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Original Article

Correlates of nocturnal sleep duration, nocturnal sleep variability, and nocturnal sleep problems in toddlers: results from the GET UP! Study

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ABSTRACT

Objective: To explore the correlates of nocturnal sleep duration, nocturnal sleep variability, and nocturnal sleep problems in a sample of Australian toddlers.
Methods: Participants were 173 toddlers (average age 19.7 ± 4.1 months) from the GET UP! Study. Nocturnal sleep duration, nocturnal sleep variability, nap(s) and physical activity were measured using 24-h accelerometry (Actigraph GT3X+) over seven consecutive days. Nocturnal sleep problems were assessed using the Tayside Children's Sleep Questionnaire. Screen time was reported by the parents. Logistic regression models were used to examine the associations between potential correlates (ie, age, sex, socio-economic status, weight status, physical activity, screen time, nap(s), bedtimes, and wake-up times) and nocturnal sleep characteristics.
Results: Older children were more likely to have greater sleep variability (OR: 1.97; 95% CI: 1.08–3.61). Less physical activity (OR: 2.38; 95% CI: 1.27–4.45), shorter nap(s) (OR: 2.42, 95% CI: 1.29–4.55), and later wake-up times (OR: 4.42; 95% CI: 2.32–8.42) were associated with higher odds of having longer nocturnal sleep duration. Late bedtimes were associated with shorter nocturnal sleep duration (OR: 0.09; 95% CI: 0.04–0.18) and with greater nocturnal sleep variability (OR: 1.97; 95% CI: 1.06–3.68). None of the potential correlates were associated with nocturnal sleep problems.
Conclusion: The present study identifies several correlates of nocturnal sleep duration (total physical activity, nap(s), bedtime, and wake-up time) and nocturnal sleep variability (age and bedtime), whereas no correlates were identified for nocturnal sleep problems. The association between late bedtimes and shorter nocturnal sleep duration and greater nocturnal variability suggests that these may be modifiable targets for future sleep interventions in early childhood.
Trial registration: Australian New Zealand Clinical Trials Registry: ACTRN12616000471482, 11/04/2016, retrospectively registered.

1. Introduction

Sleep plays an important role in growth, development, and health during our the early years [1–3]. Short sleep duration during the first five years of life has been associated with higher levels of adiposity [4–6], increased risk of psychological problems [6,7], impaired growth [6], and lower school readiness [8]. Greater nocturnal sleep variability, referred to the variations in nocturnal sleep durations (sometimes referred as variations in sleep/wake patterns) [9], has been associated with poorer preschool adjustment [10] behaviour problems [10], and less efficient neural processing [11] in young children. Nocturnal sleep problems, especially difficulties in initiating and maintaining sleep, are commonly found in young children [12] and are likely to impact children's socio-emotional functioning [13]. These implications for growth

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development and health make it important to understand the correlates of nocturnal sleep in the early years of life, when sleep patterns are being established [14–16].

Physical activity has been pointed out as a potential correlate of sleep. The few studies that have examined the associations between total physical activity and nocturnal sleep characteristics in preschoolers have reported mixed results [4,17–20]. Previous studies reported null associations between moderate-to-vigorous physical activity (MVPA) and nocturnal sleep duration in preschoolers [17,19,20]. Despite limited research in toddlers, there is evidence suggesting a positive association between MVPA and nocturnal sleep duration [4]. The inconsistency in previous literature requires greater understanding of the associations between physical activity and nocturnal sleep characteristics in early childhood, especially in toddlerhood.

Screen time has also been suggested as a correlate of nocturnal sleep duration. Longer screen time has been associated with shorter nocturnal sleep duration among preschoolers [21,22] and toddlers [23]. Previous studies have shown that television viewing for more than 2 h per day may negatively impact nocturnal sleep duration in preschoolers [24,25]. However, with the advent of other electronic devices (eg, tablets and smartphones), screen time encompasses more than television viewing; and therefore the impact of the use of these devices by young children on nocturnal sleep needs to be taken into consideration when examining the correlates of nocturnal sleep. With the development of screen time guidelines for young children in a few countries [26,27], it may also be important to understand whether meeting the guideline is associated with nocturnal sleep duration as well as with other nocturnal sleep characteristics in these children.

