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 JOURNAL OF
 ADOLESCENT
 HEALTH

www.jahonline.org

Original article

What's Keeping Teenagers Up? Prebedtime Behaviors and Actigraphy-Assessed Sleep Over School and Vacation

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Article history: Received June 10, 2015; Accepted December 8, 2015

Keywords: Prebedtime behaviors; Adolescents; Social media; Vacation; School-term; Bedtime; Chronotype; Presleep arousal; Family; Sleep duration

 A B S T R A C T

Purpose: Technology-related behaviors (e.g., *computer use*) before bedtime (BT) have been associated with poorer and shorter sleep in adolescents; however, less is known about other behaviors in relation to sleep. This study characterized a range of behaviors in the hour before bed (i.e., pre-BT behaviors [PBBs]) and examined their relationship with sleep parameters during school and vacation periods (i.e., restricted and extended sleep opportunities, respectively). Mechanistic roles of chronotype and cognitive presleep arousal (PSAcog) were also examined.

Methods: During the last week of a school term and throughout a 2-week vacation, 146 adolescents (47.26% male, age $M \pm$ standard deviation = 16.2 ± 1.0 years) from the general community completed daily sleep measure using actigraphy, self-report measures on PBBs and PSAcog (Pre-sleep Arousal Scale) for both school and vacation periods, and chronotype (Morningness–Eveningness Questionnaire).

Results: Adolescents engaged in a variety of behaviors before bed. Notably, *playing video games* was associated with significantly later school and vacation BT and shorter school sleep duration (controlling for chronotype). During vacation, *online social media* was associated with significantly longer sleep onset latency, and this relationship was mediated by higher PSAcog. In contrast, on school nights, *spending time with family* was associated with significantly earlier BT and longer sleep duration.

Conclusions: Technology-related PBBs *video games* and *online social media* were risk factors for shorter and poorer sleep, whereas *time with family* was protective of sleep duration. In addressing sleep problems in adolescents, therapeutic procedures that target the potentially addictive nature of technology use and reduce PSAcog were implicated.

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 IMPLICATIONS AND
 CONTRIBUTION

This study assessed a wide range of prebedtime behaviors in adolescents during both school and vacation periods and examined their associations with objective sleep parameters. Findings identified behaviors detrimental to, and protective of, adolescents' sleep. Potential mechanisms described have practical implications for future interventions.

Conflicts of Interest: The authors have indicated no financial conflicts of interest.

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Insufficient and poor sleep in adolescents, especially during school days, is widely reported [1] and is associated with numerous consequences, such as impaired academic performance [2], increased risk of motor vehicle accidents [3], and emotional difficulties [4]. The causes of sleep problems in adolescents are multi-factorial. Biological (e.g., delays in circadian

phase and decreases in homeostatic drive) and psychosocial factors (e.g., decreased parental control [5], increased academic and social demands [6]) are permissive of later bedtime (BT), while school start times contribute to early risetime (RT), promoting sleep restriction [7]. Pre-bedtime behaviors (PBBs) are important to understand, as they are modifiable factors that may be relevant in addressing sleep problems in adolescents.

Technology-related prebedtime behaviors

Technology-related PBBs are consistently associated with shorter sleep duration and lower sleep quality. More time spent watching television, using the Internet, and computer gaming are associated with later BT and shorter time in bed on weekdays and later RT on weekends [8]. Relevant to sleep are the location and timing of technology use. Compared with adolescents without bedroom access to this technology, those with access in bedrooms use these devices more and have later BT and shorter total sleep time (TST) on weekdays [9]. Within the hour before bed, frequent video gaming, computer use, listening to Mp3, and use of mobile phones are associated with later self-reported BT on both school and weekend nights [10]. Weekday sleep duration is also significantly shorter for adolescents who *usually/always* engaged in watching television, playing video games, using computers, using mobile phones for calling/texting or listening to music before bed, than those who *sometimes/never* engaged [11]. More frequent engagement in technology-related PBBs, such as using Mp3 players, computers, and mobile phones before bed, is also associated with longer sleep onset latency (SOL; time taken to initiate sleep) [10–12].

