Sleep characteristics and health-related quality of life in 9-11 year old children from 12 countries

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Abstract

Introduction

Previous studies have linked short sleep duration, poor sleep quality, and late sleep timing with lower health-related quality of life (HRQoL) in children. However, almost all studies relied solely on self-reported sleep information and most were conducted in high income countries. To address these gaps, we studied both device-measured and self-reported sleep characteristics in relation to HRQoL in a sample of children from 12 countries that vary widely in terms of economic and human development.

Methods

The study sample included 6,626 children aged 9-11 years from Australia, Brazil, Canada, China, Colombia, Finland, India, Kenya, Portugal, South Africa, the United Kingdom, and the United States. Waist-worn actigraphy was used to measure total sleep time, bedtime, wake-up time, and sleep efficiency on both weekdays and weekends. Children also reported ratings of sleep quantity and quality. HRQoL was measured by the KIDSCREEN-10 survey. Multilevel regression models were used to determine the relationships between sleep characteristics and HRQoL.

Results

Results showed considerable variation in sleep characteristics, particularly duration and timing, across study sites. Overall, we found no association between device-measured total sleep time, sleep timing or sleep efficiency and HRQoL. In contrast, self-reported ratings of poor sleep quantity and quality were associated with HRQoL.

Conclusions

Self-reported, rather than device-based, measures of sleep are related to HRQoL in children. The discrepancy related to sleep assessment methods highlights the importance of considering both device-measured and self-reported measures of sleep in understanding its health effects.

Key Words

Sleep duration, total sleep time, sleep efficiency, sleep timing, health related quality of life

Introduction

The American Academy of Sleep Medicine (AASM) guidelines recognize sleep as a multidimensional behavior and define healthy sleep as “adequate duration, appropriate timing, good quality, regularity, and the absence of sleep disturbances or disorders.” [1] For children and adolescents, healthy sleep is essential for healthy living, and insufficient sleep has been linked with a wide range of physical, mental and social problems,[2] including obesity,[3] hypertension,[4,5] reduced insulin sensitivity and type 2 diabetes,[6,7] depression,[8] anxiety,[9] impaired emotional regulation,[10,11] sub-optimal cognitive and academic performance[12-14] and poor relationships with peers and family.[15] The AASM recommends 9-12 hours of sleep on a regular basis for children aged 6-12 years to achieve optimal health. [1]

Health-related quality of life (HRQoL) captures all three main domains of health (physical, mental, and social) and is an important and widely used indicator of overall health in adults and children.[16] Multiple studies have examined the relationship between sleep and HRQoL in children and adolescents, yet mixed findings have been reported. For example, several studies found that self-reported short sleep duration, late sleep timing, and sleep disturbances were associated with poor physical, social, and emotional functioning as well as poor overall HRQoL, while long sleep duration and better sleep quality were related to reduced health complaints and better psychological health.[15,17-24] However, other studies have reported no association between self-reported sleep characteristics and HRQoL, or weak and inconsistent findings.[25-27] It is worth noting that almost all studies have been conducted in high income countries, and little is known about sleep and HRQoL in children living in low-to-middle income countries.

A major limitation of the current literature on sleep and HRQoL is that all the previous studies have relied on self-reported sleep information. Previous validation studies have found substantial discrepancies between self-reported and device-measured sleep in both adults and children.[28-30]

Moreover, these studies have reported that the size of such discrepancies varies by health status and sleep characteristics, and people with poor health and sleep deficiencies tend to have larger differences between device-measured and self-reported sleep measurements. Therefore, there is a need to better understand the association between device-measured sleep characteristics in relation to HRQoL in children.

To address the aforementioned limitations in the literature, we studied device-measured sleep characteristics and HRQoL in an international sample of children, and compared results with those using self-reported measures in the same study. We conducted country-specific analyses to examine and compare the associations across 12 different nations with a wide range of geographic, economic and socio-cultural variability. We hypothesized that short sleep, low sleep efficiency, later sleep timing and larger day-to-day variabilities in sleep characteristics are associated with poor HRQoL in children.

Methods

Study Population

The International Study of Childhood Obesity, Lifestyle and the Environment (ISCOLE) (ClinicalTrials.gov: NCT01722500) is an international cross-sectional study of children (9-11 years) from study sites in 12 countries (Australia, Brazil, Canada, China, Colombia, England, Finland, India, Kenya, Portugal, South Africa, and USA). Details of ISCOLE have been previously published.[31] The countries were selected to maximize geographical, socio-economic and cultural variability: these countries differed widely in several socio-economic indicators: Six countries (Australia, Canada, Finland, Portugal, England and United States) are classified as high income according to World Bank Classification, five (Brazil, Colombia, China, India and South Africa) classified as upper-middle income, and one (Kenya) classified as low income. [32] These countries also range from very high (0.93, Australia) to low (0.51, Kenya) in their

Human Development Index, a composite score based on life expectancy, gross national income, literacy and school participation. [33] Details of economic indicators for all twelve countries have been published before. [31] In each country, children were recruited from one or more school districts that located reasonably close to the local study center. Sampling included students from urban and suburban areas. Rural areas were excluded to maximize comparisons across ISCOLE sites because in some countries, study centers had limited access to rural populations. Each site aimed to recruit a sex-balanced sample of 500 children. Technicians were trained to administer the questionnaire in a standardized fashion in order to minimize bias, and provisions were made to administer the questionnaire via an interview for participants with low levels of literacy. Questionnaires were translated to local languages and children as young as 9 years showed sufficient comprehension of the study questionnaires. Of the total 7,372 children in the final ISCOLE sample, we excluded children who were missing any sleep variables (N=1,081) or HRQoL information (N=25). The analytic sample for this study therefore includes 6,266 children. The Pennington Biomedical Research Center Institutional Review Board approved the ISCOLE protocol and ethical review boards at each site approved local protocols. Written informed consent from parents and child assent were obtained as required by local review boards.

Health-Related Quality of Life

Children in the study completed the KIDSCREEN-10 survey, which provides a global measure of HRQoL in children.[34] The KIDSCREEN-10 is the brief form of KIDSCREEN-54, an instrument that was designed to measure HRQoL among children aged 8-18 years and validated in numerous low-to-middle-income countries.[35,36] The KIDSCREEN-10 included 10 questions on children's physical activity, energy and fitness, mood and emotions, social and leisure participation, social and family relationships, cognitive capacity, and school experience. Responses to each question are recorded on a 5-point scale and participant's scores were reversed when appropriate to ensure that higher scores indicate better

HRQoL. We summed each participant's score across questions to calculate Rasch person-parameters, which were transformed into t-values with a mean of 50 and a standard deviation of approximately 10.[34]

Assessment of Sleep

Sleep was measured by waist-worn accelerometers (Actigraph GT3X+, Actigraph LLC, Pensacola, FL, USA). Actigraphy data collection was conducted during the school year. Data collection was purposefully spread over this period to account for differences across seasons. Children were asked to wear the device 24-hours per day for seven consecutive days, removing it only for water-related activities such as bathing, showering and swimming. Details about the sleep variable assessments were reported before.[37,38] Briefly, for sleep variable calculation, we only included participants with at least three nights (including one weekend night) of valid sleep (total sleep period time ≥160 min). Nocturnal total sleep time was estimated from 1-min epochs using a validated, fully-automated algorithm for waist-worn accelerometers, which captures total sleep time from sleep onset to the end of sleep and all episodes of wakefulness after onset.[38]

From the accelerometry data, we measured three primary sleep variables: 1) duration measured by total sleep time; 2) timing measured by midpoint between sleep onset and offset; and 3) sleep efficiency measured by total sleep time divided by total time spent in bed. We also included an additional sleep timing variable, the onset of sleep time, as some previous studies indicated that bedtime was a significant predictor of HRQoL. [22] Finally, we also calculated mid-sleep time on free days corrected for sleep debt on work days (MSFsc) as an indicator of chronotype. [39] For each sleep variable, we calculated average values for weekday (Sunday through Thursday) and weekend (Friday and Saturday) nights separately. We also derived two indicators of variability for each sleep characteristic: the overall variability was measured by the standard deviation of the sleep characteristic for all valid nights; and the weekday-to-weekend difference was defined as the difference between weekend and weekday values (weekend mean minus weekday mean) for the sleep characteristic. We divided each sleep variable into quartiles. The reference group was chosen to represent the group that was hypothesized to have the highest HRQoL: the longest group (Q4) for total sleep time, the earliest group (Q1) for sleep onset and sleep midpoint, the highest group for sleep efficiency (Q4), and the groups with the smallest absolute value for overall and weekday-to-weekend difference (Q1 for overall variability of all three sleep characteristics as well as weekday-to-weekend difference of midpoint, and Q2 for weekday-to-weekend difference of total sleep time and efficiency). For total sleep time, we also created a 4-category variable (<7 hours, 7-8 hours, 9-12 hours, and >12 hours) and used 9-12 hours as the reference group based on the recommended amount of sleep for pediatric population. [1]

Self-reported sleep measures were obtained by asking children “during the past week, rate the quantity of your sleep overall” or “during the past week, rate the quality of your sleep overall”. Children were asked to choose from four answers: very good, fairly good, fairly bad, or very bad.

Covariates

A wide array of sociodemographic and lifestyle variables from child participants and parents were collected as part of ISCOLE, including age and sex of child participants. Parents reported parental education, and marital status. Parents at each study site also reported annual household income using a monetary scale of 8 to 10 country-specific categories using currencies of each country. These categories were grouped into four levels to facilitate multi-country analysis. The four levels were created to ensure the most balanced distribution possible within each country. Child participants completed a Food Frequency Questionnaire, which has demonstrated moderate reliability and low to moderate- validity.[40] Principal components analysis was used to identify two component scores that represent 1) a healthy diet pattern (positive loadings for vegetables, fruits, whole grains, etc.) and 2) an unhealthy diet pattern (positive loadings for fast food, soft drinks, sweets, etc.). Height and weight were measured objectively using standard techniques.[31] Body-mass index (BMI) was calculated as weight in kilograms divided by height in meters squared and transformed to age- and sex-specific z scores using the World Health Organization reference data.[41]

Statistical Analysis

To report the distribution of participant characteristics, we calculated means and standard deviations for continuous variables and percentages for categorical variables. To examine the associations between sleep variables and HRQoL, we used multi-level multiple linear regression (PROC MIXED) to calculate the mean difference and 95% confidence intervals (CIs) for each quartile of the sleep variable, comparing to the reference group. In the model we adjusted for age (continuous), sex (female, male), parental education (less than high school, high school graduate or some college, completed college or postgraduate degree), parental marital status (married, divorced or separated, never married, widowed), household income (site-specific categories representing low, low-to-medium, medium-to-high and high income levels), BMI z-score (continuous), healthy diet pattern score (continuous) and unhealthy diet pattern score (continuous). Schools were included as random effects in all models, while study sites were included as fixed effects in analysis that included the overall population. We also considered the total number of valid days for sleep recording, as well as the number of valid weekdays and weekend days as covariates, but adjusting for these variables only had a minimal impact on the results, and we did not include them in the final model. Tests for linear trends were performed using the median value for each quartile as a continuous variable. To control for false positives due to multiple comparison, we used a Bonferroni correction of p-value ($p<0.05/130=0.0004$) to determine statistical significance.

Results

The distribution of participant characteristics by study site are presented in **Table 1**. The average age of child participants was 10.4 years and ~55% were girls. Across 12 countries, we observed a relatively wide distribution of BMI z scores (lowest in Kenya and highest in Portugal) and healthy (lowest in Brazil and highest in Canada) and unhealthy diet patterns (lowest in Finland and highest in South Africa). Parental education levels and marital status also varied substantially across sites.