More studies are still warranted to understand the associations between nocturnal sleep and other sleep characteristics in young children. For example, napping, as an important part of sleep patterns in the first five years of life [28], has been explored in association with nocturnal sleep duration among young children; yet, results were mixed [4,22,29–35]. More consistent findings have been reported in the associations between late bedtimes in toddlers and shorter nocturnal sleep duration [4,22,23], whereas little is known regarding the associations between bedtimes and nocturnal sleep problems or nocturnal sleep variability at this age [36].

At the same time, some demographic variables have been associated with nocturnal sleep characteristics in early childhood, and therefore may potentially be considered as correlates. For example, age has been associated with nocturnal sleep duration in children under the age of three years, with younger children having a longer nocturnal sleep duration than older children [14,37]. Sex may also be a correlate of nocturnal sleep duration in toddlers, with evidence suggesting boys are more likely to have shorter nocturnal sleep duration than girls [23]. However, a recent systematic review [9] did not find sex differences in nocturnal sleep variability in preschool-aged children. In previous studies [4,16,23] socioeconomic status has also been associated with nocturnal sleep duration in young children. For example, a study with 240 US toddlers from low-income families [4] found that children from families below the poverty threshold had shorter nocturnal sleep duration, compared with those from more affluent families. Weight status may also be a nocturnal sleep correlate, as evidence has suggested that young children who are overweight are more likely to have shorter nocturnal sleep duration [4,25,38]. Thus, age, sex, socioeconomic status, and weight status should also be accounted for when examining the associations between nocturnal sleep characteristics and other potential correlates (eg, physical activity).

Collectively, only a limited number of studies have investigated those potential correlates in associations with nocturnal sleep characteristics in toddlerhood, especially as they relate to sleep variability [9] and sleep problems [39]. Moreover, sleep characteristics in previous studies [4,14,18–25,29–32,35,37,38,40] were assessed predominantly with subjective measures (mainly parental reports), which are less accurate than objective measures [41,42] and could therefore affect the strength of the evidence. The current gaps warrant future research on the correlates of nocturnal sleep characteristics in the early years, as this could inform the design of future interventions aimed at improving nocturnal sleep in young children.

Thus, the objective of this study was to explore the correlates of nocturnal sleep duration, nocturnal sleep variability, and nocturnal sleep problems in a sample of Australian toddlers. Our hypothesis was that girls or children in families of higher socioeconomic status would be more likely to have longer nocturnal sleep duration, greater nocturnal sleep variability, and more sleep problems; whereas older children or overweight children would be less likely to have longer nocturnal sleep duration, greater nocturnal sleep variability, and more sleep problems. We also hypothesised that toddlers having shorter nap(s) duration or late wake-up times would be more likely to have longer nocturnal sleep duration, greater nocturnal sleep variability, and more sleep problems; whereas toddlers spending less time in total physical activity or in MVPA, not meeting the Australian screen time guideline or having late bedtimes, would be less likely to have longer nocturnal sleep duration, greater nocturnal sleep variability, and more sleep problems, after adjusting for covariates including age, sex, socioeconomic status, and weight status.

2. Methods

2.1. Participants

Baseline data from the GET UP! Study [43], a 12-month cluster randomized controlled trial (RCT) aimed at examining the effects of reducing sitting time on cognitive development and executive functions in Australian toddlers, were secondarily analysed. Sampling and data collection procedures of the RCT are described elsewhere [43]. Briefly, 335 toddlers aged between 12 and 28 months (average 19.8 ± 4.1 months) at baseline participated in the RCT. Of these, 284 had valid accelerometry data and 173 had complete data on all the other variables of interest, including at least two 24-h periods of the data and therefore constitute the final sample of the current analysis. Children who were excluded did not significantly differ in their descriptive characteristics from those who were included in the present analysis. The University of Wollongong's Human Research Ethics Committee approved the study protocol (HE15/236), and the study was registered in the Australian and New Zealand Clinical Trials Registry (ACTRN12616000471482, 11/04/2016, retrospectively registered).

2.2. Measures

2.2.1. Accerometry data

Sleep (including nap and nocturnal sleep) and physical activity were assessed using waist-worn accelerometers (Actigraph GT3X+). This monitor has established validity and reliability to measure sleep time in children [44,45]. Participants were asked to wear the accelerometer for seven consecutive 24-h periods, except for water-based activities. In addition, activity logs registered by parents and educators were used as complementary sources in the evaluation of nap(s), nocturnal sleep, and accelerometer non-wear time. Accelerometry data were collected using a sampling rate of 30 Hz and then integrated into 15-s epochs [46] for analysis.

Children had to have at least two 24-h periods of accelerometry data to be considered for analysis.

