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ARTICLE

Adolescents Living the 24/7 Lifestyle: Effects of Caffeine and Technology on Sleep Duration and Daytime Functioning

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What's Known on This Subject

Aspects of adolescent lifestyle, such as academic stress or social pursuits, can interact and lead to irregular sleep patterns. Poor sleep quality and shortened sleep duration have been associated with mental and physical comorbidities and decreased quality of life in adolescents.

What This Study Adds

No studies to date have quantified nighttime technology use and caffeine consumption to assess their potential effects on sleep duration and daytime behaviors in a group of middle school and high school adolescents aged 12 to 18 years.

ABSTRACT

OBJECTIVE. Adolescents may not receive the sleep they need. New media technology and new, popular energy drinks may be implicated in sleep deficits. In this pilot study we quantified nighttime technology use and caffeine consumption to determine effects on sleep duration and daytime behaviors in adolescents. We hypothesized that with increased technology use, adolescents increase caffeine consumption, resulting in insufficient sleep duration.

PATIENTS AND METHODS. Subjects were recruited from a pediatric office in a proximal suburb of Philadelphia, Pennsylvania. Inclusion criteria for this study were middle and high school subjects aged 12 to 18 years old. The questionnaire, Adolescent Sleep, Caffeine Intake, and Technology Use, was developed by the investigators to measure adolescents' intake of caffeinated drinks, use of nighttime media-related technology, and sleep behaviors. Descriptive statistics characterized the subjects, their caffeine and technology use, and sleep variables. Regression models assessed the relationships between caffeine, technology use, and sleep variables, having adjusted for age, race, gender, and BMI.

RESULTS. Sleep was significantly related to the multitasking index. Teenagers getting 8 to 10 hours of sleep on school nights tended to have 1.5- to 2-fold lower multitasking indices compared with those getting less sleep. Thirty-three percent of the teenagers reported falling asleep during school. Caffeine consumption tended to be 76% higher by those who fell asleep. The log-transformed multitasking index was significantly related to falling asleep during school and with difficulties falling asleep on weeknights.

CONCLUSIONS. Many adolescents used multiple forms of technology late into the night and concurrently consumed caffeinated beverages. Subsequently, their ability to stay alert and fully functional throughout the day was impaired by excessive daytime sleepiness. Future studies should measure more than television hours when evaluating the impact of nighttime activities on sleep patterns in adolescents. *Pediatrics* 2009;123:e1005–e1010

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IN THE US population, sleep duration has decreased 1 to 2 hours over the last 4 decades, with a twofold increase in adolescents sleeping <7 hours per night.[1,2] Although there is evidence that many adolescents may have sleep needs that exceed the recommended 8 to 9 hours each night, they have been shown to receive less sleep.[3–5] Aspects of adolescent lifestyle, such as early school starts, academic pressure, stress, anxiety, and social pursuits, can interact and lead to irregular sleep patterns.[6–9] Shortened sleep duration in children from preschool through adolescence has been found to be associated with mood disorders, atopic conditions, asthma exacerbations, and obesity.[10–14] Poor sleep quality and shortened sleep duration had been associated with a lowered sense of well-being and decreased quality of life in young adults.[15]

Media-related technology may affect sleep duration. Adolescents today rely heavily on technology to stay connected with the world. Nearly all adolescents have at least 1 electronic item such as a television, computer, telephone, or music device in their bedroom. On average, 6th-graders have more than 2 of these items in their bedrooms, whereas 12th-graders have approximately 4.[16] One contributing factor to the pattern of shortened sleep

duration in adolescents might be an excessive use of technology (watching television, surfing the Internet, sending instant messages, text messaging with cell telephones, and playing video games), especially late at night. This use of technology, coupled with early school starts, has been predicted to result in shortened sleep duration.[4] In addition, the brightness of a television or computer screen may interfere with melatonin release, because release occurs only under dark conditions; and in turn, regulation of the sleep-wake cycle may be disturbed.[17–19] The combined use of several technologies may lead to additional delay in sleep onset in adolescence. In this study we sought to quantify nighttime technology use and associated effects on sleep duration and sleep-related behaviors.