The distribution of number of valid nights, HRQoL and sleep variables are presented in **Table 2**. Overall the number of valid nights across different sites are similar. Finland had the lowest average number of nights (4.79) while China had the highest (5.76). Most of the countries had more than 5.5 valid nights. We observed considerable variation in HRQoL scores and total sleep time and sleep timing across countries. Kenya had the lowest HRQoL score (47.1) and Portugal had the highest (53.0). Total sleep time on weekdays varied between 8.12 hr (Portugal) to 9.53 hr (Australia) while weekend total sleep time was between 8.55 hr (Finland) and 9.62 hr (Colombia). For overall variability in total sleep time, China had the smallest standard deviation (0.98) while Colombia had the largest (1.52). For weekday-to-weekend variability, the average total sleep time on weekends was generally longer than that on weekdays, except for Australia and Canada, for which weekend sleep was ~0.3 hr shorter than weekday sleep. We also observed a relatively wide range of midpoint of sleep on both weekdays (earliest: 1:46, Kenya; latest: 3:08, Brazil) and weekends (earliest: 2:59, China and Portugal; latest: 4:07, Brazil). Overall variability of sleep midpoint was between 0.64 hr (China) and 0.96 hr (Brazil). Weekend sleep midpoint was later than weekday sleep midpoint for all countries, and the difference ranged from 0.70 (Canada) to 1.14 hr (USA). In contrast, sleep efficiency was consistently high in all countries and on both weekdays and weekends, ranging from 95% to 97% on average, and there was little overall or weekday to weekend day variability in sleep efficiency. For self-reported sleep, only a small fraction of children reported very bad or fairly bad sleep quality and quantity. China had the highest percent of children reporting both bad sleep quality (15.3%) and quantity (14.3%), while Kenya (4.8%) and Portugal (3.2%) had the lowest percent for reporting bad sleep quality and quantity, respectively.

Overall, we found little evidence supporting an association between HRQoL and total sleep time (**Table 3**), midpoint of sleep (**Table 4**) or sleep efficiency (**Table 5**). Most of the effect estimates were not statistically significant and no consistent patterns emerged as the magnitude and direction of effect estimates for all three sleep variables varied considerably among countries. The results were similar before and after adjusting for covariates. For total sleep time and sleep efficiency, neither the average values on weekdays or weekend days, nor the two measures of variability, were associated with HRQoL. We also performed analysis using total sleep time as a four-category and the results were similarly null (data not shown). For midpoint of sleep, the findings were also largely null. However, we found that the average sleep midpoint on weekends was positively associated with HRQoL in England with a 5.49 point increase in HRQoL score comparing the latest quartile to the earliest ($\beta_{Q4 \text{ vs } Q1}$ (95% CI), 5.39 (2.69, 8.09), p-trend=0.0002). Results for timing of sleep onset were largely null (**Supplementary Table 1**). In addition, we did not find an association between MSFsc and HRQoL (data not shown).

Finally, we examined subjective ratings of sleep quantity and quality in relation to HRQoL. First, we found that the correlation between self-reported and actigraphy-measured sleep variables were generally null or weak (Spearman correlation coefficient, -0.07-0.10, **Supplementary Table 2**). Next, In contrast to the null findings for device-measured sleep variables, poorer ratings of both sleep quantity and quality were associated with worse HRQoL in almost all countries (**Table 6**). In the full sample, ratings of “very bad” or “fairly bad” for sleep quantity or quality were associated with a more than six point reduction in HRQoL.

Discussion

In this international sample of 9-11 year-old children, we found that sleep characteristics, especially device-measured duration and timing, vary substantially across different countries. Overall our findings do not support a relationship between device-measured sleep characteristics and HRQoL, although there appeared to be some evidence suggesting that device-measured sleep timing might be associated with HRQoL in England. On the other hand, we found that children with poor self-reported ratings of sleep quantity and quality on average reported lower HRQoL.

A growing body of literature has examined the relationship between multiple sleep characteristics and HRQoL in children and adolescents. All of the previous studies used self-reported sleep measures and most examined sleep duration. Several studies have reported a positive association between self-reported sleep duration and HRQoL in children and adolescents in a wide range of countries, including Israel,[20] US,[17] Korea,[18] Switzerland,[19] and Spain.[15] For example, in over 3,000 children (age 11-17 years) from Houston, Texas, Roberts et al. found that self-reporting less than 6 hours of sleep on weekdays and weekends was associated with a higher likelihood of reporting low life satisfaction, poor perceived mental health, depressed mood, problems at school and lower grades, as well as drug use.[17] In another study that included a large sample of Korean adolescents (age 13-17 years), self-reported short sleep duration (<7 hours) was associated with a higher probability of reporting depressive symptoms, suicidal ideation and overweight and obesity, and lower probability of reporting "very healthy" for self-rated health.[18] In addition, a few studies also examined self-reported sleep characteristics related to sleep quality, including daytime sleepiness and morning tiredness (nonrestorative sleep), and symptoms related to insomnia, such as sleep latency and waking during the night.[15,20,21] Overall their findings suggested that self-reported poor sleep quality was related to multiple domains of health and well-being, including perceived health status, life satisfaction, quality of relationships, and academic performance.

A major gap in the literature was a lack of studies that examined device-measured sleep characteristics, as all the aforementioned studies used survey questionnaires. In this current study, although we confirmed a positive association between self-reported poor sleep quantity and quality and low HRQoL, we found no association when evaluating device-measured sleep characteristics. In the adult population, studies that have compared self-reported with device-measured sleep duration generally found only a moderate correlation between the two (r=0.45-0.47).[28,29] The studies generally found that self-report comparatively overestimates sleep duration by ~1 hr, and the validity of self-reported sleep was lower among people with poor health status, shorter sleep duration and higher device-measured sleep variability. Although similar validation studies are limited in children, some evidence suggests that there is also considerable discrepancy between self-reported and device-based sleep measurements in children. For example, Alfano et al. reported no or weak correlations between self/parent-reported and actigraphy-measured sleep characteristics.[30] Moreover, the study by Alfano et al. also found that the differences between device-based and self-reported sleep were larger in children with anxiety disorders when compared to healthy children. On one hand, these validation studies in children and adults suggest that self-reported sleep patterns may not accurately reflect objective characteristics of the sleep behavior, particularly in populations with poor sleep and health status, which may introduce both errors and biases in studies focusing on the relationships between sleep and health outcomes. On the other hand, it is worth noting that self-reported sleep can capture subjective perceptions about sleep and the fact that it correlates better with health outcomes suggest it may better reflect self-appraisal of overall health, which itself is an important domain of health and well-being. Therefore self-reported sleep should not be dismissed as merely an inaccurate measure. Instead, we encourage future studies to include both device-based and self-reported sleep measures as they may reveal how different aspects of sleep behavior may be associated with health outcomes.

Besides sleep duration and quality, sleep timing has received increasing attention in the past decade and has been recognized as an important aspect of sleep health. Particularly, late sleep timing has been highlighted as a risk factor for multiple adverse health outcomes in children and adolescents, including obesity and mental health.[42] For school children, the schedule of school on weekdays has a substantial impact on their sleep timing, particularly the timing for waking up. When school start time is early, those children with a preference for a later sleep timing (or later chronotype) are more likely to suffer from sleep deficiency and its related health consequences. Indeed, several studies reported a relationship between a late sleep timing and poor HRQoL. For instance, Chen et al. reported that a late self-reported bedtime was associated with poor feelings, poor daily activities, pain and an overall poor rating of health in a group of Japanese children ages 12-13. [23] Similarly, in another study of Israeli adolescents who were ~14 years old, Tizischinsky et al. found that a later self-reported chronotype was associated with lower HRQoL.[20] Additionally, in a sample of nearly 5,000 Australian children with self-reported sleep timing data, those with a bedtime later than the sample median reported poorer HRQoL when compared to those with an earlier bedtime.[22] However, overall our results do not support a relationship between device-measured sleep timing and HRQoL, which again may be due to the differences between device-based and self-reported sleep measurements. Interestingly we found that later device-measured sleep timing on weekends was associated with a higher HRQoL in England. This particular result could be due to chance alone, or it could be explained by unmeasured cultural or environmental factors unique to England.

Our study has some important strengths. As discussed above, we used both device-measured and self-reported sleep measurements, which could provide different perspectives about sleep and its relationship with health outcomes. Moreover, we studied an international sample of children from 12 countries with vastly different cultural and economic conditions, which has expanded the previous literature that focused on developed regions alone. However, our study also has several limitations. First of all, we did not have information on sports training and schedules of other important extracurricular activities, which may have a substantial impact on both sleep and HRQoL. Second, although children were recruited from different countries, all of the recruitment centers were located in relatively large cities and our sample was not representative of the population in each country. Specifically we lacked information on children living in rural communities. Third, the distribution of device-measured sleep efficiency was limited in range and almost all children had high sleep efficiency, probably due to the tendency of waist-worn actigraphy to overestimate sleep duration (by approximately 1 hour) compared to wrist-worn protocols.[43] Fourth, children's sleep can be impacted by school schedules and a wide range of weekday and weekend activities, such as sports and other extracurricular lessons, church attendance and community activities, all of which may vary across different schools and societies. Unfortunately we do not have detailed information on these activities, and could not control for their influence on sleep and HRQoL in our analysis. Fifth, seasonal and geographic variations in the time of sunrise and sunset are also known to have an impact on sleep, but we did not collect data on sunrise and sunset time during the period of actigraphy assessment and weren't able to control for their potential impact on our results. Moreover, we only recorded sleep for seven days, which may not represent the habitual sleep patterns of children. Also, self-reported sleep information was only obtained at one time point and may not capture children's long-term perceptions about sleep. Finally, most of the children included in our study were relatively healthy and on average they reported high HRQoL. Therefore we were not able to examine the relationship between sleep and HRQoL in children with less healthy status.

In conclusion, while lower self-reported sleep quantity and quality were associated with poor HRQoL, device-measured sleep characteristics were not. These findings highlight the importance of using both device-based and subjective measures of sleep to fully understand its relationship with health outcomes, particularly self-reported outcomes such as HRQoL.

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Table 1 Study characteristics by study site in 6,266 children in ISCOLE (2011-2013).