2.2.2. Sleep duration, sleep timing, and sleep variability

Accelerometry data were visually inspected minute by minute, considering the activity logs, in order to identify nap(s), bedtimes, and wake-up times. Bedtime was initially located when a change in the accelerometer output from the sitting or standing position to the lying or off position was detected [45], which should roughly agree with the nap and bedtimes registered in the activity logs. Bedtime was then identified as the first minute followed by at least 10 consecutive minutes with a vector magnitude of 0 in the accelerometry data files. Wake-up time was first located when a change in the inclinometer output from the lying or off position to the sitting or standing position was detected, which should roughly agree with the nap and wake-up time registered in the activity logs. Wake-up time was then identified as the first minute of at least 10 consecutive minutes with a vector magnitude of >0.

Nocturnal sleep duration was defined as time between bedtime and wake-up time. Average nap and nocturnal sleep duration were categorized into two groups (shorter vs longer durations) according to the median values (nap: 87.2 min/day; nocturnal sleep: 646.8 min/day). Nocturnal sleep timing (bedtime/wake-up time) was calculated as the mean over days with valid data. Using median split (19:54:00) for bedtime of the sample, participants were classified into two groups: early bedtime and late bedtime. Similarly, participants were also classified as either an early wake-up time group or late wake-up time group, according to the median value of the sample (6:46:29 am). Nocturnal sleep variability was identified as the intrasubject standard deviation over the days with valid data and was categorized into two groups according to the median (59.2 min/day).

2.2.3. Physical activity

After identifying sleep period times, accelerometry data were analysed by an automated data reduction program (ActiLife Software, Version 6.12.1 for Windows) to identify the duration and intensity of physical activity. Additionally, 20 min of consecutive minutes of zero counts of the accelerometer were flagged as non-wear awake time [46] and were also excluded from the analysis. Physical activity was classified using the following cut-points for toddlers [47]: light-intensity physical activity (25–420 counts/15 s) and MVPA (>420 counts/15 s). Total physical activity duration was also calculated as the sum of light-intensity physical activity and MVPA. Average total physical activity duration was initially dichotomized according to current Australian physical activity guidelines (180 min of total physical activity for toddlers) [26]. However, most children (98.8%) in the sample met the guideline, making this classification inappropriate for further statistical analyses. Therefore, a median split (302.9 min/day) for total physical activity was used instead to dichotomize the sample. Average MVPA duration was also categorized into two groups according to the median (55.1 min/day).

2.3. Questionnaire data

Age, sex, nocturnal sleep problems, and screen time were reported by parents.

2.3.1. Age

Age was dichotomized according to the median value (20 months).

2.3.2. Nocturnal sleep problems

Sleep problems were assessed using the Tayside Children's Sleep Questionnaire, which is a 10-item scale (Table S1) that evaluates the ability of initiating and maintaining sleep in children aged 1–5 years [48,49]. For each item, the scores range from 0 to 4. For the first question, the five-point scale is rated according to intensity: “How long after going to bed does your child usually fall asleep?” (0 = ≤15 min, 1 = 15–30 min, 2 = 30–45 min, 3 = 45–60 min, and 4 = ≥60 min); and for the remaining questions the five-point scale are rated according to frequency (0 = the sleep behaviour never occurs; 1 = the problem occurs once or twice a month; 2 = the problem occurs one or two times a week; 3 = the problem occurs between three and five nights a week and 4 = the sleep problem happens every night). Only the first nine questions are designed to be summed, with a possible cumulative score ranging from 0 to 36; higher scores indicate more sleep problems [48]; question 10 is to ascertain parents' perception of the problem. The sample was dichotomized according to a diagnostic cut-off score of 8, with higher scores indicating disorders in initiating and maintaining sleep [48]. Cronbach's α for the full scale was 0.79 in our sample, and removing question 10 affected the parameter only marginally to 0.78.

2.3.3. Screen time

Screen time was assessed with the question ‘For how long does this child use screen entertainment, on a typical weekend day?’ and ‘For how long does this child use screen entertainment, on a typical weekday?’ According to parents' reports, daily average screen time was calculated as: (weekday screen time * 5 + weekend day screen time * 2)/7. Participants were classified into two groups (meeting the guideline vs not meeting the guideline), according to the current Australian guidelines for screen time in young children (none for children <2 years and ≤60 min/day for children aged 2–5 years) [26].