Three potential mechanisms have been proposed to explain the links between technology-related behaviors and adolescents' sleep [13]: (1) technology-related behaviors may displace sleep time by delaying BT and shortening sleep duration; (2) evening media use may contribute to greater cognitive arousal (i.e., mental activation such as thoughts and worries), which is associated with later BT and longer SOL in both adults [14] and adolescents [15]; and (3) light from screen-based devices may suppress melatonin and delay sleep onset [16].

Nontechnology-related prebedtime behaviors

Few studies have examined the relationship between nontechnology-related PBBs and sleep. Reading at BT was shown to promote earlier school BT and thus is protective of sleep duration [17]. While not directly examined in relation to sleep, spending more time with family is associated with greater parental control over BT and media usage [18], and greater parental control is associated with earlier BT [10]. Conversely, homework, spending time with friends, and physical exercise can be hurdles to adequate sleep in adolescents [19,20].

Gaps in the literature and the present study

There are several important gaps in the literature: (1) nontechnology-related PBBs are poorly understood; (2) with one exception [11], studies have not controlled for chronotype, an important confounder of the association between PBBs and sleep timing, making it unclear whether PBBs lead to later BT beyond circadian preference or whether evening preferences drive engagement in PBBs; (3) most studies have relied on retrospective self-reports of sleep, which is open to recall and subjective

biases [21]; (4) the relationship between PBBs and sleep during relatively unconstrained sleep opportunity (i.e., vacation) is unexplored [22]; and (5) despite plausible theories [13], mechanisms underlying the relationships between PBBs and sleep have not been well examined. Therefore, the present study aimed to:

- (1) Characterize patterns of both technology and nontechnology-related PBBs during school (School) and vacation (Vacation) periods using a longitudinal design.
- (2) Examine how PBBs relate to objectively measured sleep timing (BT and RT) and duration (TST) controlling for chronotype and SOL (chronotype was not controlled for in SOL analyses as it shared negligible correlation with SOL ($r = -.02$ and $-.04$ for School and Vacation, respectively). Based on the existing literature, these sleep variables represent key aspects of sleep that might be directly affected by PBBs [13].
- (3) Examine whether cognitive presleep arousal (PSAcog) is a mechanism mediating significant associations between technology-related PBBs and longer SOL.

Methods

Participants

This study aimed to recruit a community sample of adolescents attending Years 10, 11, and 12 in schools in Melbourne, Australia. As described in the procedures, no exclusion criteria were applied at the time of recruitment.

Materials

Actigraphy. Actigraphy is widely used to study sleep/wake patterns in adolescents [23], providing objective estimates of sleep duration and quality close to PSG [24]. This study used comparable models of Actiwatch-2 and Actiwatch-64 (Mini Mitter, Bend, OR) [25]. Data were collected with 1-minute epochs and analyzed based on “medium” threshold for sleep/wake detection in Actiware 5.5. Both actigraph models contain an “event marker” button for registering BT and RT. The following variables were generated using Actiware: BT, RT, TST, and SOL (see [22] for actigraphy data processing). For the School variables, data from Monday to Thursday nights (i.e., 24-hour cycles that started and ended on a school day) were averaged; for Vacation, data during a 2-week vacation were averaged.

Prebedtime behaviors. The Prebedtime Behavior Questionnaire (PBBQ) is a self-report inventory that assesses frequencies of 25 evening behaviors adolescents commonly engaged in, such as *reading a book, web browsing* (Table 1). No existing scale measures PBBs in adolescents; therefore, items in the PBBQ were selected through a focused discussion among seven researchers (including two licensed Clinical Psychologists) specialized in adolescent sleep and mental health. An “other” item was included for capturing any PBBs not listed on the PBBQ. Participants were asked to rate how often they engaged in each behavior within the hour before intending to sleep over the past week on a four-point scale: 0 (*never*), 1 (*once or twice a week*), 2 (*three to four times a week*), and 3 (*most nights*).

Chronotype. The Morningness–Eveningness Questionnaire (MEQ) is a 19-item scale on preferred timing of physical and mental activities (i.e., chronotype) [26] with higher scores

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