							Highest Parental Education (%) [b]			Parental Marital Status (%) [b]			
	No.	Female (%)	Age, yr mean (SD)	zBMI [a] mean (SD)	Healthy diet score mean (SD)	Unhealthy diet score mean (SD)	Less than high school	High school or some college	College or higher	Married	Divorced or separated	Never Married	Widowed
Overall	6266	54.8	10.4 (0.6)	0.46 (1.26)	0.00 (1.00)	-0.05 (0.95)	19.0	40.5	36.3	64.0	14.0	16.0	1.7
Australia (Adelaide)	464	53.7	10.7 (0.4)	0.58 (1.12)	0.24 (0.96)	-0.30 (0.73)	11.2	45.7	40.5	72.0	19.6	4.5	0.7
Brazil (Sao Paulo)	479	51.4	10.5 (0.5)	0.84 (1.41)	-0.43 (1.05)	0.10 (0.90)	21.7	50.3	20.9	52.2	15.7	21.9	2.9
Canada (Ottawa)	513	59.1	10.5 (0.4)	0.41 (1.21)	0.47 (0.98)	-0.49 (0.57)	2.0	26.1	70.8	75.8	13.8	8.8	0.8
China (Tianjin)	470	48.7	9.9 (0.5)	0.73 (1.54)	0.07 (0.90)	-0.26 (0.93)	34.5	44.5	20.6	93.0	6.2	0.0	0.6
Colombia (Bogota)	843	50.7	10.5 (0.6)	0.21 (1.04)	-0.45 (0.74)	-0.08 (0.55)	30.5	51.3	18.2	24.9	24.4	47.6	3.0
England (Bath and North East Somerset)	424	56.8	10.9 (0.5)	0.45 (1.09)	0.03 (0.92)	-0.15 (0.76)	2.8	46.0	42.5	59.4	18.9	13.0	0.2
Finland (Helsinki, Espoo, and Vantaa)	464	54.7	10.5 (0.4)	0.26 (1.04)	-0.16 (0.86)	-0.55 (0.44)	2.6	51.1	40.5	61.4	17.5	14.7	0.4
India (Bangalore)	548	54.4	10.4 (0.5)	0.23 (1.36)	-0.08 (0.89)	-0.10 (0.83)	5.1	21.2	72.6	95.6	1.1	0.4	1.8
Kenya (Nairobi)	469	54.8	10.2 (0.7)	-0.03 (1.21)	0.27 (0.99)	0.12 (1.01)	14.1	46.3	39.5	81.7	6.8	6.8	4.1
Portugal (Porto)	651	56.8	10.4 (0.3)	0.85 (1.15)	0.22 (1.04)	-0.35 (0.66)	41.2	30.0	19.1	69.1	14.3	7.1	0.5
South Africa (Cape Town)	461	61.2	10.3 (0.7)	0.27 (1.29)	0.23 (1.08)	1.14 (1.20)	41.7	32.3	12.4	52.5	8.7	20.4	3.9
USA (Baton Rouge)	480	58.1	9.9 (0.6)	0.74 (1.29)	-0.14 (1.14)	0.63 (1.40)	6.0	41.7	50.8	53.5	15.4	27.7	1.0

[a] Body mass index z-score (World Health Organization)

[b] Percentages do not add up to 100% due to missingness

Abbreviations: ISCOLE, International Study of Childhood Obesity, Lifestyle and the Environment; USA, United States of America

Table 2 Distribution of HRQoL and objective and subjective sleep variables by study site in ISCOLE

	Australia	Brazil	Canada	China	Colombia	England	Finland	India	Kenya	Portugal	South Africa	USA
HRQoL (mean (SD))	49.86 (8.63)	47.23 (7.72)	51.18 (9.2)	51.2 (11.48)	49.9 (8.11)	50.07 (8.78)	52.62 (8.71)	48.14 (9.26)	47.07 (9.86)	53.04 (10.54)	49.34 (10.88)	50.81 (10.37)
Actigraph sleep variables, (mean (SD))												
No. of valid nights (mean (SD))	5.67 (0.67)	5.67 (0.62)	5.73 (0.59)	5.76 (0.59)	5.69 (0.66)	5.50 (0.80)	4.79 (0.59)	5.44 (0.72)	5.17 (0.93)	5.67 (0.68)	5.57 (0.76)	5.28 (0.84)
Weekday												
Total sleep time, h	9.53 (0.74)	8.34 (1.04)	9.18 (0.92)	8.57 (0.69)	8.38 (0.99)	9.44 (0.79)	8.41 (1.02)	8.35 (0.84)	8.30 (0.98)	8.12 (0.95)	9.06 (0.87)	8.79 (1.05)
Sleep onset, HH:MM	21:19 (0:46)	23:59 (1:10)	21:03 (0:50)	21:01 (0:41)	21:11 (0:50)	21:07 (0:43)	22:25 (0:56)	22:28 (0:47)	21:19 (0:44)	23:53 (0:55)	21:20 (0:44)	21:04 (0:53)
Sleep offset, HH:MM	7:08 (0:38)	7:17 (1:23)	7:03 (0:44)	6:28 (0:24)	6:07 (0:49)	7:14 (0:35)	6:55 (0:39)	6:48 (0:40)	5:54 (0:44)	7:10 (0:42)	6:38 (0:42)	6:38 (0:45)
Midpoint of sleep, HH:MM	2:23 (0:35)	3:08 (1:10)	2:28 (0:38)	2:01 (0:26)	1:56 (0:40)	2:31 (0:31)	2:43 (0:38)	2:38 (0:36)	1:46 (0:33)	3:07 (0:40)	2:07 (0:34)	2:15 (0:39)
Sleep efficiency	0.95 (0.01)	0.96 (0.01)	0.96 (0.01)	0.97 (0.01)	0.96 (0.01)	0.96 (0.01)	0.97 (0.01)	0.97 (0.01)	0.96 (0.02)	0.97 (0.01)	0.96 (0.02)	0.96 (0.01)
Weekend												
Total sleep time, h	9.23 (1.35)	9.00 (1.42)	8.88 (1.24)	9.22 (1.11)	9.62 (1.27)	9.61 (1.34)	8.55 (1.45)	9.13 (1.19)	9.30 (1.37)	8.58 (1.39)	9.43 (1.36)	9.04 (1.37)
Sleep onset, HH:MM	22:22 (1:13)	23:20 (1:23)	22:12 (1:10)	22:34 (1:01)	22:44 (1:13)	22:23 (1:07)	23:44 (1:07)	22:09 (1:01)	21:01 (1:05)	23:13 (1:10)	22:40 (1:07)	22:04 (1:18)
Sleep offset, HH:MM	7:46 (1:10)	8:37 (1:22)	7:35 (1:09)	7:35 (1:02)	7:49 (1:14)	8:08 (1:09)	7:46 (1:10)	7:55 (1:08)	7:12 (1:10)	8:18 (1:18)	7:42 (1:09)	7:55 (1:16)
Midpoint of sleep, HH:MM	3:10 (1:00)	4:07 (1:11)	3:10 (0:59)	2:59 (0:52)	3:01 (1:03)	3:21 (0:55)	3:29 (0:54)	3:21 (0:54)	2:34 (0:54)	4:01 (1:02)	2:59 (0:55)	3:24 (1:06)
Sleep efficiency	0.96 (0.02)	0.96 (0.02)	0.96 (0.02)	0.96 (0.02)	0.96 (0.02)	0.96 (0.02)	0.97 (0.01)	0.97 (0.01)	0.96 (0.02)	0.97 (0.01)	0.96 (0.02)	0.96 (0.02)
Overall variability [a]												
Total sleep time, h	1.04 (0.60)	1.50 (0.70)	1.11 (0.58)	0.98 (0.53)	1.52 (0.73)	1.06 (0.56)	1.24 (0.70)	1.13 (0.61)	1.17 (0.69)	1.23 (0.59)	1.21 (0.64)	1.26 (0.73)
Sleep onset, h	0.88 (0.48)	1.04 (0.54)	0.92 (0.52)	0.76 (0.41)	0.90 (0.46)	0.81 (0.44)	0.97 (0.66)	0.75 (0.46)	0.73 (0.45)	0.98 (0.53)	0.92 (0.5)	1.05 (0.56)
Sleep offset, h	0.82 (0.49)	1.34 (0.62)	0.85 (0.47)	0.81 (0.48)	1.43 (0.70)	0.88 (0.50)	0.97 (0.49)	0.97 (0.53)	1.01 (0.67)	1.09 (0.49)	0.97 (0.57)	1.08 (0.63)
Midpoint of sleep, h	0.69 (0.36)	0.96 (0.41)	0.71 (0.37)	0.64 (0.33)	0.94 (0.44)	0.69 (0.35)	0.79 (0.40)	0.68 (0.36)	0.69 (0.40)	0.85 (0.39)	0.76 (0.38)	0.88 (0.43)
Sleep efficiency	0.01 (0.01)	0.01 (0.01)	0.01 (0.01)	0.01 (0.01)	0.01 (0.01)	0.01 (0.01)	0.01 (0)	0.01 (0.01)	0.01 (0.01)	0.01 (0)	0.01 (0.01)	0.01 (0.01)
Weekday-to-weekend difference [b]												
Total sleep time, h	-0.30 (1.41)	0.66 (1.75)	-0.31 (1.27)	0.66 (1.15)	1.24 (1.49)	0.17 (1.37)	0.14 (1.53)	0.78 (1.29)	1.00 (1.42)	0.46 (1.48)	0.37 (1.57)	0.24 (1.54)
Sleep onset, h	0.94 (1.08)	0.65 (1.12)	0.84 (1.05)	0.45 (0.89)	0.44 (1.09)	0.74 (0.96)	0.68 (1.16)	0.31 (0.90)	0.29 (1.02)	0.67 (1.14)	0.67 (1.08)	1.01 (1.18)
Sleep offset, h	0.65 (1.09)	1.33 (1.50)	0.55 (1.00)	1.11 (1.00)	1.69 (1.28)	0.92 (1.10)	0.85 (1.14)	1.11 (1.08)	1.30 (1.20)	1.14 (1.26)	1.06 (1.17)	1.27 (1.24)
Midpoint of sleep, h	0.80 (0.83)	0.99 (1.00)	0.70 (0.82)	0.79 (0.75)	1.07 (0.93)	0.83 (0.78)	0.77 (0.86)	0.71 (0.76)	0.80 (0.86)	0.91 (0.96)	0.87 (0.82)	1.14 (0.94)
Sleep efficiency	0 (0.01)	0 (0.02)	0 (0.01)	-0.01 (0.02)	0 (0.02)	0 (0.01)	0 (0.01)	0 (0.01)	0 (0.02)	0 (0.01)	0 (0.02)	0 (0.02)
Self-reported sleep variables, N (%)												
Sleep quantity, fairly bad or very bad	49 (8.2)	26 (5.4)	45 (8.8)	67 (14.3)	60 (7.1)	49 (11.6)	40 (8.6)	74 (13.5)	40 (8.5)	31 (4.8)	54 (11.7)	61 (12.7)
Sleep quality, fairly bad or very bad	39 (8.4)	22 (4.6)	42 (8.2)	72 (15.3)	35 (4.2)	64 (15.1)	33 (7.1)	44 (8.0)	15 (3.2)	24 (3.7)	33 (7.2)	59 (12.3)

[a] Measured as standard deviation of all valid nights

[b] Measured as the average of sleep variables for weekends minus that for weekdays

Abbreviations: HRQoL, health-related quality of life; ISCOLE, International Study of Childhood Obesity, Lifestyle and the Environment SD, standard deviation; USA, United States of America

Table 3 Multivariable adjusted [a] associations between HRQoL and objectively-measured total sleep time in ISCOLE