In addition, the impact of newer, high-caffeine energy drinks on sleep duration has not been sufficiently studied. A single cross-sectional study of 4243 subjects in the 1998 Health Behavior in School Aged Children survey examined the effect of caffeine intake (coffee or soft drinks only) on sleep in adolescents and found a twofold increased risk in sleep disturbance in adolescents who drank either coffee or soft drinks.[20] Yet with the new trend in adolescents to drink highly caffeinated energy drinks marketed with popular, youthful names, and a higher-than-normal caffeine amount, there are no data regarding the consequences on sleep duration.[21,22] No studies to date have quantified caffeine intake in adolescents and explored the associations, if any, with shortened sleep or daytime sequelae.

The purpose of this pilot study, therefore, was to quantify nighttime technology use and caffeine consumption to assess their potential effects on sleep duration and daytime behaviors in a group of middle school and high school adolescents 12 to 18 years old. We hypothesized that with increased technology use, adolescents increase caffeine consumption; as a result, sleep duration is inadequate.

METHODS

Participants

Subjects were recruited from a large pediatric primary care office in a proximal suburb of Philadelphia, Pennsylvania, during the period of September 2007 to March 2008. Inclusion criteria for this study were middle school and high school subjects aged 12 to 18 years who were patients in the pediatric practice at which the questionnaires were administered, were accompanied by caregivers, and were proficient in speaking and writing English. Children with profound mental disability precluding them from reading and writing were excluded from this study. This study was approved by the University of Pennsylvania Institutional Review Board, and the Children's Hospital of Philadelphia Institutional Review Board. Parental consent and adolescent assent was obtained before questionnaire completion.

Questionnaire

The Adolescent Sleep, Caffeine Intake, and Technology Use is a 36-item, 3-concept instrument developed by the investigators to measure adolescents' intake of caffeinated drinks, use of nighttime media-related technology, and sleep behaviors. All data were deidentified to ensure confidentiality. Items on the self-administered questionnaire include sleep and sleep-related behaviors, media-related technology usage, sleep/wake cycle features, caffeine intake, and sleepiness and driving. Content and face validity were established by using 5 sleep experts to judge the relevancy of each item to the intent of the questionnaire. Eight adolescents pilot tested the survey to ensure readability and content validity. Flesch–Kincaid grade-level evaluation of this tool determined complexity at a 5th-grade reading level.[23]

Adolescents who were scheduled for well-child appointments each week were approached to complete the questionnaire. After verbal consent from the parents and assent from the subjects were obtained, data collection involved completion of questionnaire by pencil and paper. Subjects completed questionnaires separately in the privacy of their examination rooms before or after a well-child visit. Parents completed a demographic questionnaire regarding race, marital status, and employment.

Caffeine content of proprietary beverages was obtained from the manufacturers' Web sites. Caffeine content for tea and coffee was obtained from the respective national associations. Estimated caffeine intake for tea refers to black tea; estimated caffeine intake for coffee refers to brewed coffee.

To capture the hours spent engaged in technology activities at night, a multitasking index was created as the total number of hours spent across all the activities divided by 9 (the number of hours from 9 PM to 6 AM).

Statistical Analysis

Descriptive statistics were used to characterize the subjects, their caffeine and technology use, and multiple sleep variables. Relationships between variables were first examined via correlation coefficients, *t* tests, and Fisher's exact tests, as appropriate. Multiple regression techniques (linear or logistic) were then used to assess further the relationship between caffeine and technology use and sleep variables, having adjusted for age, race, gender, and BMI. All analyses were conducted by using SPSS 15.0 (SPSS Inc, Chicago, IL).