2.4. Socioeconomic status data

Participants’ socioeconomic status was assessed using the family postcode address considering the Australian Socio-Economic Indexes for Areas 2011(SEIFA–Index of Relative Socio-Economic Disadvantage) [50]. The index ranges from 1 to 10 (higher index indicates relatively less socio-economic disadvantage [50]). Participants were categorized into three groups: low socio-economic status (SEFIA = 1–3); middle socio-economic status (SEFIA = 4–6); and high socio-economic status (SEIFA = 7–10). Participants were also dichotomized according to the median value of four for this indicator as low socio-economic status and middle to high socio-economic status.

2.5. Anthropometry data

Height and weight were measured according to standard procedures [43]. Body mass index (BMI) was then calculated as weight (kg)/height $(m)^2$. Participants were also classified as nonoverweight (ie, underweight or normal weight) or overweight/obese according to the World Health Organization age- and sex-specific criteria [51].

2.6. Statistical analysis

Descriptive characteristics are presented as means and standard deviations or as percentages. Preliminary analysis precluded from performing linear regression analysis, as the residuals from linear regression models were not normally distributed. Therefore, the dependent variables were dichotomized using a median split; logistic regression analyses was performed instead to examine the relationships between potential correlates (ie, age, sex, socio-economic status, body mass index, physical activity, screen time, nap(s), bedtimes, and wake-up times) and nocturnal sleep duration, sleep variability, or sleep problems as dependent variables. The choice of potential correlates was based on previous evidence and availability of data.

A sensitivity analysis was performed with children with at least three days accelerometry data, and the results remained the same. Statistical analyses were performed using SPSS 21.0 software (IBM Corporation, Armonk, NY). The significance level was set at $p < 0.05$.

3. Results

Descriptive characteristics of the participants are presented in Table 1. On average, nocturnal sleep duration was 10.9 ± 1.2 h/night and the sleep variability was 87.4 ± 122.0 min. Almost 60% of toddlers had problems initiating and maintaining nocturnal sleep, whereas none of the parents of our sample perceived sleep problems in their children. Regarding accelerometer wear time, 4.6% of the participants had two 24-h days, 8.1% had three days, 6.9% had four days, and 80.4% had five or more days of accelerometry data; children were monitored on average for 5.8 ± 1.6 days.

As shown in Table 2, after adjustments for covariates, children with late wake-up times (OR: 4.42; 95% CI: 2.32–8.42), shorter nap(s) (OR: 2.42, 95% CI: 1.29–4.55) and less total physical activity (OR: 2.38; 95% CI: 1.27–4.45) were more likely to have longer nocturnal sleep duration. In contrast, children with late bedtimes were less likely to have longer nocturnal sleep duration than those with early bedtimes (OR: 0.09; 95% CI: 0.04–0.18).

Older children were also likely to have greater nocturnal sleep variability (OR: 1.97; 95% CI: 1.08–3.61). Late bedtimes were associated with nocturnal sleep variability after adjusting for covariates (OR: 1.97; 95% CI: 1.06–3.68) (Table 3). None of the potential correlates were associated with nocturnal sleep problems (Table 4).

4. Discussion

4.1. Overview of findings

The results indicate that less physical activity, shorter nap(s) duration, and late wake-up times were associated with increased odds of having longer nocturnal sleep duration in toddlers, whereas late bedtimes were associated with reduced odds of having longer nocturnal sleep duration. At the same time, older children and those with late bedtimes were more likely to have greater nocturnal sleep variability.

Previous studies, with subjective measures (eg, parental questionnaires) of nocturnal sleep duration, have reported mixed results regarding the association between physical activity and nocturnal sleep in young children [4,18,20]. However, our results suggest an inverse relationship between physical activity and nocturnal sleep in toddlers. This is consistent with recent cross-sectional findings from preschoolers and school-aged children in studies that used actigraphy to assess sleep [17,52,53]. One possible explanation is that the time spent in physical activity displaces the time spent in sleep, or vice versa. Specifically, in a 24-h period, a reduction in the time spent in one activity (ie, sleep, physical activity, or sedentary behaviour) may intrinsically relate to an increase in the duration of other activities, given the finite nature of time [54,55]. For example, children with more total physical activity are likely to spend less time in nocturnal sleep if they still spend the same amount of time on other daily routine activities (eg, having meals, being with family members, or watching television) as those who have less total physical activity. As total physical activity and nocturnal sleep represent large proportions of daily time, the durations of these two activities tend to be inversely related. This hypothesis is further supported by the findings of a recent study [53] using temporal analysis, in which a negative association was found between physical activity during the day and sleep duration on that night, as well as between nocturnal sleep duration and physical activity on the following day. Due to this intrinsically co-dependent relationship between total physical activity and nocturnal sleep in a 24-h period, future studies are recommended to use novel statistical analysis method, such as compositional data analysis [54], to further understand the association between total physical activity and nocturnal sleep duration, as well as their relationships with health outcomes [54–56]. Furthermore, some recent studies have reported that increased physical activity was associated with better nocturnal sleep quality (eg, efficiency of staying asleep [56]) in adolescents [57–59]. It could be important for future studies to consider sleep quality when understanding the influence of total physical activity on young children's nocturnal sleep.