	Quartiles of Sleep Variable					
	Q 1	**Q 2**	**Q 3**	**Q 4**	***p-for-trend***	**1 h increase**
			Weekday total sleep time, h			
Median and IQR	7.51 (7.08, 7.80)	8.38 (8.21, 8.53)	8.99 (8.83, 9.16)	9.78 (9.53, 10.14)		
Adjusted mean difference and 95% CI in HRQoL						
Australia	-1.04 (-6.63, 4.55)	-2.47 (-5.16, 0.21)	-0.92 (-2.67, 0.82)	ref	*0.08*	0.56 (-0.53, 1.65)
Brazil	-2.00 (-4.03, 0.04)	-2.05 (-4.19, 0.10)	-3.06 (-5.34, -0.78)	ref	*0.25*	0.65 (-0.02, 1.32)
Canada	-0.50 (-3.20, 2.20)	-0.03 (-2.30, 2.23)	-0.38 (-2.30, 1.54)	ref	*0.85*	0.05 (-0.81, 0.92)
China	-3.38 (-7.23, 0.47)	-0.42 (-3.89, 3.04)	-3.14 (-6.69, 0.41)	ref	*0.61*	0.52 (-0.95, 1.99)
Colombia	-0.38 (-2.01, 1.25)	-0.27 (-1.95, 1.41)	0.53 (-1.26, 2.32)	ref	*0.38*	0.19 (-0.36, 0.73)
England	0.30 (-5.14, 5.73)	0.81 (-1.78, 3.41)	0.46 (-1.42, 2.35)	ref	*0.54*	-0.39 (-1.45, 0.66)
Finland	-0.28 (-2.75, 2.19)	-1.29 (-3.83, 1.24)	-1.13 (-3.63, 1.36)	ref	*0.97*	0.08 (-0.71, 0.87)
India	-0.20 (-2.79, 2.40)	-1.14 (-3.70, 1.42)	-0.37 (-3.05, 2.31)	ref	*0.93*	-0.27 (-1.19, 0.65)
Kenya	-0.29 (-3.00, 2.41)	-0.61 (-3.37, 2.15)	-0.42 (-3.41, 2.57)	ref	*0.89*	0.05 (-0.81, 0.91)
Portugal	0.80 (-2.20, 3.81)	0.66 (-2.47, 3.79)	1.56 (-1.68, 4.81)	ref	*0.95*	0.07 (-0.76, 0.90)
South Africa	2.90 (-0.52, 6.32)	0.04 (-2.57, 2.65)	-0.76 (-3.07, 1.54)	ref	*0.24*	-0.51 (-1.62, 0.60)
USA	1.34 (-1.45, 4.12)	1.04 (-1.57, 3.66)	0.74 (-1.72, 3.21)	ref	*0.32*	-0.53 (-1.43, 0.37)
Overall	-0.40 (-1.09, 0.30)	-0.40 (-1.07, 0.28)	-0.38 (-1.03, 0.28)	ref	*0.30*	0.09 (-0.15, 0.33)
			Weekend total sleep time, h			
Median and IQR	7.68 (7.00, 8.08)	8.82 (8.60, 9.01)	9.57 (9.37, 9.77)	10.50 (10.20, 11.03)		
Adjusted mean difference and 95% CI in HRQoL						
Australia	-0.25 (-2.45, 1.95)	-1.28 (-3.49, 0.93)	-0.44 (-2.51, 1.64)	ref	*0.63*	0.00 (-0.57, 0.57)
Brazil	-0.60 (-2.60, 1.41)	0.22 (-1.86, 2.30)	-0.67 (-2.72, 1.38)	ref	*0.76*	0.12 (-0.37, 0.61)
Canada	0.42 (-2.11, 2.95)	1.56 (-0.95, 4.07)	-0.78 (-3.24, 1.68)	ref	*0.31*	-0.46 (-1.13, 0.20)
China	-0.19 (-3.39, 3.01)	-0.51 (-3.33, 2.31)	0.26 (-2.57, 3.09)	ref	*0.74*	-0.05 (-0.96, 0.85)
Colombia	-0.61 (-2.27, 1.05)	0.75 (-0.74, 2.24)	-0.63 (-1.97, 0.70)	ref	*0.94*	0.01 (-0.41, 0.43)
England	-2.35 (-4.82, 0.12)	-0.92 (-3.21, 1.37)	1.10 (-0.98, 3.19)	ref	*0.05*	0.61 (-0.02, 1.23)
Finland	-2.19 (-4.68, 0.30)	-0.08 (-2.73, 2.58)	-0.51 (-3.19, 2.18)	ref	*0.05*	0.25 (-0.31, 0.80)
India	0.26 (-1.94, 2.46)	1.05 (-1.00, 3.10)	-1.19 (-3.34, 0.97)	ref	*0.33*	0.04 (-0.57, 0.66)
Kenya	-1.30 (-3.79, 1.18)	-0.51 (-2.81, 1.79)	-1.39 (-3.66, 0.87)	ref	*0.45*	0.26 (-0.36, 0.88)
Portugal	-0.13 (-2.61, 2.36)	-0.76 (-3.42, 1.89)	1.12 (-1.62, 3.85)	ref	*0.52*	0.24 (-0.34, 0.82)
South Africa	-0.32 (-3.12, 2.48)	-0.44 (-3.02, 2.14)	0.39 (-2.22, 3.00)	ref	*0.71*	0.08 (-0.66, 0.81)
USA	0.86 (-1.85, 3.57)	-0.18 (-2.81, 2.45)	-0.39 (-3.20, 2.43)	ref	*0.50*	-0.33 (-1.01, 0.36)

Overall	-0.20 (-0.87, 0.47)	0.07 (-0.58, 0.72)	-0.14 (-0.78, 0.51)	ref	*0.72*	-0.01 (-0.18, 0.17)
Overall variability total sleep time, [b] h						
Median and IQR	0.56 (0.44, 0.65)	0.91 (0.82, 0.99)	1.29 (1.18, 1.42)	2.00 (1.74, 2.43)		
Adjusted mean difference and 95% CI in HRQoL						
Australia	ref	1.43 (-0.48, 3.34)	0.12 (-2.12, 2.36)	0.77 (-1.50, 3.05)	*0.65*	-0.23 (-1.54, 1.07)
Brazil	ref	0.07 (-2.66, 2.80)	-0.40 (-3.02, 2.23)	-1.04 (-3.63, 1.54)	*0.22*	-0.80 (-1.78, 0.18)
Canada	ref	0.63 (-1.41, 2.68)	2.23 (0.11, 4.36)	0.94 (-1.45, 3.33)	*0.15*	0.94 (-0.43, 2.30)
China	ref	0.22 (-2.23, 2.67)	0.06 (-2.77, 2.88)	1.11 (-2.33, 4.55)	*0.63*	0.09 (-1.80, 1.97)
Colombia	ref	0.09 (-1.87, 2.04)	-0.57 (-2.44, 1.29)	0.50 (-1.26, 2.25)	*0.50*	0.22 (-0.51, 0.95)
England	ref	-1.12 (-3.23, 1.00)	-2.99 (-5.12, -0.86)	0.57 (-1.92, 3.05)	*0.39*	-0.18 (-1.63, 1.27)
Finland	ref	-2.10 (-4.44, 0.23)	-1.68 (-3.90, 0.54)	-1.41 (-3.55, 0.74)	*0.26*	-0.42 (-1.55, 0.71)
India	ref	-0.13 (-2.12, 1.86)	-0.26 (-2.33, 1.80)	1.25 (-0.89, 3.40)	*0.34*	0.85 (-0.37, 2.08)
Kenya	ref	-0.27 (-2.54, 2.00)	0.25 (-2.10, 2.60)	0.35 (-2.06, 2.76)	*0.70*	-0.13 (-1.35, 1.09)
Portugal	ref	-1.31 (-3.71, 1.09)	0.27 (-1.97, 2.50)	-1.02 (-3.38, 1.34)	*0.75*	-0.62 (-1.96, 0.72)
South Africa	ref	-1.52 (-4.24, 1.20)	1.53 (-1.13, 4.20)	-0.86 (-3.66, 1.94)	*0.83*	0.22 (-1.26, 1.70)
USA	ref	2.40 (-0.18, 4.97)	1.17 (-1.51, 3.84)	-0.06 (-2.59, 2.46)	*0.70*	-0.74 (-2.05, 0.56)
Overall	ref	-0.11 (-0.75, 0.54)	0.13 (-0.52, 0.78)	0 (-0.66, 0.65)	*0.84*	-0.11 (-0.46, 0.24)
Weekday-to-weekend difference of total sleep time, [c] h						
Median and IQR	-1.18 (-1.76, -0.78)	0.03 (-0.20, 0.24)	0.89 (0.67, 1.13)	2.17 (1.72, 2.76)		
Adjusted mean difference and 95% CI in HRQoL						
Australia	-0.65 (-2.42, 1.12)	ref	0.30 (-2.06, 2.65)	-1.89 (-4.86, 1.09)	*0.95*	-0.14 (-0.68, 0.40)
Brazil	-0.69 (-2.75, 1.37)	ref	-2.20 (-4.29, -0.11)	-0.81 (-2.80, 1.18)	*0.52*	-0.13 (-0.54, 0.27)
Canada	-0.01 (-1.84, 1.81)	ref	-1.16 (-3.47, 1.16)	-0.38 (-3.50, 2.73)	*0.46*	-0.41 (-1.03, 0.21)
China	-1.21 (-4.64, 2.21)	ref	-1.76 (-4.31, 0.79)	-0.94 (-3.77, 1.88)	*0.65*	-0.21 (-1.08, 0.66)
Colombia	-0.81 (-2.87, 1.25)	ref	-0.95 (-2.61, 0.71)	-0.58 (-2.13, 0.96)	*0.87*	-0.08 (-0.44, 0.28)
England	-2.22 (-4.28, -0.16)	ref	1.42 (-0.84, 3.68)	-1.02 (-3.58, 1.53)	*0.06*	0.68 (0.09, 1.27)
Finland	0.55 (-1.50, 2.60)	ref	-0.21 (-2.45, 2.03)	1.16 (-1.18, 3.49)	*0.77*	0.18 (-0.33, 0.70)
India	2.13 (-0.23, 4.50)	ref	0.59 (-1.38, 2.55)	1.53 (-0.46, 3.52)	*0.89*	0.14 (-0.44, 0.72)
Kenya	1.84 (-1.17, 4.84)	ref	1.67 (-0.84, 4.17)	2.03 (-0.41, 4.47)	*0.41*	0.22 (-0.38, 0.82)
Portugal	0.44 (-1.77, 2.65)	ref	0.45 (-1.83, 2.73)	1.77 (-0.49, 4.03)	*0.23*	0.18 (-0.36, 0.72)
South Africa	-2.90 (-5.55, -0.26)	ref	-1.91 (-4.63, 0.81)	-0.82 (-3.63, 1.99)	*0.28*	0.22 (-0.40, 0.83)
USA	-0.86 (-3.29, 1.58)	ref	-0.03 (-2.69, 2.64)	-1.00 (-3.72, 1.73)	*0.98*	-0.02 (-0.62, 0.59)
Overall	-0.25 (-0.90, 0.39)	ref	-0.40 (-1.04, 0.25)	-0.15 (-0.81, 0.51)	*0.94*	-0.03 (-0.19, 0.12)

[a] Models were adjusted for age, sex, parental education, parental marital status, household income, healthy diet score, unhealthy diet score and body-mass index. School was included as a random effect.

[b] Measured as standard deviation of all valid nights.

[c] Measured as the weekend sleep duration – weekday sleep duration.
Abbreviation: CI, confidence interval; HRQoL, health-related quality of life; IQR, interquartile range; ISCOLE, International Study of Childhood Obesity, Lifestyle and the Environment USA, United States of America.

Table 4 Multivariable adjusted [a] associations between HRQoL and objectively-measured sleep midpoint in ISCOLE.

