing fat mass (kg) by height squared (m^2).

To calculate the anthropometric indices (BMI and WHR), height was measured with a calibrated portable stadiometer (Seca, Germany), with shoes and socks removed and head in the Frankfort plane. Using non-elastic tape (Seca, Germany), waist circumference was measured during mid-expiration at the midpoint between the lower costal margin and the level of the anterior superior iliac crest, and hip circumference was measured around the widest portion of the buttocks. Age and sex specific BMI z-scores were calculated using the 2007 World Health Organization (WHO) method,[21] and BMI values were categorized using the International Obesity Task Force sex- and age-dependent cut-off points.[22]

Statistics Analyses

Statistical analyses were performed using Statistical Package for Social Sciences version 22 (SPSS, Inc., Chicago, Illinois). Only participants who had complete data for all sleep and all adiposity variables were included in the analyses. Linear regression analyses were performed using Gaussian family generalized estimating equations with robust standard errors, to allow for the clustering in data among students attending the same schools[23], to ensure results are representative of the population in the sampled area. Each analysis included one dependent variable (body fat %, fat mass, FMI, WHR, BMI) and all three independent variables (sleep duration, social jet lag, sleep disturbances). For each analysis, the influence of confounding variables was assessed by fitting two models, with Model 1 adjusting for school clustering only. Model 2 was additionally adjusted for age, sex, ethnicity and school decile rating. Model 3 included the relevant sex interaction terms. All regression models were assessed by examination of the model residuals plotted against their normal scores. Anonymised data will be shared on reasonable request.

RESULTS

Of the 392 participants who took part in the PACMAC study, 341 had complete adiposity and sleep data (**Figure 1**). The 341 children included in the current study were comparable to the full 392 participants (9.54 y, 50% F, 29% overweight, 54% low decile school). Table 1 presents the demographic characteristics of the participants included in the current analysis. Among the 341 participants, 29% were classified as overweight and 40% had disturbed sleep. The majority of participants (92%, n=315) slept for at least 9 hours each night, and on average the total sleep duration did not differ for the week compared to the weekend (10.1 vs. 10.1 hr, p = 0.490). However, all but two children went to bed later on the weekend (mean: 42 min, 95%CI: 44, 50), and 97% (n=330) awoke later on the weekend (42 min, 95%CI: 37, 46). As a result, the average social jetlag was 43 min (95%CI: 40, 47), and 35% had $\geq$1 hr social jetlag.

Univariate models

The univariate outcomes are shown in Table 2. Sleep duration was associated with fat mass (p = 0.022), BMI (p = 0.018), and WHR (p = 0.025), sleep disturbances with fat mass (p = 0.010), FMI (p = 0.009) and BMI (p = 0.019), and social jetlag with all five adiposity variables (p = <0.001 – 0.008).

Multivariate models

Multivariate models 1-2 are shown in Table 2. When adjusted for confounders (Model 2), sleep duration was not associated with any sleep variable, and sleep disturbances were associated with FMI (p = 0.041), while social jetlag remained associated with all five adiposity variables (p = 0.010 – 0.033). One hour of social jetlag was associated with a 3 % increase in body fat, a 1.73 kg increase in fat mass, a 0.76 kg/m^2 increase in FMI, a 0.89 kg/m^2 increase in BMI, and a 0.13 (ratio) increase in WHR.

Sensitivity Analysis: Sex interaction

Model 3 included the sex interaction term (data not shown). The interaction term was only significant for the associations between sleep duration and sleep disturbances with WHR. When stratified by sex, the association between sleep duration and WHR was not significant for girls (β = -0.007, 95%CI: -0.015, 0.000, p = 0.053) or boys (β = -0.005, 95%CI: -0.015, 0.005, p = 0.360). Similarly, the association between sleep disturbances and WHR was not significant for girls (β =-0.001, 95%CI: -0.002, 0.000, p = 0.060) or boys (β = 0.001, 95%CI: 0.000, 0.002, p = 0.062).

DISCUSSION

Following adjustment for potential confounders, sleep duration was independently associated with WHR, and sleep disturbances were independently associated with fat mass and FMI, while social jetlag was independently associated with all five adiposity markers. The importance of the association between social jetlag and adiposity is strengthened when considering that 92% of the children did achieve, on average, the minimum nine hours of sleep recommended by the national guidelines in New Zealand,[14] and the findings were not confounded by different sleep durations on weekdays and free (weekend) days. Collectively, these findings suggest that social jetlag is at least as important as sleep duration and sleep disturbances in this age group.