Results from studies in adults have consistently shown that exercise is beneficial for nocturnal sleep [60]. However, the findings regarding the association between MVPA and nocturnal sleep duration in children are equivocal. In our study, MVPA was not associated with nocturnal sleep duration, which is in contrast to the positive association found in a previous study in the United States, with 240 toddlers from families of low socioeconomic status [4]. Our study is consistent with the null association that was reported in preschoolers [17]. Indeed, there are several proposed pathways linking MVPA with better sleep in adults, such as fatigue [61], increased energy consumption [62], and changes in mood/anxiety symptoms [61,63]. However, children, especially those less than five years of age [16], may react differently to MVPA, due to their immature sleep regulation system and sleep pattern [15]. A further understanding of how MVPA impacts nocturnal sleep in young children warrants future work to explore the potential causal relationships, as well as relevant physiological mechanisms.

The nap is a distinct sleep component in early childhood. During this period, frequencies and durations of daytime nap(s) gradually decline as nocturnal sleep becomes consolidated [15,16,28]. In our study, shorter nap(s) in toddlers was associated with longer nocturnal sleep duration, which is consistent with recent findings from a systematic review in children less than five years of age [28]. Despite the inverse association, daytime nap(s) is unlikely to be a substitute for nocturnal sleep, as they tend to have different physiological functions for young children [6,23,29,64]. For

Table 1
Sample characteristics.

	All sample (n = 173)
Age (months)	19.73 ± 4.09
Socio-economic status	
Low (% of total)	41.6
Middle (% of total)	37.0
High (% of total)	21.4
Body mass index	18.0 ± 1.7
Total physical activity (average min/day)	303.0 ± 51.7
MVPA (average min/day)	58.0 ± 20.2
Screen time (average min/day)	77.0 ± 62.3
Bedtime	19:57:02 ± 1:05:37
Wake time	06:51:59 ± 0:51:08
Nap (average h/day)	1.5 ± 0.4
Nocturnal sleep duration (average h/night)	10.9 ± 1.2
Nocturnal sleep variability (average min)	87.4 ± 121.0
Yes (% of total)	59.5
No (% of total)	40.5

Data are mean ± standard deviation. MVPA, moderate-to-vigorous physical activity.

Table 2
Odds ratios and 95% confidence intervals of having longer nocturnal sleep duration.

	Nocturnal sleep duration (mean ± SD) (average h/night)	Unadjusted models		Adjusted models	
		OR (95% CI)	*p*	OR (95% CI)	*p*
Age					
<20 months (n = 82)	10.9 ± 1.1	Reference		Reference	
≥20 months (n = 91)	10.9 ± 1.2	0.81 (0.45–1.48)	0.50	–	–
Sex					
Boys (n = 84)	10.9 ± 1.3	Reference		Reference	
Girls (n = 89)	10.8 ± 1.0	0.89 (0.49–1.62)	0.71	–	–
Socio-economic status					
Low (n = 88)	10.9 ± 1.1	Reference		Reference	
Middle to high (n = 85)	10.8 ± 1.2	0.89 (0.49–1.62)	0.70	–	–
Body mass index					
Normal weight (n = 126)	10.9 ± 1.2	Reference		Reference	
Overweight/obese (n = 47)	10.9 ± 1.0	1.21 (0.62–2.37)	0.58	–	–
Total physical activity					
More (n = 87)	10.6 ± 1.0	Reference		Reference	
Less (n = 86)	11.2 ± 1.2	2.38 (1.30–4.39)	0.01*	2.38 (1.27–4.45)	0.01*
MVPA					
More (n = 86)	10.8 ± 1.1	Reference		Reference	
Less (n = 87)	10.9 ± 1.2	1.07 (0.59–1.95)	0.82	1.06 (0.58–1.95)	0.84
Screen time					
Meeting the guideline (n = 20)	11.0 ± 1.2	Reference		Reference	
Not meeting the guideline (n = 153)	10.9 ± 1.2	0.99 (0.39–2.51)	0.98	0.98 (0.38–2.51)	0.97
Nap					
Longer (n = 86)	10.6 ± 1.1	Reference		Reference	
Shorter (n = 87)	11.1 ± 1.1	2.27 (1.24–4.18)	0.01*	2.42 (1.29–4.55)	0.01*
Bedtime					
Early (n = 87)	11.5 ± 1.1	Reference		Reference	
Late (n = 86)	10.3 ± 0.8	0.10 (0.05–0.19)	<0.001*	0.09 (0.04–0.18)	<0.001*
Wake time					
Early (n = 87)	10.3 ± 0.8	Reference		Reference	
Late (n = 86)	11.1 ± 1.2	4.37 (2.31–8.25)	<0.001*	4.42 (2.32–8.42)	<0.001*