RESULTS

One hundred adolescents were studied, ranging in age from 12 to 18 years, with a median age of 15 years. Fifty-eight percent of the sample was female, 62% non-Hispanic white, and 27% non-Hispanic black. The median BMI was 21.9 kg/m^2 (range: 14.7–39.1 kg/m^2). Median household incomes from the sample area ranged from $16 000 to $143 000, with a median household income of $51 800.

Technology Use

The majority of the sample used some form of technology, with 66% having a television in their bedroom, 30% a computer, 90% a cellular telephone, and 79% an

TABLE 1 Sleep Patterns and Habits of Subjects ($n = 100$)

Characteristic	*n*	Median (Range)
Television in bedroom	66	—
Computer in bedroom	30	—
Cell phone	90	—
iPod or MP3 player	79	—
No. of activities after 9 PM	—	4 (0–8)
Multitasking index	—	0.6 (0.0–3.6)
Drinks caffeine	85	—
Total caffeine intake, mg		
Entire sample	92	141.1 (0.0–1457.8)
Caffeine drinkers only	80	147.3 (23.0–1457.8)
Has difficulty falling asleep		
Week nights	63	—
Weekends	33	—
Hard to stay awake during day	46	—
Hard to stay awake during school	44	—
Fell asleep during school	33	—
No. times fall asleep during school	33	2 (1–8)
Sleepy before lunch	29	—
Sleepy after lunch	19	—
Naps after school	37	—
Naps on weekend	42	—
Duration of sleep on school nights		
3–5 h	15	—
6–8 h	62	—
8–10 h	20	—

MP3 digital audio player (Table 1). Overall, 82% of the adolescents reported watching some television after 9 PM (Table 2), which increased to 86.4% among those with a television in their bedroom. Adolescents watched 1 to 8 hours of television after 9 PM, with 1.5 hours watched on average. After 9 PM, 34% of the adolescents reported text messaging, 44% reported talking on the telephone, 55% reported being online, 24% played computer games, 36% watched movies, and 42% listened to an MP3 player. An average of 1 to 2 hours was spent on each of these activities, with some adolescents reporting up to 12 hours of text messaging and 6 hours from other activities (Table 2). On average, adolescents engaged in 4 (range: 0–8) technology activities after 9 PM. This technology usage corresponded to an average multitasking index of 0.59 (Table 1); this was the equivalent of doing 1 activity for 5.3 hours or 4 activities for 1 hour 20 minutes each.

TABLE 2 Summary of Activities After 9 PM: Components From the Multitasking Index

Task	% of Subjects Engaged in Activity After 9 PM	Hours Spent With Activity, Median (Range)
Watching television	82	1.5 (1.0–8.0)
Text messaging	34	1.0 (0.05–12.0)
Talking on telephone	44	1.0 (0.2–6.0)
Online computer use	55	1.0 (1.0–4.0)
Computer games	24	1.0 (0.5–2.0)
DVD/video watching	36	2.0 (1.0–5.0)
Listening to MP3 player	42	1.0 (0.2–6.0)
Completing homework	57	1.0 (0.2–6.0)
Other	18	1.0 (0.5–4.0)

Of note, income levels were not significantly related to the possession of any technology except televisions. Adolescents with televisions in their bedrooms tended to be from households with 43% lower median incomes than adolescents without televisions ($41 200 vs $71 700; $P < .001$). Median household income estimated from reported census median earning for states parental occupation (s) in the area.

Caffeine Consumption

Eighty-five percent of the sample reported drinking caffeine (Table 1). A summary of the drinks consumed by the adolescents is shown in Table 3. For these teenagers, the overall median daily caffeine intake was 144 mg (mean: 215 mg), with a range of 23 to 1458 mg. Only 27.5% of the adolescents consumed <100 mg of caffeine daily (the equivalent of drinking a single espresso), whereas 11.2% drank >400 mg/day (the equivalent of 2 Vivarin [GlaxoSmithKline, Middlesex, United Kingdom] tablets or 4 espressos daily). Of the 75 adolescents who reported usual consumption times, caffeine intake generally occurred either before (6–8 AM [18.7%]) or after (3–5 PM [25.3%] or 6–8 PM [21.3%]) school hours.