	Quartiles of Sleep Variable					
	Q 1	**Q 2**	**Q 3**	**Q 4**	***p-for-trend***	**1 h increase**
			Weekday sleep midpoint, HH:MM			
Median and IQR	1:35 (1:20, 1:46)	2:09 (2:02, 2:15)	2:36 (2:29, 2:43)	3:16 (3:03, 3:38)		
Adjusted mean difference and 95% CI in HRQoL						
Australia	ref	-2.07 (-4.23, 0.10)	-1.01 (-3.14, 1.12)	-1.10 (-3.50, 1.30)	*0.54*	-0.58 (-1.92, 0.77)
Brazil	ref	-0.74 (-3.47, 1.99)	-0.31 (-2.80, 2.18)	0.74 (-1.50, 2.97)	*0.24*	0.22 (-0.39, 0.82)
Canada	ref	0.72 (-1.56, 3.00)	-0.02 (-2.32, 2.28)	-2.08 (-4.41, 0.25)	*0.04*	-1.45 (-2.68, -0.22)
China	ref	0.38 (-2.19, 2.95)	-0.73 (-3.66, 2.20)	-0.86 (-5.73, 4.00)	*0.54*	-1.06 (-3.53, 1.40)
Colombia	ref	0.42 (-0.93, 1.77)	-0.30 (-1.81, 1.21)	-0.44 (-2.46, 1.57)	*0.65*	-0.02 (-0.84, 0.80)
England	ref	2.75 (-0.34, 5.84)	3.25 (0.23, 6.28)	4.34 (1.13, 7.56)	*0.01*	2.52 (0.92, 4.13)
Finland	ref	-0.48 (-3.81, 2.86)	-0.32 (-3.56, 2.92)	-1.45 (-4.62, 1.72)	*0.25*	-0.59 (-1.83, 0.65)
India	ref	-0.51 (-3.41, 2.39)	-0.38 (-3.17, 2.41)	-1.79 (-4.62, 1.04)	*0.14*	-0.71 (-1.97, 0.55)
Kenya	ref	2.16 (0.19, 4.14)	-2.06 (-5.25, 1.14)	-2.24 (-6.69, 2.21)	*0.55*	-0.92 (-2.46, 0.62)
Portugal	ref	-3.07 (-9.58, 3.44)	0.52 (-5.48, 6.51)	1.21 (-4.68, 7.10)	*0.03*	1.48 (0.29, 2.67)
South Africa	ref	0.20 (-2.16, 2.56)	0.36 (-2.40, 3.13)	0.73 (-3.13, 4.60)	*0.69*	0.31 (-1.51, 2.13)
USA	ref	-1.88 (-4.24, 0.48)	-0.70 (-3.31, 1.92)	-3.25 (-6.19, -0.31)	*0.08*	-1.68 (-3.16, -0.20)
Overall	ref	0.22 (-0.45, 0.88)	0.41 (-0.28, 1.09)	0.25 (-0.48, 0.98)	*0.42*	0.11 (-0.23, 0.45)
			Weekend sleep midpoint, HH:MM			
Median and IQR	2:08 (1:48, 2:21)	2:54 (2:43, 3:03)	3:33 (3:23, 3:45)	4:34 (4:13, 5:03)		
Adjusted mean difference and 95% CI in HRQoL						
Australia	ref	-0.63 (-2.68, 1.41)	-1.68 (-3.83, 0.47)	-1.65 (-3.87, 0.57)	*0.09*	-0.70 (-1.48, .007)
Brazil	ref	-0.20 (-3.18, 2.79)	0.54 (-2.30, 3.38)	0.50 (-2.08, 3.07)	*0.53*	-0.05 (-0.65, 0.55)
Canada	ref	-1.25 (-3.35, 0.85)	-1.64 (-3.84, 0.56)	-1.56 (-3.92, 0.80)	*0.15*	-0.73 (-1.55, 0.09)
China	ref	-0.06 (-2.60, 2.48)	3.00 (0.16, 5.84)	0.05 (-3.38, 3.49)	*0.27*	0.08 (-1.12, 1.28)
Colombia	ref	-0.95 (-2.34, 0.45)	0.99 (-0.43, 2.4)	0.45 (-1.17, 2.07)	*0.22*	0.17 (-0.35, 0.68)
England	ref	3.13 (0.69, 5.56)	3.68 (1.18, 6.18)	5.39 (2.69, 8.09)	*0.0002*	1.62 (0.71, 2.54)
Finland	ref	1.13 (-1.49, 3.75)	0.01 (-2.44, 2.46)	-0.42 (-3.00, 2.15)	*0.41*	-0.45 (-1.35, 0.46)
India	ref	0.13 (-2.10, 2.35)	0.63 (-1.51, 2.77)	0.49 (-1.84, 2.82)	*0.57*	0.04 (-0.80, 0.87)
Kenya	ref	0.38 (-1.69, 2.46)	-0.51 (-3.03, 2.00)	-1.66 (-4.92, 1.60)	*0.40*	-0.16 (-1.09, 0.77)
Portugal	ref	2.52 (-1.21, 6.26)	2.09 (-1.50, 5.67)	3.00 (-0.43, 6.43)	*0.15*	0.91 (0.13, 1.69)
South Africa	ref	-0.69 (-3.05, 1.68)	0.84 (-1.81, 3.49)	-1.51 (-4.55, 1.54)	*0.69*	-0.49 (-1.54, 0.56)

USA	ref	-0.36 (-3.07, 2.34)	1.37 (-1.22, 3.97)	-0.26 (-3.02, 2.49)	*0.81*	0.09 (-0.78, 0.95)
Overall	ref	0.10 (-0.55, 0.75)	0.80 (0.14, 1.46)	0.42 (-0.26, 1.10)	*0.07*	0.13 (-0.10, 0.35)
Overall variability of sleep midpoint, h [b]						
Median and IQR	0.36 (0.28, 0.42)	0.60 (0.54, 0.65)	0.84 (0.77, 0.93)	1.27 (1.13, 1.48)		
Adjusted mean difference and 95% CI in HRQoL						
Australia	ref	2.01 (0.06, 3.95)	-1.70 (-3.84, 0.44)	-0.80 (-3.04, 1.45)	*0.12*	-1.66 (-3.77, 0.45)
Brazil	ref	-2.10 (-4.79, 0.60)	-1.67 (-4.17, 0.83)	-1.93 (-4.37, 0.51)	*0.30*	-1.57 (-3.28, 0.13)
Canada	ref	-0.25 (-2.27, 1.77)	0.92 (-1.32, 3.16)	-0.09 (-2.52, 2.34)	*0.75*	-0.003 (-2.20, 2.19)
China	ref	-0.34 (-2.78, 2.10)	4.08 (1.27, 6.90)	-0.02 (-3.21, 3.18)	*0.17*	1.37 (-1.69, 4.42)
Colombia	ref	-1.08 (-2.94, 0.78)	-0.79 (-2.59, 1.01)	-0.39 (-2.08, 1.30)	*0.94*	-0.09 (-1.32, 1.13)
England	ref	0.17 (-1.94, 2.28)	1.62 (-0.64, 3.87)	1.62 (-1.01, 4.25)	*0.11*	2.67 (0.25, 5.10)
Finland	ref	1.94 (-0.31, 4.20)	3.25 (1.05, 5.44)	0.66 (-1.60, 2.92)	*0.32*	0.12 (-1.89, 2.14)
India	ref	-0.06 (-1.97, 1.85)	0.37 (-1.56, 2.31)	0.92 (-1.40, 3.25)	*0.43*	0.90 (-1.15, 2.94)
Kenya	ref	0.99 (-1.15, 3.12)	-1.54 (-3.87, 0.78)	-1.11 (-3.51, 1.28)	*0.17*	-1.33 (-3.41, 0.75)
Portugal	ref	0.20 (-2.34, 2.74)	-0.20 (-2.60, 2.20)	0.83 (-1.59, 3.25)	*0.54*	0.21 (-1.86, 2.28)
South Africa	ref	-0.36 (-3.01, 2.28)	0.22 (-2.42, 2.86)	-0.68 (-3.40, 2.05)	*0.76*	-0.58 (-3.09, 1.93)
USA	ref	1.58 (-1.41, 4.56)	0.91 (-1.81, 3.64)	0.61 (-2.08, 3.29)	*0.89*	0.63 (-1.50, 2.76)
Overall	ref	0.37 (-0.27, 1.01)	0.52 (-0.13, 1.17)	0.17 (-0.50, 0.83)	*0.55*	-0.06 (-0.64, 0.52)
Weekday-to-weekend difference of sleep midpoint, h [c]						
Median and IQR	-0.03 (-0.35, 0.17)	0.57 (0.44, 0.69)	1.06 (0.93, 1.22)	1.59 (1.87, 2.31)		
Adjusted mean difference and 95% CI in HRQoL						
Australia	ref	-0.61 (-2.68, 1.46)	0.07 (-2.10, 2.23)	-2.09 (-4.27, 0.10)	*0.12*	-0.70 (-1.62, 0.20)
Brazil	ref	0 (-2.17, 2.16)	0.79 (-1.19, 2.77)	-0.5 (-2.39, 1.40)	*0.72*	-0.37 (-1.07, 0.34)
Canada	ref	-0.91 (-2.91, 1.08)	-0.78 (-2.97, 1.41)	-0.93 (-3.30, 1.44)	*0.42*	-0.13 (-1.13, 0.86)
China	ref	-0.65 (-3.38, 2.09)	0.53 (-2.30, 3.36)	2.26 (-0.80, 5.33)	*0.12*	0.40 (-0.96, 1.76)
Colombia	ref	-0.49 (-2.19, 1.21)	0.56 (-1.05, 2.18)	0.50 (-1.06, 2.05)	*0.30*	0.22 (-0.36, 0.81)
England	ref	2.67 (0.40, 4.94)	2.58 (0.25, 4.91)	2.66 (0.21, 5.12)	*0.05*	1.05 (-0.02, 2.11)
Finland	ref	0.27 (-1.94, 2.48)	1.05 (-1.20, 3.31)	0.21 (-2.11, 2.53)	*0.68*	-0.15 (-1.10, 0.80)
India	ref	0.39 (-1.54, 2.32)	0.37 (-1.68, 2.42)	0.59 (-1.75, 2.92)	*0.63*	0.48 (-0.50, 1.46)
Kenya	ref	3.18 (0.91, 5.45)	1.32 (-0.93, 3.57)	0.47 (-2.05, 3.00)	*0.93*	0.21 (-0.78, 1.20)
Portugal	ref	-1.25 (-3.59, 1.08)	-0.82 (-3.11, 1.46)	-0.39 (-2.58, 1.80)	*0.83*	0.32 (-0.52, 1.17)
South Africa	ref	0.30 (-2.38, 2.97)	-0.54 (-3.23, 2.16)	-0.98 (-3.76, 1.81)	*0.40*	-0.73 (-1.90, 0.43)
USA	ref	0.44 (-2.51, 3.38)	1.73 (-1.20, 4.65)	1.87 (-0.83, 4.57)	*0.12*	0.83 (-0.14, 1.81)
Overall	ref	0.12 (-0.52, 0.76)	0.43 (-0.22, 1.08)	0.20 (-0.45, 0.86)	*0.38*	0.11 (-0.16, 0.37)

[a] Models were adjusted for age, sex, parental education, parental marital status, household income, healthy diet score, unhealthy diet score and body-mass index. School was included as a random effect.

[b] Measured as standard deviation of all valid nights.

[c] Measured as weekend sleep midpoint – weekday sleep midpoints.

Abbreviation: CI, confidence interval; HRQoL, health-related quality of life; IQR, interquartile range; ISCOLE, International Study of Childhood Obesity, Lifestyle and the Environment USA, United States of America.

Table 5 Multivariable adjusted [a] associations between HRQoL and objectively-measured sleep efficiency in ISCOLE.