Adjusted models included age, sex, socio-economic status, and body mass index as covariates. CI, confidence interval; MVPA, moderate to vigorous physical activity; OR, odds ratio; SD, standard deviation.
* $p < 0.05$.

example, nap(s) may reduce daytime physiological stress by reducing cortisol levels [65], whereas nocturnal sleep is likely to promote physical growth [66], as the largest peak secretion of growth hormone occurs after nocturnal sleep onset [67]. Although current sleep guidelines refer to 24-h sleep duration for young children [68], the optimal distribution between nap(s) and nocturnal sleep remains unknown. It will be important for future studies to identify the optimal distribution that maximizes health benefits, by examining the dose–response relationships between combinations of nap(s) and nocturnal sleep duration and health outcomes.

In our study, toddlers with a late bedtime were less likely to sleep longer at night, which is consistent with previous findings in toddlers and infants [16,37,69]. We also found that late wake-up times were associated with longer nocturnal sleep duration. However, young children with late bedtimes may not naturally wake up late to maintain nocturnal sleep duration, as late bedtimes may influence nocturnal sleep duration through the melatonin rhythm, a reliable marker of the circadian rhythm that regulates sleep [70,71]. Specifically, late bedtimes can delay melatonin rhythm [72], which in turn can shorten melatonin rhythm duration [73,74] and therefore decrease nocturnal sleep duration [75]. Our results also show that late bedtimes were associated with greater nocturnal sleep variability. The associations between late bedtimes and nocturnal sleep outcomes may be important when considering interventions to promote nocturnal sleep in young children.

In previous studies, screen time has been associated with shorter nocturnal sleep duration [23,76–79], irregular bedtime schedule [80], and sleep problems [81,82] in preschoolers. However, in our study, not meeting the Australian screen time guideline was not associated with any of the nocturnal sleep outcomes. One reason for the discrepancy could be the younger age range of our sample, as the majority of the significant findings regarding the associations between screen time and nocturnal sleep characteristics have been reported in studies with preschool-aged children [21,24,25]. Indeed, the associations may vary with age, because of the significant developmental trend of young children's sleep. For example, in a study with 7000 preschoolers in the United States, there was no significant difference in nocturnal sleep duration between children with more than 2 h of television viewing per day and children watching less than 2 h of television per day at the age of four years; yet the difference was significant at the age of five years [25]. Second, the timing of screen use may influence the association between nocturnal sleep characteristics and screen time; however, it was not assessed in the present study. For example, in a previous British study with 1702 toddlers, shorter nocturnal sleep duration and later bedtime were associated with more than 1 h of television watching in evening; however there was no significant association between nocturnal sleep duration and television viewing for more than 1 h per day in morning [23]. This is likely to be explained by the prolonged light exposure of screen before bedtime that suppresses the secretion of melatonin [83,84] as well as inappropriate content (eg, violence) in screen use that increase arousal and anxiety [81], which in turn may disturb nocturnal sleep. In consideration of this, it may be important for future studies in toddlers to consider the timing of screen use when looking into the association between nocturnal sleep characteristics and screen time. Finally, the significant findings reported by previous studies used examining the association between nocturnal sleep duration and the minutes of screen time or a cut-off of 2 h of television viewing time. Given that (1) in our study, the guideline cut-off for screen time was lower than that in previous

Table 3
Odds ratios and 95% confidence intervals of having greater nocturnal sleep variability.