The multitasking index was significantly correlated with caffeine intake both in the entire sample ($\rho = 0.302$; $P = .003$) and among the subsample who drank caffeine ($r = 0.359$; $P = .001$) (Fig 1). When adjusted for age, race, gender and BMI z scores, there was an ~37% increase in caffeine intake for each 0.5 increase in the multitasking index ($P = .001$).

Sleep Duration and Daytime Consequences

On school nights, only 20.6% of the adolescents in this sample obtained the recommended 8 to 10 hours of sleep per night (Table 1), with the rest getting <8 hours of sleep. Although caffeine consumption tended to be lower in the group of those who had 8 to 10 hours of sleep (medians: 8–10 hours: 54.1 mg; 6–8 hours: 144.0 mg; 3–5 hours: 157.6 mg), this difference did not reach statistical significance ($P = .067$). Having a television in the bedroom was not significantly related to hours of sleep on either a school night ($P = .249$) or weekend ($P = .528$). However, sleep was significantly related to the multitasking index ($P = .043$). Teenagers getting 8 to 10 hours of sleep tended to have lower multitasking indices (median: 0.39) compared with those getting 6 to 8 hours (median = 0.59) and 3 to 5 hours (median: 0.83) of sleep on school nights.

Lack of sleep in the sample resulted in some health concerns and educational issues. Thirty-three percent of the teenagers surveyed reported falling asleep during school (Table 1), on average twice (range: 1–8). Caffeine consumption tended to be 76% higher in those who fell asleep, but this did not reach statistical significance in adjusted models. The multitasking index was significantly related to falling asleep during school in adjusted models ($P < .001$). For each unit increase in the log-transformed multitasking index, an adolescent was 70 times more likely to fall asleep during school (odd ratio: 69.9 [95% confidence interval: 8.8–556.1]). In addition,

TABLE 3 Summary of Caffeine Consumption Among Subjects

Beverage	Caffeine, mg/oz[a]	% of Subjects Drinking Beverages	Beverage Intake, Median (Range), oz/d	Amount of Caffeine, mg[b]
Tea (black)	5.88	53	24 (8–60)	141.12
Coffee (brewed)	13.44	14	12 (8–24)	161.28
Cappuccino	7.25	8	10 (2–24)	72.5
Frappuccino (Starbucks, Seattle, WA)	9.47	3	4 (8–12)	37.9
Dr Pepper (Dr Pepper Snapple Group, Inc, Plano, TX)	3.43	4	16 (8–24)	54.72
Coca-Cola (Coca-Cola Company, Atlanta, GA)	2.88	41	12 (8–48)	34.56
Mountain Dew (PepsiCo Inc, Purchase, NY)	4.58	10	24 (8–62)	110
Pepsi (PepsiCo Inc)	3.17	30	12 (1–48)	38.04
Full Throttle (Coca-Cola Company)	9	3	16 (16–48)	144
Red Bull (RBNA Headquarters, Santa Monica, CA)	9.67	4	15 (10–20)	145
Vault (Coca-Cola Company)	5.8	8	16 (16–48)	93.3
Monster (Monster Beverage Company, Corona, CA)	10	10	16 (12–117)	160
Jolt (Wet Planet Beverages, Rochester, NY)	9.36	2	23.4 (1–23.4)	219
SoBe Adrenaline Rush (PepsiCo Inc)	9.52	1	20 (8–32)	190.4
AMP (PepsiCo Inc)	8.93	2	16 (8–24)	143
KMX (Coca-Cola Company)	8.7	2	8 (1–8)	69.6

[a] The caffeine content of proprietary beverages was obtained from the manufacturers' Web sites.
[b] Amount of caffeine per ounce multiplied by median intake per day.