	Quartiles of Sleep Variable					
	Q 1	**Q 2**	**Q 3**	**Q 4**	***p-for-trend***	**1% increase**
			Weekday sleep efficiency, %			
Median and IQR	94.5 (93.8, 95.1)	95.9 (95.6, 96.1)	96.8 (96.6, 97.0)	97.8 (97.5, 98.2)		
Adjusted mean difference and 95% CI in HRQoL						
Australia	1.11 (-1.81, 4.03)	0.50 (-2.60, 3.59)	1.82 (-1.37, 5.02)	ref	0.88	-0.17 (-0.71, 0.37)
Brazil	0.41 (-2.04, 2.85)	-0.08 (-2.59, 2.43)	0.34 (-2.38, 3.06)	ref	0.78	-0.04 (-0.52, 0.44)
Canada	1.88 (-0.41, 4.17)	-0.03 (-2.28, 2.21)	-1.28 (-3.59, 1.03)	ref	0.05	-0.74 (-1.32, -0.16)
China	2.85 (-0.30, 5.99)	-0.68 (-3.56, 2.20)	0.79 (-1.73, 3.32)	ref	0.24	-0.48 (-1.30, 0.34)
Colombia	0.21 (-1.46, 1.88)	-0.75 (-2.41, 0.92)	-0.75 (-2.46, 0.97)	ref	*0.58*	-0.08 (-0.49, 0.32)
England	-1.65 (-4.39, 1.09)	-0.52 (-3.32, 2.29)	-1.07 (-3.96, 1.82)	ref	*0.30*	0.15 (-0.40, 0.71)
Finland	0.97 (-1.79, 3.73)	-0.19 (-2.32, 1.95)	-1.46 (-3.40, 0.49)	ref	*0.67*	-0.05 (-0.74, 0.65)
India	0.72 (-1.53, 2.96)	0.91 (-1.03, 2.85)	0.63 (-1.27, 2.54)	ref	*0.39*	-0.42 (-0.98, 0.14)
Kenya	0.77 (-1.71, 3.25)	-0.05 (-2.55, 2.44)	0.67 (-1.82, 3.16)	ref	*0.69*	-0.18 (-0.75, 0.36)
Portugal	-2.89 (-6.87, 1.09)	0.08 (-2.22, 2.37)	0.86 (-0.97, 2.68)	ref	*0.57*	0.14 (-0.66, 0.94)
South Africa	-1.77 (-4.47, 0.93)	-0.84 (-3.50, 1.83)	0.04 (-2.70, 2.78)	ref	*0.15*	0.46 (-0.17, 1.09)
USA	-0.17 (-2.83, 2.49)	-0.80 (-3.44, 1.83)	1.44 (-1.22, 4.09)	ref	*0.46*	0.09 (-0.59, 0.77)
Overall	0.07 (-0.61, 0.75)	-0.50 (-1.16, 0.16)	0.06 (-0.58, 0.71)	ref	*0.74*	-0.03 (-0.19, 0.14)
			Weekend sleep efficiency, %			
Median and IQR	94.3 (93.5, 94.8)	95.8 (95.5, 96.1)	96.8 (96.6, 97.1)	97.9 (97.6, 98.4)		
Adjusted mean difference and 95% CI in HRQoL						
Australia	1.19 (-1.28, 3.65)	1.41 (-1.14, 3.97)	0.24 (-2.40, 2.88)	ref	*0.24*	-0.17 (-0.64, 0.29)
Brazil	0.08 (-2.2, 2.36)	-0.18 (-2.53, 2.18)	1.02 (-1.49, 3.52)	ref	*0.66*	0.09 (-0.35, 0.52)
Canada	2.37 (0.20, 4.54)	1.59 (-0.64, 3.82)	-0.77 (-2.91, 1.36)	ref	*0.008*	-0.72 (-1.22, 0.22)
China	0.26 (-2.67, 3.19)	0.27 (-2.61, 3.15)	0.65 (-2.19, 3.50)	ref	*0.94*	-0.13 (-0.72, 0.46)
Colombia	0.57 (-1.02, 2.17)	-0.48 (-2.06, 1.11)	0.70 (-0.98, 2.38)	ref	*0.82*	-0.06 (-0.39, 0.27)

England	-0.67 (-3.14, 1.8)	-0.43 (-2.91, 2.06)	-1.04 (-3.67, 1.58)	ref	*0.79*	0.03 (-0.44, 0.49)
Finland	-0.60 (-3.48, 2.29)	-0.42 (-2.62, 1.78)	-0.21 (-2.1, 1.69)	ref	*0.62*	0.07 (-0.54, 0.68)
India	2.60 (0.47, 4.73)	-0.55 (-2.56, 1.46)	-0.94 (-2.85, 0.96)	ref	*0.05*	-0.69 (-1.18, -0.21)
Kenya	0.77 (-1.71, 3.26)	-0.56 (-3.10, 1.97)	1.44 (-1.30, 4.17)	ref	*0.95*	-0.25 (-0.74, 0.23)
Portugal	-2.17 (-5.60, 1.25)	0.06 (-2.21, 2.34)	0.85 (-1.01, 2.70)	ref	*0.53*	0.15 (-0.53, 0.84)
South Africa	-0.10 (-2.73, 2.54)	0.02 (-2.71, 2.74)	1.28 (-1.60, 4.15)	ref	*0.72*	0.20 (-0.34, 0.73)
USA	-0.30 (-3.05, 2.46)	-1.37 (-4.05, 1.30)	-1.14 (-3.79, 1.50)	ref	*0.85*	0.08 (-0.49, 0.66)
Overall	0.15 (-0.52, 0.81)	-0.23 (-0.88, 0.42)	0.12 (-0.52, 0.77)	ref	*0.93*	-0.05 (-0.19, 0.09)
Overall variability of sleep efficiency, [b] %						
Median and IQR	0.66 (0.52, 0.75)	1.03 (0.94, 1.10)	2.38 (1.29, 1.49)	2.00 (1.77, 2.33)		
Adjusted mean difference and 95% CI in HRQoL						
Australia	ref	-1.85 (-4.25, 0.55)	-0.59 (-2.87, 1.7)	-1.13 (-3.38, 1.13)	*0.63*	-0.13 (-1.43, 1.18)
Brazil	ref	-0.23 (-2.42, 1.96)	0.84 (-1.31, 2.98)	-0.18 (-2.25, 1.88)	*0.97*	-0.37 (-1.43, 0.69)
Canada	ref	-1.93 (-4.03, 0.17)	-1.90 (-4.06, 0.26)	0.78 (-1.59, 3.14)	*0.72*	0.79 (-0.55, 2.12)
China	ref	-0.64 (-3.77, 2.49)	-2.84 (-5.98, 0.31)	0.04 (-3.06, 3.14)	*0.89*	0.29 (-1.21, 1.80)
Colombia	ref	0.06 (-1.73, 1.85)	0.19 (-1.49, 1.88)	0.33 (-1.31, 1.97)	*0.65*	0.05 (-0.77, 0.86)
England	ref	-0.93 (-3.43, 1.56)	-1.01 (-3.49, 1.47)	-1.94 (-4.42, 0.54)	*0.14*	-0.72 (-1.97, 0.54)
Finland	ref	0.94 (-1.06, 2.93)	-1.60 (-3.70, 0.51)	0.22 (-2.48, 2.93)	*0.49*	-0.51 (-2.12, 1.10)
India	ref	-0.47 (-2.52, 1.58)	-1.26 (-3.32, 0.81)	0.81 (-1.32, 2.94)	*0.68*	1.48 (0.17, 2.78)
Kenya	ref	-1.83 (-4.44, 0.79)	-1.49 (-3.97, 0.98)	-0.38 (-2.79, 2.04)	*0.98*	0.46 (-0.67, 1.59)
Portugal	ref	0.25 (-1.63, 2.12)	0.72 (-1.67, 3.11)	-2.25 (-5.94, 1.44)	*0.75*	-0.40 (-2.42, 1.62)
South Africa	ref	-0.12 (-3.05, 2.80)	-1.60 (-4.51, 1.32)	-1.80 (-4.77, 1.16)	*0.12*	-0.57 (-2.02, 0.89)
USA	ref	0.41 (-2.27, 3.09)	-1.17 (-3.86, 1.51)	-1.78 (-4.34, 0.78)	*0.09*	-0.77 (-2.20, 0.67)
Overall	ref	-0.57 (-1.21, 0.08)	-1.14 (-1.79, -0.48)	-0.69 (-1.35, -0.03)	*0.02*	-0.18 (-0.55, 0.18)
Weekday-to-weekend difference of sleep efficiency, [c] %						
Median and IQR	-1.56 (-2.24, -1.17)	-0.41 (-0.61, -0.20)	0.38 (0.19, 0.58)	1.45 (1.08, 2.01)		
Adjusted mean difference and 95% CI in HRQoL						
Australia	-0.50 (-2.86, 1.85)	ref	0.45 (-1.84, 2.75)	-0.17 (-2.25, 1.91)	*0.97*	-0.06 (-0.59, 0.48)
Brazil	1.13 (-0.87, 3.13)	ref	1.02 (-0.90, 2.95)	0.89 (-1.00, 2.78)	*0.40*	0.13 (-0.33, 0.59)
Canada	-0.41 (-2.86, 2.03)	ref	-1.01 (-3.33, 1.32)	-0.99 (-3.40, 1.41)	*0.35*	-0.25 (-0.84, 0.35)
China	0.61 (-1.96, 3.19)	ref	-0.49 (-3.25, 2.28)	1.22 (-1.74, 4.18)	*0.64*	0.14 (-0.50, 0.79)
Colombia	-0.02 (-1.51, 1.48)	ref	0.23 (-1.32, 1.79)	-0.18 (-1.63, 1.26)	*0.88*	-0.01 (-0.35, 0.35)
England	1.27 (-1.13, 3.67)	ref	-0.79 (-3.15, 1.58)	0.23 (-2.04, 2.51)	*0.74*	-0.12 (-0.68, 0.44)
Finland	-1.04 (-3.39, 1.31)	ref	-0.37 (-2.75, 2)	0.55 (-1.80, 2.89)	*0.43*	0.11 (-0.53, 0.76)
India	-0.56 (-2.54, 1.43)	ref	-0.49 (-2.61, 1.62)	-1.66 (-3.78, 0.45)	*0.15*	-0.53 (-1.12, 0.05)

Kenya	-1.57 (-3.90, 0.76)	ref	-0.99 (-3.31, 1.33)	0.21 (-2.10, 2.52)	*0.86*	-0.13 (-0.64, 0.37)
Portugal	-0.84 (-3.22, 1.55)	ref	-1.07 (-3.43, 1.28)	0.81 (-1.95, 3.56)	*0.70*	0.09 (-0.78, 0.96)
South Africa	0.07 (-2.54, 2.68)	ref	-0.08 (-2.7, 2.55)	-0.85 (-3.54, 1.84)	*0.56*	-0.17 (-0.76, 0.43)
USA	0.96 (-1.69, 3.62)	ref	1.98 (-0.65, 4.61)	0.34 (-2.19, 2.86)	*0.71*	0.02 (-0.58, 0.62)
Overall	0.15 (-0.49, 0.79)	ref	-0.05 (-0.7, 0.6)	0.09 (-0.56, 0.73)	*0.95*	-0.04 (-0.20, 0.11)

[a] Models were adjusted for age, sex, parental education, parental marital status, household income, healthy diet score, unhealthy index score and body-mass index. School was included as a random effect.

[b] Measured as standard deviation of all valid nights.

[c] Measured as the difference between weekday and weekend means.

Abbreviation: CI, confidence interval; HRQoL, health-related quality of life; IQR, interquartile range; ISCOLE, International Study of Childhood Obesity, Lifestyle and the Environment; USA, United States of America.