	Nocturnal sleep variability (mean ± SD) (average min/day)	Unadjusted models		Adjusted models	
		OR (95% CI)	*p*	OR (95% CI)	*p*
Age					
<20 months (n = 82)	69.4 ± 73.6	Reference		Reference	
≥20 months (n = 91)	103.6 ± 151.7	1.97 (1.08–3.61)	0.03*	–	–
Sex					
Boys (n = 84)	84.7 ± 107.2	Reference		Reference	
Girls (n = 89)	89.9 ± 135.0	0.71 (0.39–1.28)	0.25	–	–
Socio-economic status					
Low (n = 88)	99.0 ± 135.3	Reference		Reference	
Middle to high (n = 85)	75.4 ± 105.9	0.59 (0.32–1.07)	0.08	–	–
Body mass index					
Normal weight (n = 126)	87.0 ± 112.0	Reference		Reference	
Overweight/obese (n = 47)	88.3 ± 128.5	0.58 (0.29–1.14)	0.12	–	–
Total physical activity					
More (n = 87)	96.7 ± 154.7	Reference		Reference	
Less (n = 86)	77.9 ± 75.5	1.18 (0.65–2.14)	0.59	1.27 (0.68–2.40)	0.45
MVPA					
More (n = 86)	100.3 ± 155.2	Reference		Reference	
Less (n = 87)	74.6 ± 73.6	1.12 (0.62–2.04)	0.70	1.23 (0.66–2.31)	0.51
Screen time					
Meeting the guideline (n = 20)	70.7 ± 61.8	Reference		Reference	
Not meeting the guideline (n = 153)	89.6 ± 127.7	2.04 (0.77–5.38)	0.15	2.13 (0.77–5.90)	0.15
Nap					
Longer (n = 86)	78.8 ± 104.8	Reference		Reference	
Shorter (n = 87)	95.8 ± 137.0	1.02 (0.56–1.86)	0.94	1.02 (0.54–1.94)	0.95
Bedtime					
Early (n = 87)	79.5 ± 106.3	Reference		Reference	
Late (n = 86)	95.4 ± 136.2	2.06 (1.13–3.78)	0.02*	1.97 (1.06–3.68)	0.03*
Wake time					
Early (n = 87)	67.5 ± 71.9	Reference		Reference	
Late (n = 86)	107.5 ± 155.1	1.71 (0.94–3.12)	0.08	1.72 (0.92–3.20)	0.09

Adjusted models included age, sex, socio-economic status, and body mass index as covariates. CI, confidence interval; MVPA, moderate to vigorous physical activity; OR, odds ratio; SD, standard deviation.
* $p < 0.05$.

studies, and (2) screen time in some studies [23,25] was not limited only to television viewing, it could be that the guideline cut-off used in our study (ie, non-screen time for children under two years and 1 h of screen time for children two or more years of age) was too strict to influence nocturnal sleep. However, this hypothesis needs to be tested in future studies looking at the dose–response relationship between nocturnal sleep and screen time.

In our study, older children were more likely to have greater sleep variability than younger children, whereas null associations were reported in preschoolers [85,86]. We also found that age was not associated with nocturnal sleep duration or sleep problems. However, age has been reported as a correlate of nocturnal sleep duration in children less than three years of age (ie, infants tend to sleep more than toddlers) [14,37].

A recent British twin cohort study [23] with 1702 toddlers found that boys were more likely to have shorter nocturnal sleep duration than girls, which contrasts with our findings. Being a girl was also not associated with nocturnal sleep variability in our study, which is in line with previous findings in preschoolers [9].

Although socio-economic status and weight status have been associated with nocturnal sleep characteristics in previous studies [4,23,87,88], these factors were not associated with nocturnal sleep duration, sleep variability, or sleep problems in our study.

In a study with involving 184 US preschoolers from low-income communities, the average nocturnal sleep variability was 1 h [10]. Compared to these older children, the nocturnal sleep variability in our toddlers was relatively high, approximately 1.5 h on average, although few correlates were identified herein. At the same time, 60% of toddlers in this study had problems in initiating and maintaining nocturnal sleep, whereas none of the potential correlates examined in this study were associated with sleep problems. These null results seem to be consistent with previous studies. For example, a null association has been reported between nap duration and nocturnal sleep variability [31] and nocturnal sleep problems [22]. Perhaps the correlates of nocturnal sleep variability and sleep problems in young children are other factors, such as parents' beliefs, knowledge, and practise [15,16,89,90]. For example, despite the high prevalence of sleep problems in our sample, none of the parents perceived the problems in their children. At the same time, environmental factors, such as bedroom arrangement (eg, television in the bedroom [79,91], temperature [92,93], ventilation [92,94], noise [95], and light [40]) have been report to that may be related to children's nocturnal sleep, and therefore should be taken into consideration in future studies.