Strengths and Limitations

This study had several potential limitations. Firstly, the cross-sectional study design makes it difficult to interpret the temporal sequence and clinical importance of the absolute 3% greater body fat. Longitudinal studies are required to determine causality. Second, the use of parent-reported questionnaires may have led to some measurement and reporting errors. Nonetheless, the use of single item habitual school/weekday sleep survey shows reasonable concurrent validity with actigraphy and diary data.[18] Third, the CSHQ is a screening rather than diagnostic tool for sleep disturbances, and relies on parent self-report. Future studies would do well to incorporate objective measures of sleep quality). Fourth, this study might have been underpowered to detect a significant sex interaction as moderation analyses require substantial sample sizes.[24] Fifth, we adjusted our statistical models used a school-level proxy of socio-economic status; further studies would do well to adjust using a family-level indicator of socio-economic status. Lastly, further study is required to generalize these findings to pre-adolescents in other nations. However, a major strength of this study is the relatively large and representative cohort of New Zealand-based pre-adolescents.

Comparison with other studies

While the univariate analysis confirmed previous findings, showing a negative relationship between sleep duration and increased adiposity,[1] and a positive relationship between sleep disturbances and increased adiposity,[2, 5] multivariate analysis revealed that only social jetlag was independently associated with all five estimates of adiposity. The findings are in agreement with a previous cross sectional study of 77 adolescents, which reported a positive association between social jetlag with BMI and WHR.[8] Of particular note, the increase in fat mass and BMI per one hour's social jetlag was greater than that previously reported in 815 non-shift working adults [0.10 kg (SE:

0.48) and 0.12 kg/m^2 (SE: 0.24), respectively].[6] The aforementioned study in adults was longitudinal, strengthening the argument for causality.

In adults, social jetlag is thought to be influenced by an individual's chronotype, which refers to their biologically preferred time for sleep, with some people preferring to go to bed early and rise early and others preferring to go to bed later and rise later. [4, 13] An individual whose preference is to go to bed late and rise late may have their sleep truncated during the work week due to the need to rise in time for work. During the weekend they then spend a longer time sleeping to recover from the sleep debt accrued across the work week as well as sleeping at more naturally preferred times. In studies of adults, both sleep duration [25, 26] and social jetlag [6, 7] have been independently associated with metabolic changes and adiposity. It is not clear, however, whether social jetlag presents the same way in younger individuals.

In the present sample, the amount of sleep children obtained during the week, on average, was the same as that during the weekend. However, experienced social jetlag was, on average, 43 min, and was greater than one hour for 35% of children. This suggests that these children are shifting both their bedtimes and rise times between weekdays and weekends. Children of this age may be in a transitional developmental period where they can still fall asleep earlier on school nights but are delaying their bedtimes and beginning to sleep in at the weekends. This is in contrast to teenagers who become significantly more phase delayed and cannot fall asleep earlier on weekdays.[27]

To maintain good metabolic health the central circadian pacemaker in the suprachiasmatic nucleus must remain in synchrony with circadian rhythms in the peripheral organs.[28] Desynchrony between the central and peripheral clocks occurs when the timing of sleep is disturbed, and may also be possible when the timing of eating is altered, although we currently know very little about what happens to eating patterns when individuals experience social jetlag. This circadian desynchrony is thought to create disturbances in metabolic processes that are linked to weight gain.[28, 29] At present our understanding of the biological mechanisms that link social jetlag to obesity are still limited but the relationships are likely to be complex and involve both behavioral and biological components.

Policy implications

Healthy dietary behavior and sufficient physical activity are entrenched aspects of obesity prevention, but the focus must also extend to good sleep behavior. Good sleep behavior, however, does not simply pertain to the total duration of sleep, but also entails ensuring consistent sleep-wake cycles. To our knowledge there is no evidence suggesting that an intervention altering the sleep times of children would have an effect on measures of adiposity. However, considering the potential for relatively simple translation of social jetlag into a public health message, further longitudinal trials are warranted which utilize objective sleep measures such as actigraphy. Further study is also warranted to determine the interactions with chronotype, nutritional behaviours, and metabolism in children.[28]

Conclusions

Independent of sleep duration or sleep disturbances, one hour of social jetlag was associated with five measures of adiposity, including 3% greater absolute body fat. While further studies are required to confirm causality, these preliminary findings suggest that social jetlag may be an important and measurable public health target in children.

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DATA SHARING

Anonymized data will be shared on reasonable request.

DISCLOSURE STATEMENT

No competing financial interests exist.