Table 6 Multivariable adjusted [a] associations between HRQoL and subjectively-measured sleep quantity and quality in ISCOLE

	Sleep Rating				
	Very good	**Fairly good**	**Fairly bad**	**Very bad**	***P-for-trend***
		Sleep Quantity			
N (%)	2858 (45.6)	2812 (44.9)	437 (7.0)	159 (2.5)	
Adjusted mean difference and 95% CI in HRQoL					
Australia	ref	-3.58 (-5.27, -1.88)	-6.09 (-8.94, -3.24)	2.14 (-5.09, 9.36)	*<.0001*
Brazil	ref	-1.83 (-3.26, -0.39)	-6.17 (-10.16, -2.19)	-7.65 (-12.19, -3.10)	*<.0001*
Canada	ref	-5.47 (-7.11, -3.84)	-10.08 (-13.15, -7.02)	-9.70 (-15.68, -3.72)	*<.0001*
China	ref	-6.18 (-8.25, -4.11)	-10.28 (-13.47, -7.09)	-13.40 (-19.03, -7.77)	*<.0001*
Colombia	ref	-2.16 (-3.30, -1.02)	-4.83 (-7.45, -2.21)	-4.77 (-8.02, -1.52)	*<.0001*
England	ref	-3.34 (-5.21, -1.48)	-7.43 (-10.44, -4.43)	-8.43 (-14.43, -2.43)	*<.0001*
Finland	ref	-5.13 (-6.75, -3.50)	-7.74 (-10.77, -4.70)	-9.06 (-17.34, -0.78)	*<.0001*
India	ref	1.29 (-0.29, 2.87)	-3.50 (-6.04, -0.97)	-2.68 (-6.84, 1.49)	*0.08*
Kenya	ref	-1.95 (-3.70, -0.20)	-6.64 (-10.31, -2.97)	-1.53 (-6.67, 3.60)	*0.002*
Portugal	ref	-2.18 (-3.82, -0.55)	-5.02 (-9.46, -0.58)	1.37 (-5.44, 8.18)	*0.01*
South Africa	ref	-1.94 (-4.08, 0.19)	-5.12 (-9.34, -0.89)	-4.44 (-8.38, -0.51)	*0.002*
USA	ref	-1.81 (-3.78, 0.17)	-4.58 (-7.84, -1.33)	-3.67 (-8.66, 1.33)	*0.003*
Overall	ref	-2.56 (-3.04, -2.08)	-6.21 (-7.12, -5.30)	-5.31 (-6.75, -3.88)	*<.0001*
		Sleep Quality			
N (%)	3501 (55.9)	2283 (36.4)	338 (5.4)	144 (2.3)	
Adjusted mean difference and 95% CI in HRQoL					
Australia	ref	-2.64 (-4.30, -0.99)	-4.28 (-7.58, -0.99)	-0.95 (-6.25, 4.35)	*0.004*
Brazil	ref	-2.31 (-3.86, -0.77)	-3.14 (-6.81, 0.53)	-7.37 (-14.08, -0.66)	*0.0002*
Canada	ref	-5.02 (-6.61, -3.42)	-5.50 (-8.84, -2.16)	-9.93 (-15.24, -4.62)	*<.0001*

China	ref	-6.06 (-8.15, -3.98)	-9.92 (-13.18, -6.67)	-11.88 (-16.33, -7.42)	*<.0001*
Colombia	ref	-3.38 (-4.61, -2.14)	-5.89 (-9.41, -2.37)	-7.61 (-11.45, -3.76)	*<.0001*
England	ref	-3.74 (-5.50, -1.97)	-7.65 (-10.27, -5.03)	-11.36 (-16.39, -6.32)	*<.0001*
Finland	ref	-4.81 (-6.36, -3.26)	-7.78 (-10.96, -4.6)	-7.40 (-15.55, 0.75)	*<.0001*
India	ref	-3.00 (-4.52, -1.48)	-6.36 (-9.47, -3.26)	-5.70 (-10.91, -0.50)	*<.0001*
Kenya	ref	-2.23 (-4.28, -0.17)	-9.88 (-16.69, -3.08)	-3.22 (-9.59, 3.16)	*0.004*
Portugal	ref	-2.29 (-3.93, -0.65)	-7.67 (-12.55, -2.78)	0.78 (-7.49, 9.04)	*0.001*
South Africa	ref	-4.80 (-7.58, -2.02)	-5.26 (-9.87, -0.64)	-8.95 (-14.54, -3.36)	*<.0001*
USA	ref	-4.63 (-6.61, -2.66)	-5.33 (-8.93, -1.73)	-8.41 (-12.41, -4.40)	*<.0001*
Overall	ref	-3.43 (-3.92, -2.94)	-6.08 (-7.09, -5.07)	-7.34 (-8.83, -5.85)	*<.0001*

[a] Models were adjusted for age, sex, parental education, parental marital status, household income, healthy diet score, unhealthy diet score and body-mass index. School was included as a random effect.

Abbreviation: CI, confidence interval; HRQoL, health-related quality of life; ISCOLE, International Study of Childhood Obesity, Lifestyle and the Environment; USA, United States of America.

Supplementary Table 1 Multivariable adjusted[a] associations between HRQoL and timing of sleep onset in ISCOLE.

	Quartiles of Sleep Variable					
	Q 1	**Q 2**	**Q 3**	**Q 4**	***p-for-trend***	**1 h increase**
Weekday timing of sleep onset, HH:MM						
Median and IQR of sleep variable	21:01 (20:44, 21:13)	21:43 (21:34, 21:52)	22:08 (22:13, 22:30)	22:55 (23:00, 23:30)		
Adjusted mean difference and 95% CI in HRQoL						
Australia	ref	-1.91 (-3.78, -0.03)	-0.79 (-2.95, 1.38)	-1.53 (-4.43, 1.36)	*0.23*	-0.64 (-1.70, 0.42)
Brazil	ref	-0.50 (-3.58, 2.57)	-0.24 (-3.05, 2.57)	0.06 (-2.49, 2.60)	*0.74*	-0.04 (-0.64, 0.55)
Canada	ref	-1.75 (-3.79, 0.28)	-1.46 (-3.61, 0.69)	-1.02 (-3.4, 1.36)	*0.33*	-0.86 (-1.80, 0.08)
China	ref	0.89 (-1.87, 3.64)	-0.09 (-3.00, 2.82)	-1.56 (-5.28, 2.17)	*0.37*	-0.72 (-2.25, 0.81)
Colombia	ref	0.92 (-0.45, 2.29)	0.08 (-1.35, 1.51)	-0.34 (-2.04, 1.36)	*0.72*	-0.15 (-0.80, 0.49)
England	ref	2.17 (0.09, 4.24)	1.36 (-0.88, 3.6)	3.81 (0.65, 6.98)	*0.05*	1.60 (0.42, 2.78)
Finland	ref	-0.69 (-3.85, 2.48)	-1.02 (-4.03, 1.98)	-1.65 (-4.61, 1.31)	*0.21*	-0.31 (-1.15, 0.52)
India	ref	-1.14 (-4.43, 2.14)	-0.46 (-3.66, 2.73)	-0.82 (-3.99, 2.35)	*0.92*	-0.28 (-1.25, 0.69)
Kenya	ref	-0.08 (-2.06, 1.91)	0.45 (-1.89, 2.79)	-1.82 (-4.99, 1.36)	*0.59*	-0.55 (-1.70, 0.61)
Portugal	ref	-0.83 (-6.87, 5.21)	4.73 (-0.89, 10.34)	3.41 (-2.07, 8.89)	*0.08*	0.73 (-0.14, 1.60)
South Africa	ref	-2.81 (-5.12, -0.49)	-0.2 (-2.77, 2.38)	2.69 (-1.29, 6.67)	*0.53*	0.54 (-2.72, 1.23)
USA	ref	0.17 (-2.2, 2.54)	1.01 (-1.56, 3.58)	-0.47 (-3.30, 2.36)	*0.98*	-0.43 (-1.49, 0.64)
Overall	ref	-0.32 (-0.97, 0.33)	0.32 (-0.35, 0.98)	0.09 (-0.63, 0.81)	*0.43*	0.01 (-0.25, 0.27)
Weekend timing of sleep onset, HH:MM						
IQR of sleep variable	21:20 (20:55, 21:36)	22:14 (22:03, 22:26)	23:00 (22:48, 23:13)	0:13 (23:48, 0:52)		
Adjusted mean difference and 95% CI in HRQoL						
Australia	ref	-1.24 (-3.3, 0.82)	-2.1 (-4.24, 0.04)	-1.3 (-3.61, 1.01)	*0.15*	-0.44 (-1.06, 0.17)
Brazil	ref	1.88 (-1.08, 4.85)	2.04 (-0.61, 4.68)	1.61 (-0.84, 4.05)	*0.44*	-0.10 (-0.61, 0.40)
Canada	ref	-1.00 (-3.15, 1.15)	-1.72 (-4.05, 0.61)	-0.99 (-3.31, 1.32)	*0.33*	-0.26 (-0.93, 0.42)
China	ref	-0.13 (-2.74, 2.47)	2.29 (-0.46, 5.03)	0.75 (-2.72, 4.22)	*0.22*	0.08 (-0.92, 1.09)
Colombia	ref	0.22 (-1.08, 1.53)	1.12 (-0.43, 2.66)	0.46 (-1.22, 2.15)	*0.29*	0.12 (-0.31, 0.56)
England	ref	2.07 (-0.16, 4.31)	1.63 (-0.70, 3.96)	1.74 (-0.87, 4.35)	*0.23*	0.65 (-0.11, 1.41)
Finland	ref	-0.15 (-3.13, 2.82)	0.89 (-1.95, 3.74)	-1.30 (-4.10, 1.51)	*0.27*	-0.47 (-1.18, 0.23)
India	ref	0.70 (-1.64, 3.05)	0.52 (-1.75, 2.80)	0.28 (-2.30, 2.86)	*0.94*	-0.02 (-0.75, 0.72)
Kenya	ref	-1.35 (-3.38, 0.68)	1.39 (-1.13, 3.90)	-0.18 (-3.44, 3.07)	*0.76*	-0.27 (-1.04, 0.49)
Portugal	ref	5.70 (0.95, 10.45)	7.60 (3.14, 12.05)	6.22 (1.86, 10.58)	*0.19*	0.51 (-0.17, 1.18)
South Africa	ref	-2.14 (-4.45, 0.17)	-0.86 (-3.55, 1.84)	-1.1 (-4.24, 2.03)	*0.45*	-0.38 (-1.24, 0.47)
USA	ref	-0.62 (-3.41, 2.18)	1.71 (-0.93, 4.36)	0.04 (-2.68, 2.77)	*0.57*	0.20 (-0.51, 0.91)
Overall	ref	0.06 (-0.59, 0.71)	0.98 (0.31, 1.64)	0.35 (-0.34, 1.04)	*0.07*	0.08 (-0.10, 0.27)
Overall variability of timing of sleep onset, h[b]						
IQR of sleep variable	0.41 (0.31, 0.47)	0.65 (0.59, 0.72)	0.94 (0.86, 1.05)	1.49 (1.30, 1.82)		