4.2. Strengths and limitations

To our knowledge, the present study is the first to explore correlates of nocturnal sleep duration, nocturnal sleep variability, and nocturnal sleep problems in toddlers, with the use of 24-h accelerometry data. Accelerometer monitoring is one important strength of our study, which allows objective measures of nocturnal sleep duration and variability. However, due to the cross-sectional design, causality cannot be inferred. Second, our inclusion criteria were limited to two 24-h periods of accelerometry data, which may not be representative of a child's usual sleep and other movement behaviour; however, the average wear days of 24-h periods were more than five days in our sample, with a majority (95.4%) having a least three days of accelerometry data, which is consistent with previous studies [96,97]. Third, our sample is not nationally representative, and therefore the results are not generalizable.

Table 4
Odds ratios and 95% confidence intervals of having problems initiating and maintaining nocturnal sleep.

	Having problems initiating and maintaining nocturnal sleep (%)	Unadjusted models		Adjusted models	
		OR (95% CI)	*p*	OR (95% CI)	*p*
Age					
<20 months (n = 82)	63.4	Reference		Reference	
≥20 months (n = 91)	56.0	0.74 (0.40–1.36)	0.33	–	–
Sex					
Boys (n = 84)	60.7	Reference		Reference	
Girls (n = 89)	58.4	0.91 (0.50–1.67)	0.76	–	–
Socio-economic status					
Low (n = 88)	65.9	Reference		Reference	
Middle to high (n = 85)	52.9	0.58 (0.32–1.07)	0.08	–	–
Body mass index					
Normal weight (n = 126)	59.5	Reference		Reference	
Overweight/obese (n = 47)	59.6	1.00 (0.51–1.98)	0.995	–	–
Total physical activity					
More (n = 87)	56.3	Reference		Reference	
Less (n = 86)	62.8	1.31 (0.71–2.41)	0.39	1.33 (0.71–2.50)	0.38
MVPA					
More (n = 86)	60.5	Reference		Reference	
Less (n = 87)	58.6	0.93 (0.51–1.70)	0.81	0.96 (0.51–1.79)	0.89
Screen time					
Meeting the guideline (n = 20)	60.8	Reference		Reference	
Not meeting the guideline (n = 153)	50.0	1.55 (0.61–3.95)	0.36	1.41 (0.55–3.65)	0.48
Nap					
Longer (n = 86)	57.0	Reference		Reference	
Shorter (n = 87)	62.1	1.24 (0.67–2.27)	0.50	1.19 (0.63–2.25)	0.59
Bedtime					
Early (n = 87)	58.6	Reference		Reference	
Late (n = 86)	60.5	1.05 (0.59–1.98)	0.81	1.06 (0.57–1.96)	0.86
Wake time					
Early (n = 87)	56.3	Reference		Reference	
Late (n = 86)	62.8	1.31 (0.71–2.41)	0.39	1.24 (0.67–2.30)	0.49

Adjusted models included age, sex, socio-economic status, and body mass index as covariates. CI, confidence interval; MVPA, moderate to vigorous physical activity; OR, odds ratio.

Another limitation is the proxy-reported screen time, which tends to be subject to parents' bias. Finally, due to the availability of data, some potential correlates, such as dietary behaviours [98], were not considered in the analysis.

5. Conclusion

The present study identifies multiple correlates of nocturnal sleep duration (eg, total physical activity, nap, bedtime, and wake-up time) and nocturnal sleep variability (eg, age and bedtime) in toddlers, although our hypothesis regarding the correlates of nocturnal sleep problems was not confirmed by our results. The association between late bedtimes and shorter nocturnal sleep duration, as well as greater nocturnal variability, indicates their potential to be modifiable targets for future sleep interventions in early childhood. Future studies with rigorous designs are also needed to confirm these associations and to explore other correlates of nocturnal sleep in children of the early years.

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Conflict of interest

The authors have no financial relationships relevant to this article to disclose. This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

The ICMJE Uniform Disclosure Form for Potential Conflicts of Interest associated with this article can be viewed by clicking on the following link: https://doi.org/10.1016/j.sleep.2018.08.035.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.sleep.2018.08.035.

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