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Caffeine Consumption and Weekly Sleep Patterns in US Seventh-, Eighth-, and Ninth-Graders

Charles P. Pollak, MD*, and David Bright

ABSTRACT. *Objective.* **To survey caffeine use by seventh-, eighth-, and ninth-graders and relate its use to age, sex, sleep characteristics, and day of week.**

Methods. **Students kept a daily, 2-week diary of their sleep times and use of caffeine containing drinks and foods. Data were analyzed by fitted multiple regression models.**

Results. **A total of 191 students participated. Caffeine intake ranged between 0 and 800 mg/d. Mean use over 2 weeks ranged up to 379.4 mg/d and averaged 62.7 mg/d (corrected for underrepresentation in our sample of boys, who consumed more caffeine). Higher caffeine intake in general was associated with shorter nocturnal sleep duration, increased wake time after sleep onset, and increased daytime sleep.**

Sleep Patterns. **Mean bedtime was 10:57 PM, and mean wake time was at 7:14 AM. Older children delayed bedtime longer on weekends, and younger ones had longer nightly sleep durations. Sleep duration lengthened on weekends, reflecting the combined effects of the circadian timing system and a mechanism that regulates the duration of sleep. Caffeine (soda) consumption also increased on weekends, for reasons that may be primarily social.**

Conclusions. **Regardless of whether caffeine use disturbed sleep or was consumed to counteract the daytime effect of interrupted sleep, caffeinated beverages had detectable pharmacologic effects. Limitation of the availability of caffeine to teenagers should therefore be considered.** ***Pediatrics*** **2003;111:42–46;** ***caffeine, sleep, soda, coffee, teenagers, adolescents.***

ABBREVIATION. WASO, wake time after sleep onset.

Caffeine has been called the most widely consumed psychoactive substance on earth.[1] It is used at least weekly by nearly all adults.[2] Barone and Roberts[3] have noted that, according to available literature, the caffeine content of foods and beverages is widely variable.

In adults, caffeine can have positive or negative behavioral, cognitive, and health effects. Which effect it is depends in part on the amount consumed and the chronicity of use. The most familiar adverse effect of caffeine is disruption of sleep.[4] In a well-controlled sleep laboratory assessment of caffeine's effects, Karacan et al[5] demonstrated a dose-related increase of sleep latency and awakenings during the sleep period. Caffeine also changes the temporal organization of slow-wave and rapid eye movement sleep. Caffeine has been used to model insomnia in normal sleepers.[6] Tolerance and physical dependence to caffeine may develop in adults.[7–9]

The pharmacology of caffeine has been less well-studied in adolescents (reviewed in reference 10). Caffeine is consumed at least weekly by 98% of 5- to 18-year-olds,[11] mostly in carbonated beverages. Seven-year-olds consume an average of 12.3 mg/d, increasing to 24.8 mg/d by age 10.[12] For adolescents, it is likely that the main dietary source of caffeine is soft drinks to which caffeine has been added, either as a flavoring agent or, more likely, for its mood-altering or dependence-producing effects.[13]

Nevertheless, no limitations have been placed on the consumption of caffeinated soft drinks by children, and soda dispensing machines have become increasingly common in middle and high schools in the United States. The health issues raised by caffeine use by children have not been discussed much, and to our knowledge, no public policy regarding caffeine consumption by youngsters has been formulated by any school board. Whether such a discussion should take place will depend on information regarding the use of caffeine by teens, along with evidence regarding any benefits or adverse effects it may have.

The aims of this study were: 1) to survey the use of caffeine in its various forms by seventh-, eighth-, and ninth-graders, and 2) to relate the use of caffeine to demographic factors, subjective sleep characteristics, and day of the week. Because of evidence of a tendency of teenagers to delay bedtimes, even on school nights,[14] we hypothesized that they become increasingly sleep-deprived as the school week progresses. They may therefore use caffeinated beverages to counteract daytime sleepiness, as suggested by Lee et al.[15]

A preliminary report was presented to the annual meeting of the Sleep Research Society (Chicago, IL; June 6–9, 2001).[16]

METHODS

Procedures

Seventh-, eighth-, and ninth-grade students of a public middle school and a public high school in Columbus, Ohio, were surveyed in 1998 and 1999. The schools serve a relatively affluent part of the city. The surveys were conducted by one of us (D.B.), while he was himself a ninth-grade student in 1998 and a 10th-grader in

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1999. D.B. recruited science teachers to let their students complete a questionnaire in class each morning for 14 consecutive days. A separate questionnaire went home with the student for the weekend, where it was filled out each day. The weekend form was brought to class and copied by the student on the in-class form. Written parental consent forms were sent home with all seventh- and eighth-graders and about half of ninth-graders (total: 537), at times that students were unlikely to be preparing for or taking tests. One hundred ninety-one forms were returned for an overall 2-year participation rate of 35.6%. The study was approved by the Human Subjects Committee of Ohio State University. Five teachers participated in 1998 and 6 teachers participated in 1999.