Adjusted mean difference and 95% CI in HRQoL						
Australia	ref	-1.40 (-3.57, 0.77)	-0.83 (-3.01, 1.34)	-2.14 (-4.36, 0.08)	*0.11*	-1.24 (-2.80, 0.32)
Brazil	ref	0.42 (-1.93, 2.77)	1.98 (-0.32, 4.29)	0.37 (-1.85, 2.59)	*0.69*	-0.50 (-1.79, 0.79)
Canada	ref	-0.12 (-2.34, 2.10)	1.19 (-1.07, 3.45)	1.29 (-1.00, 3.58)	*0.16*	1.47 (-0.04, 2.97)
China	ref	0.73 (-1.87, 3.33)	0.86 (-1.85, 3.56)	1.82 (-1.27, 4.90)	*0.26*	0.62 (-1.79, 3.03)
Colombia	ref	-0.31 (-1.89, 1.26)	0.17 (-1.43, 1.77)	-0.22 (-1.88, 1.43)	*0.99*	-0.12 (-1.26, 1.01)
England	ref	0.30 (-1.90, 2.50)	-0.87 (-3.13, 1.40)	-0.63 (-2.98, 1.73)	*0.43*	-0.21 (-2.07, 1.64)
Finland	ref	0.51 (-1.92, 2.94)	1.02 (-1.26, 3.30)	0.41 (-1.73, 2.56)	*0.64*	-0.30 (-1.50, 0.89)
India	ref	-1.33 (-3.19, 0.53)	0.35 (-1.64, 2.34)	0.37 (-1.90, 2.63)	*0.58*	0.38 (-1.19, 1.94)
Kenya	ref	-0.16 (-2.29, 1.97)	0.38 (-1.99, 2.75)	-0.54 (-2.95, 1.88)	*0.81*	-0.19 (-2.02, 1.64)
Portugal	ref	-2.38 (-4.84, 0.08)	-2.05 (-4.44, 0.33)	-1.22 (-3.49, 1.05)	*0.53*	-0.52 (-2.01, 0.96)
South Africa	ref	-1.41 (-4.29, 1.47)	0.05 (-2.80, 2.90)	-0.14 (-3.07, 2.79)	*0.70*	0.38 (-1.47, 2.22)
USA	ref	-3.09 (-6.12, -0.05)	-1.12 (-3.9, 1.66)	-1.32 (-4.02, 1.38)	*0.74*	0.48 (-1.14, 2.10)
Overall	ref	-0.50 (-1.14, 0.14)	0.13 (-0.51, 0.78)	-0.06 (-0.72, 0.59)	*0.67*	0.05 (-0.39, 0.50)
Weekend-weekday variability of timing of sleep onset, h [c]						
IQR of sleep variable	-0.48 (-0.85, -0.23)	0.27 (0.13, 0.40)	0.85 (0.70, 1.03)	1.82 (1.46, 2.42)		
Adjusted mean difference and 95% CI in HRQoL						
Australia	ref	-0.12 (-2.68, 2.44)	0.65 (-1.43, 2.74)	-0.91 (-2.94, 1.12)	*0.47*	-0.28 (-0.97, 0.41)
Brazil	ref	1.12 (-0.92, 3.17)	0.85 (-1.14, 2.84)	0.29 (-1.63, 2.21)	*0.60*	-0.11 (-0.73, 0.50)
Canada	ref	1.13 (-1.31, 3.57)	-0.09 (-2.25, 2.07)	1.44 (-0.70, 3.58)	*0.64*	0.22 (-0.52, 0.97)
China	ref	-0.16 (-2.92, 2.59)	0.99 (-1.72, 3.69)	1.44 (-1.62, 4.5)	*0.23*	0.46 (-0.66, 1.59)
Colombia	ref	-0.15 (-1.58, 1.27)	1.06 (-0.47, 2.59)	0.73 (-0.88, 2.33)	*0.12*	0.24 (-0.24, 0.73)
England	ref	-0.93 (-3.43, 1.58)	0.86 (-1.41, 3.13)	-1.21 (-3.55, 1.13)	*0.90*	-0.01 (-0.87, 0.84)
Finland	ref	1.05 (-1.26, 3.36)	-0.81 (-3.01, 1.39)	1.29 (-0.88, 3.45)	*0.87*	-0.23 (-0.91, 0.45)
India	ref	-1.13 (-2.98, 0.72)	-0.82 (-2.83, 1.19)	-0.28 (-2.74, 2.18)	*0.59*	0.17 (-0.63, 0.97)
Kenya	ref	-0.47 (-2.57, 1.62)	0.31 (-2.27, 2.88)	-0.46 (-3.16, 2.24)	*0.79*	-0.04 (-0.87, 0.79)
Portugal	ref	-1.33 (-3.73, 1.06)	-2.60 (-4.96, -0.25)	-2.10 (-4.46, 0.25)	*0.20*	0.07 (-0.63, 0.76)
South Africa	ref	0.46 (-2.21, 3.12)	-0.5 (-3.22, 2.21)	-0.83 (-3.48, 1.81)	*0.31*	-0.63 (-1.51, 0.25)
USA	ref	-0.65 (-3.76, 2.47)	0.78 (-1.92, 3.48)	1.09 (-1.33, 3.51)	*0.18*	0.44 (-0.31, 1.20)
Overall	ref	-0.27 (-0.91, 0.37)	0.08 (-0.56, 0.72)	0.11 (-0.53, 0.76)	*0.25*	0.10 (-0.11, 0.31)

[a] Models were adjusted for age, sex, parental education, parental marital status, household income, healthy diet score, unhealthy index score and body-mass index. School was included as a random effect.

[b] Measured as standard deviation of all valid nights.

[c] Measured as weekend sleep midpoint – weekday sleep midpoints.

Abbreviation: CI, confidence interval; HRQoL, health-related quality of life; IQR, interquartile range; USA, United States of America.

Supplementary Table 2 Distribution of objective sleep variables by subjective sleep categories in ISCOLE.

	Self-reported sleep quantity						Self-reported sleep quality					
	Very good	Fairly good	Fairly bad	Very bad	*p-value* [a]	Correlation Coefficient [b]	Very good	Fairly good	Fairly bad	Very bad	*p-value* [a]	Correlation Coefficient [b]
Weekday												
Total sleep time, h	8.63 (1.01)	8.70 (1.04)	8.65 (1.03)	8.54 (0.99)	*0.01*	0.03	8.61 (1.02)	8.73 (1.04)	8.72 (0.97)	8.79 (0.97)	<.0001	0.07
Sleep onset, HH:MM	22:04 (0:59)	22:07 (1:00)	22:04 (0:58)	22:04 (1:02)	*0.20*	0.02	22:05 (1:01)	22:07 (1:00)	22:10 (0:56)	23:53 (0:50)	0.02	0.01
Sleep offset, HH:MM	6:41 (0:55)	6:49 (0:52)	6:43 (0:46)	6:37 (0:52)	*<.0001*	0.05	6:41 (0:55)	6:50 (0:50)	6:52 (0:46)	6:40 (0:50)	<.0001	0.10
Midpoint of sleep, HH:MM	2:23 (0.49)	2.29 (0:46)	2:24 (0:43)	2:21 (0:49)	*0.0001*	0.04	2:23 (0:49)	2:24 (0:46)	2:32 (0:42)	2:17 (0:41)	<.0001	0.06
Sleep efficiency	0.96 (0.01)	0.96 (0.01)	0.96 (0.01)	0.96 (0.01)	*0.73*	0.00	0.96 (0.01)	0.96 (0.01)	0.96 (0.01)	0.96 (0.01)	0.67	0.01
Weekend												
Total sleep time, h	9.18 (1.39)	9.11 (1.36)	9.11 (1.29)	9.05 (1.16)	*0.23*	-0.03	9.19 (1.41)	9.07 (1.32)	9.1 (1.31)	9.18 (1.21)	0.02	-0.03
Sleep onset, HH:MM	22:41 (1:19)	22:47 (1:17)	22:43 (1:16)	22:36 (1:18)	*0.006*	0.03	22:41 (1:20)	22:49 (1:17)	22:49 (1.17)	22:32 (1:08)	0.0002	0.04
Sleep offset, HH:MM	7:51 (1:16)	7:54 (1:14)	7:50 (1:15)	7:39 (1:08)	*0.07*	-0.002	7:52 (1:17)	7:52 (1:12)	7:55 (1:13)	7:42 (1:04)	0.24	0.00
Midpoint of sleep, HH:MM	3:16 (1.05)	3:21 (1:04)	3:17 (1:05)	3:08 (1:04)	*0.007*	0.02	3:17 (1:06)	3:21 (1:03)	3:23 (1:04)	3:07 (0:55)	0.01	0.03
Sleep efficiency	0.96 (0.02)	0.96 (0.02)	0.96 (0.02)	0.96 (0.02)	*0.74*	0.01	0.96 (0.02)	0.96 (0.02)	0.96 (0.02)	0.96 (0.02)	0.08	0.02
Overall variability [b]												
Total sleep time, h	1.25 (0.69)	1.21 (0.65)	1.18 (0.63)	1.19 (0.63)	*0.09*	-0.02	1.26 (0.69)	1.18 (0.65)	1.21 (0.62)	1.15 (0.6)	<.0001	-0.05
Sleep onset, h	0.91 (0.51)	0.91 (0.54)	0.89 (0.51)	0.92 (0.53)	*0.83*	-0.01	0.91 (0.51)	0.9 (0.54)	0.93 (0.52)	0.92 (0.51)	0.57	0.00
Sleep offset, h	1.08 (0.62)	1.01 (0.58)	1.02 (0.59)	1.02 (0.58)	*0.0003*	-0.05	1.08 (0.62)	1 (0.58)	0.98 (0.55)	0.93 (0.55)	<.0001	-0.07
Midpoint of sleep, h	0.8 (0.41)	0.77 (0.4)	0.77 (0.42)	0.8 (0.39)	*0.05*	-0.04	0.8 (0.41)	0.77 (0.4)	0.76 (0.39)	0.76 (0.38)	0.08	-0.03
Sleep efficiency	0.01 (0.01)	0.01 (0.01)	0.01 (0.01)	0.01 (0.01)	*0.06*	0.02	0.01 (0.01)	0.01 (0.01)	0.01 (0.01)	0.01 (0.01)	0.29	0.01
Weekday-to-weekend difference [c]												
Total sleep time, h	0.54 (1.53)	0.41 (1.53)	0.47 (1.49)	0.51 (1.39)	*0.01*	-0.03	0.58 (1.56)	0.34 (1.46)	0.39 (1.52)	0.39 (1.4)	<.0001	-0.07
Sleep onset, h	0.61 (1.11)	0.67 (1.1)	0.65 (1.06)	0.53 (1.04)	*0.13*	0.02	0.6 (1.11)	0.69 (1.09)	0.66 (1.08)	0.65 (1.03)	0.002	0.04
Sleep offset, h	1.16 (1.24)	1.08 (1.21)	1.12 (1.26)	1.04 (1.16)	*0.11*	-0.03	1.18 (1.26)	1.04 (1.18)	1.04 (1.21)	1.03 (1.06)	<.0001	-0.06
Midpoint of sleep, h	0.88 (0.89)	0.87 (0.87)	0.89 (0.88)	0.79 (0.86)	*0.60*	-0.01	0.89 (0.89)	0.87 (0.87)	0.85 (0.86)	0.84 (0.78)	0.76	-0.01
Sleep efficiency	0 (0.01)	0 (0.01)	0 (0.01)	0 (0.02)	*0.98*	0.01	0 (0.01)	0 (0.01)	0 (0.01)	0 (0.01)	0.39	0.01

[a] Derived from ANOVA test

[b] Spearman correlation coefficient

[c] Measured as standard deviation of all valid nights

[d] Measured as the average of sleep variables for weekends minus that for weekdays

Abbreviations: HRQoL, health-related quality of life; ISCOLE, International Study of Childhood Obesity, Lifestyle and the Environment SD, standard deviation; USA, United States of America