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TABLES

Table 1. Characteristics of participants, stratified by sex

	All N=341			Female N=169			Male N=172			P
Categorical variables				**Count (%)**						
Ethnicity										
Māori	37	(11)		21	(12)		16	(9)		0.724
Pacific	22	(6)		12	(7)		10	(6)		
New Zealand European	277	(81)		134	(79)		143	(83)		
Not Recorded	5	(1)		2	(1)		3	(2)		
School Year										
4	73	(21)		38	(22)		35	(20)		
5	95	(28)		44	(26)		51	(30)		
6	110	(32)		55	(33)		55	(32)		
7	63	(18)		32	(19)		31	(18)		
School Decile										
Low (≤5)	174	(51)		85	(50)		89	(52)		0.531
High (>5)	167	(49)		84	(50)		83	(48)		
Obesity Status										
Overweight	98	(29)		48	(28)		50	(29)		0.892
Non-Overweight	243	(71)		121	(72)		122	(71)		
Sleep										
≥ 9 hr duration	315	(92)		156	(92)		159	(92)		0.562
Sleep Disorder	136	(40)		70	(41)		66	(38)		0.565
≥1 hr Social Jetlag	121	(35)		61	(36)		60	(35)		0.578
Continuous variables				**Mean (95%CI)**						
Age (years)	9.6	(9.4	,9.7)	9.6	(9.4	,9.7)	9.5	(9.4	,9.7)	0.898
Sleep										
Weekday Bed (h:min)	8:19	(8:15	,8:19)	8:19	(8:14	,8:25)	8:19	(8:13	,8:26)	0.999
Weekend Bed (h:min)	9:05	(9:00	,9:06)	9:06	(8:58	,9:15)	9:04	(8:56	,9:12)	0.669
Weekday Awake (h:min)	7:02	(6:58	,7:04)	7:04	(6:59	,7:09)	6:59	(6:54	,7:04)	0.152
Weekend Awake (h:min)	7:44	(7:38	,7:51)	7:51	(7:43	,7:59)	7:36	(7:28	,7:45)	0.013
Weekday Duration (hrs)	10.1	(10.0	,10.2)	10.1	(10.0	,10.2)	10.1	(10.0	,10.3)	0.779
Weekend Duration (hrs)	10.1	(10.0	,10.2)	10.1	(10.0	,10.3)	10.1	(9.9	,10.2)	0.581
Sleep Disorders	40.4	(39.8	,41.1)	40.8	(39.8	,41.8)	40.0	(39.2	,40.8)	0.228

Social Jetlag (hrs)	0.72	(0.7	,0.8)	0.78	(0.7	,0.9)	0.66	(0.6	,0.8)	0.053
Adiposity										
Weight (kg)	34.4	(33.4	,35.4)	34.5	(33.1	,35.9)	34.3	(32.9	,35.6)	0.792
Body Fat (%)	19.8	(18.8	,20.8)	21.6	(20.2	,23.1)	18.0	(16.6	,19.4)	<0.001
Fat Mass (kg)	7.2	(6.6	,7.7)	7.8	(7.0	,8.6)	6.6	(5.8	,7.3)	0.025
Fat Mass Index (kg/m^2)	3.7	(3.4	,3.9)	4.0	(3.6	,4.3)	3.4	(3.0	,3.7)	0.013
Body Mass Index (kg/m^2)	17.7	(15.9	,19.4)	17.8	(15.2	,20.3)	17.6	(15.1	,20.0)	0.572
Waist to Hip Ratio	0.84	(0.75	,0.93)	0.83	(0.82	,0.84)	0.85	(0.84	,0.85)	0.016

Table 2. Linear associations between body composition measures and sleep measures

	Univariate				Multivariate							
					Model 1 (school adjusted)				Model 2 (multivariate adjusted)			
	β	LCI	UCI	*P*	*β*	LCI	UCI	*P*	*β*	LCI	UCI	*P*
Body Fat (%)												
Ave. Duration (Hrs)	-0.513	-1.709	0.682	0.399	-0.293	-2.057	1.471	0.745	-0.293	-1.363	0.777	0.591
Sleep Disturbances	0.185	0.018	0.352	0.030	0.162	0.064	0.259	0.001	0.162	-0.012	0.335	0.068
Social Jetlag (Hrs)	3.087	1.401	4.772	<0.001	2.963	0.462	5.463	0.020	2.963	0.398	5.528	0.024
Fat Mass (kg)												
Ave. Duration (Hrs)	-0.753	-1.395	-0.110	0.022	-0.579	-1.580	0.421	0.256	-0.579	-1.298	0.140	0.114
Sleep Disturbances	0.118	0.028	0.208	0.010	0.094	0.026	0.162	0.007	0.094	-0.001	0.190	0.053
Social Jetlag (Hrs)	1.845	0.937	2.753	<0.001	1.727	0.256	3.199	0.021	1.727	0.144	3.311	0.033
Fat Mass Index (kg/m^2)												
Ave. Duration (Hrs)	-0.253	-0.553	0.047	0.098	-0.181	-0.658	0.295	0.456	-0.181	-0.499	0.137	0.264
Sleep Disturbances	0.056	0.014	0.098	0.009	0.047	0.018	0.077	0.002	0.047	0.002	0.093	0.041
Social Jetlag (Hrs)	0.806	0.383	1.229	<0.001	0.759	0.185	1.333	0.010	0.759	0.132	1.386	0.018
Body Mass Index (kg/m^2)												
Ave. Duration (Hrs)	-0.467	-0.867	-0.066	0.023	-0.351	-0.861	0.159	0.177	-0.351	-0.827	0.124	0.148
Sleep Disturbances	0.067	0.011	0.124	0.019	0.054	0.001	0.106	0.045	0.054	-0.003	0.110	0.064
Social Jetlag (Hrs)	0.954	0.384	1.525	0.001	0.885	0.422	1.348	0.000	0.885	0.208	1.562	0.010
Waist to Hip Ratio												
Ave. Duration (Hrs)	-0.008	-0.015	-0.001	0.025	-0.006	-0.014	0.002	0.145	-0.006	-0.012	0.001	0.072