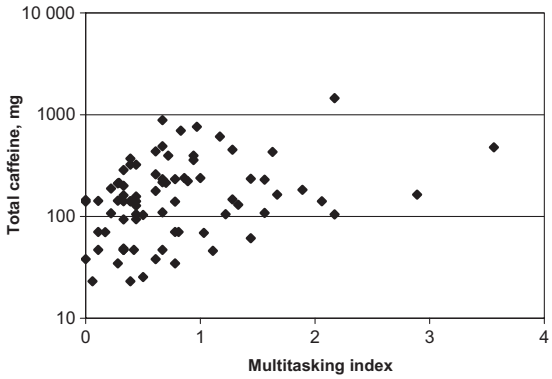

FIGURE 1
Relationship between multitasking index and total caffeine consumption in caffeine-drinking adolescents.

the log-transformed multitasking index was related to difficulties falling asleep on a weeknight, with each unit increase resulting in adolescents being 20 times more likely to have difficulties (odds ratio: 19.79 [95% confidence interval: 3.1–126.6]; $P = .002$).

Fourteen adolescents had their driver's license in this sample. Of these, 50% ($n = 7$) responded that they feel tired when driving, 50% ($n = 7$) had driven while sleepy, and 14.3% ($n = 2$) had drunk caffeine to stay awake while driving. In addition, 1 teenager reported having fallen asleep at the wheel.

DISCUSSION

The concerns about media's effect on sleep in children has been an ongoing issue for more than 30 years.[16] In 2002, a study conducted by the Kaiser Family Foundation revealed that 74% of adolescents between the ages of 15 and 17 reported having Internet access at home, with 31% having access in their bedrooms.[24] No previous study has evaluated the consequences of caffeine and technology at night and effect on adolescent sleep. With the availability of caffeinated drinks and sophisticated, portable, and personalized technology, our findings demonstrate that, despite the drive to sleep, adolescents use multiple forms of technology and consume caffeinated beverages to stay awake later into the night. Subsequently, their ability to stay alert and fully functional throughout the day was impaired by excessive daytime sleepiness.

Currently, it is believed that adolescents need ~9 hours of sleep, although they typically obtain closer to 7 hours of sleep.[25] Sleep deficits are diminished by sleeping longer on weekends or sleeping in class or are not made up at all, with a resultant effect on health and alertness.[26] Given the increasing availability of different technology formats for adolescents to engage others, regardless of the hour, sleep and daytime functioning are affected. Eighty-two percent of adolescents in this study watched television after 9 PM, with a median of 1.5 hours nightly. Moreover, they were engaged in several other activities that were potentially stimulating and delayed sleep. Subjects who slept the least also multitasked the most. Regardless of socioeconomic status, adolescents multitasked on average 4 activities late into the night. The subjects who multitasked the most had significant decrease in hours of sleep, as well as significant sleep disturbance during school hours. One subject in particular, who slept <5 hours each night, reported falling asleep on average 8 times during a school day. In addition, 37% took naps after school and 42% did so on the weekend, apparently trying to make up for lost sleep. With 33% on average falling asleep at least twice per day, these adolescents who multitask the most are at risk for changes in school performance, difficulties with executive function, and degradation of neurobehavioral function.[25,27]

Use of more than 1 device for long periods potentially may delay production of melatonin, which typically in-

creases in the evening as a response to decreasing ambient light levels. Previous studies hypothesized that sufficient light exposure from electronic displays, such as a computer screen, may delay melatonin production.[18,19] By contrast, because of distance from television during viewing, because intensity of light decays in distance from the source, there may be little effect on melatonin secretion.[19] Given multiple use of technology devices by adolescents in this study, such as a cell phone held close to text-message or scrolling through the MP3 display while sitting close to a computer screen, the combination of these devices could easily delay melatonin release.