Sleep Disturbances	0.000	-0.001	0.001	0.654	0.000	-0.001	0.001	0.981	0.000	-0.001	0.001	0.986
Social Jetlag (Hrs)	0.014	0.004	0.023	0.008	0.013	0.005	0.021	0.002	0.013	0.003	0.023	0.012

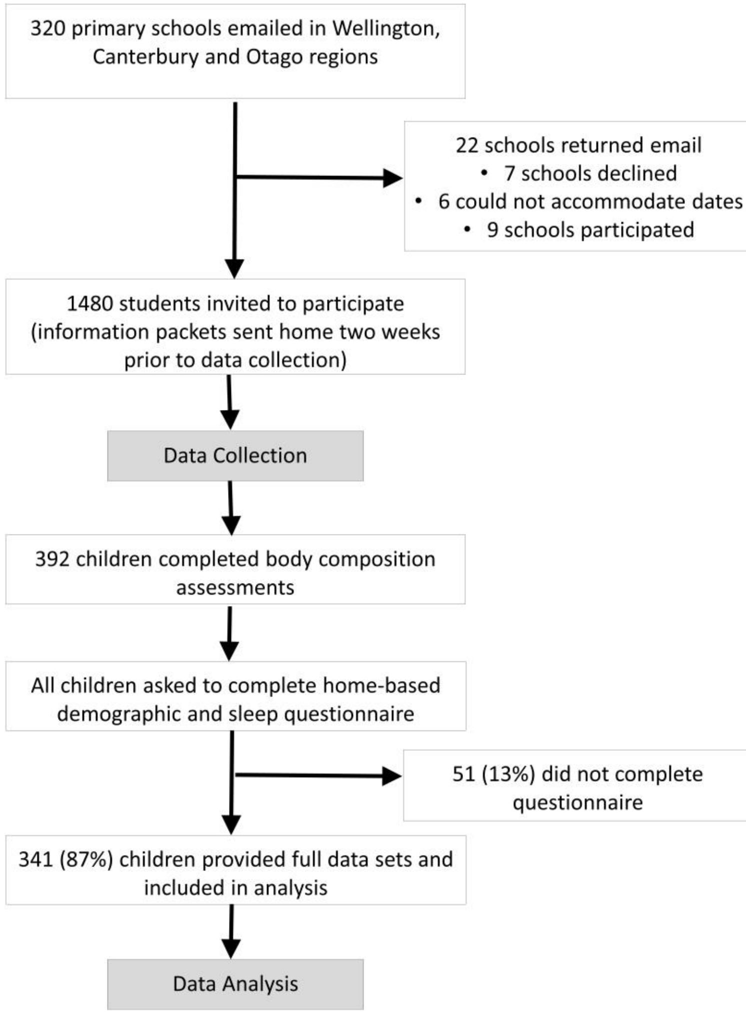
Model 2: school decile, ethnicity, sex, age
Note: the univariate models specify the sleep measures (sleep duration, sleep disturbances, social jet lag) separately (separate models). The multivariate models include all sleep measures in the same model.

Model 2: school decile, ethnicity, sex, age

Note: the univariate models specify the sleep measures (sleep duration, sleep disturbances, social jet lag) separately (separate models). The multivariate models include all sleep measures in the same model.

FIGURES

Figure 1. Participant recruitment flowchart


320 primary schools emailed in Wellington, Canterbury and Otago regions
22 schools returned email
• 7 schools declined
• 6 could not accommodate dates
• 9 schools participated
1480 students invited to participate (information packets sent home two weeks prior to data collection)
Data Collection
392 children completed body composition assessments
All children asked to complete home-based demographic and sleep questionnaire
51 (13%) did not complete questionnaire
341 (87%) children provided full data sets and included in analysis
Data Analysis