Caffeine, a methylxanthine and adenosine receptor antagonist, can be considered the most commonly consumed psychoactive substance worldwide.[28] Human sleep has been shown in numerous studies to be sensitive to the effects of caffeine. An evening ingestion of caffeine has been shown to lengthen sleep latency, decrease sleep efficiency, and decrease sleep duration.[29] Studies in mammalian systems have demonstrated that adenosine is a physiologic sleep factor, the levels of which in the brain increase in relation to previous wakefulness; accordingly, elevated concentrations of adenosine seem to profoundly modulate the depth and duration of sleep. Thus, adenosine has been proposed as a key component of homeostatic sleep regulation.[30] The accumulation of adenosine is believed to increase drowsiness, decrease electroencephalogram arousal, and enhance electroencephalogram δ (slow wave) activity during subsequent sleep. Adenosine levels, in turn, decrease slowly during sleep.[31] There are 4 subtypes of G protein–coupled adenosine receptors (A_1, A_{2A}, A_{2B}, and A_3) that mediate the cellular effects of adenosine.[32] Caffeine, in turn, is an adenosine receptor antagonist. At low doses, caffeine binds preferentially to A_{2A} receptors, particularly in the striatum; at higher levels, caffeine binds to A_1 receptors in the brain. Importantly, caffeine reduces homeostatic sleep pressure, as shown with decreases in electroencephalogram δ power in the frontal, central, and parietal regions after caffeine ingestion.[29]

The subjects who multitasked the most also consumed the most caffeine. This was because of a high consumption of traditional caffeinated drinks (tea and coffee) and energy drinks, particularly Monster (Monster Beverage Company, Corona, CA), SoBe Adrenaline Rush (PepsiCo Inc, Purchase, NY), and Jolt (Wet Planet Beverages, Rochester, NY) that contained much higher levels of caffeine than tea or traditional soft drinks. With the combination of multitasking and caffeine intake, these subjects had a 70% greater risk of falling asleep at school as well as a 20% risk of increased difficulty falling asleep on school nights.

The adolescents in this study attended school districts that have made it their policy to remove vending machines containing soda or energy drinks from school premises. For these subjects, limiting access to caffeine during school had been effective. However, caffeine intake typically began after school hours and extended into the early morning hours, thereby profoundly impacting sleep hygiene and putting them at risk for health and daytime functional issues.[25]

In this study, 43% of the subjects who multitasked and consumed greater amounts of caffeine also reported feeling tired as they drove, with 7.1% (1 in 14 drivers) falling asleep at the wheel. This is a major concern, because motor vehicle crashes are the leading cause of injury, disability, and death in youth of the United States, accounting for 2 of every 5 deaths in adolescents aged 15 to 19 years.[33] Adolescence, therefore, is a time when sleepiness could be a major, yet often overlooked, factor contributing to automobile crashes in this vulnerable population.[34,35] In these subjects, multitasking and greater caffeine intake enabled a pattern adversely affecting sleep quality, putting them at risk.

The strength of this study includes the diversity of the convenience sample and use of a questionnaire that captured sleep, caffeine, and technology data. Limitations include that the use of caffeine and technology was subjectively reported, and reports of both may be underrepresented. Furthermore, the study was observational, so only associations can be presented; causality cannot be proven. Another limitation was the relatively small sample size. Results also may not be generalized to the greater population because of potential cultural differences by location.

CONCLUSIONS

With this study we have demonstrated the importance of using a novel approach in the form of a multitasking index to capture adolescents' use of technologies simultaneously in the evening and nighttime hours. Importantly, we have shown that this multitasking index is significantly associated with caffeine use. Future studies should measure more than just television hours when evaluating the impact of nighttime activities on sleep patterns in adolescents. In addition, because early school start times are known to affect sleep, more study is needed on the potential interaction between caffeine, technology, and early school start times.[6,7] Assessment of caffeine intake can also be challenging because of the wide and expanding selection of beverage choices, many marketed with high caffeine content. Policy makers should assess whether energy-drink manufacturers with the intense marketing of energy drinks to the adolescent population should be including education on the effects of ingesting large amounts of caffeine. Given the complex relationships between caffeine intake and the use of media-related technology in adolescents, future research should explore how these risk factors for shortened sleep duration can be effectively modified.

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