Questionnaire

A questionnaire developed by the investigators included the following items: students identifying code number (to protect the students' privacy, the key was not shared with the investigators), date, time to bed last night, time up this morning, times of any naps, wake time after sleep onset, and names of caffeine-containing items consumed during the previous day (Table 1).

One year before the start of the study, we attempted to collect information with a graphical sleep log that had been used successfully by us in older adults, but many logs completed by the teenagers were found to be unusable. We therefore adopted a simple, tallybox style of daily questionnaire. A preliminary version of the questionnaire was piloted in seventh- and eighth-graders and was revised as necessary. All questionnaires of the final type were initially reviewed by one of us (D.B.) and were found to be correctly filled out. Our success in this regard was explained by careful training of teachers by D.B. Teachers were also provided with written instructions. D.B. also visited the middle school and high school classes to instruct the students on the first day of data recording.

Data Processing

Questionnaire data were entered into the S environment for graphical and statistical analysis.[17] The variables were: age, grade, sex, day of week, number of caffeine-containing items consumed, number of naps, time of sleep onset, time of sleep offset in the morning, duration of sleep, and time awake after sleep onset. Each child's total daily caffeine intake was calculated from the caffeine contents of all caffeine-containing beverages, foods, and medications that were consumed. These included coffee, tea, soda of high caffeine content ("soda.h" in Table 1), regular soda ("soda.l"), condiments such as coffee ice cream or yogurt, chocolate, and over-the-counter medications. The average caffeine contents of these items[18] are shown in Table 1.

Data Analysis

Data were analyzed by multiple regression. The regression models included main effects and first-order interactions among age, sex, day of week (first-, second-, and third-order polynomials), duration of nightly sleep, wake time after sleep onset (WASO) and total duration of daytime naps. A result was considered statistically significant if $\alpha \leq .05$.

RESULTS

The respondents were 125 girls and 66 boys. Seventh-graders ranged from 12 to 14 years of age (mean: 12.7 years), eighth-graders from 13 to 15 years of age (mean: 13.6 years), and ninth-graders 13 to 15 years of age (mean: 14.5 years). The 191 respondents completed questionnaires for an average of 21.5 days. Of the total of 57 372 possible data items, 1621 were missing (2.8%).

Caffeine Intake

The respondents consumed a mean of 1.1 caffeine-containing items per day representing 52.7 mg of caffeine (Table 1). Of the 191 respondents, 109 (57.1%) averaged 0 to 50 mg of caffeine per day, 46 (24.1%) averaged 50 to 100 mg/d, 23 (12.0%) averaged 100 to 150 mg/d, and 13 (6.8%) averaged 150 mg/d or more (Fig 1). The largest reported mean caffeine intake was 379.4 mg/d by a 13.3-year-old male eighth-grader. Of the 3951 days that were surveyed, caffeine was consumed on 2817 days (71.2%). Daily caffeine consumption ranged from 0 mg to 800 mg. Sodas with modest caffeine content (≤40 mg/unit) accounted for 64% of the caffeine-containing items and 53.8% of the caffeine consumed.

Caffeine use did not increase from 12 years to age 15 ($t = 0.61$; $P = .54$). There was a sex difference, however. Boys averaged 69.9 mg of caffeine a day, girls 55.1 mg/d ($t = 5.5$, $P < .001$). Because the boys were disproportionate users of caffeine but were underrepresented in this sample (34.6%), we calculated the mean intake of a hypothetical sample that accurately represented the genders of the US population. It is 62.7 mg/d.

Caffeine use followed a weekly cycle, peaking at 77.1 mg on Saturday (a nonschool day) and falling to a minimum of 54.0 mg on Wednesday (for the cubic polynomial of day of week, $t = -3.5$; $P = .001$; Fig 2. The weekly cycle was largely accounted for by higher consumption of caffeinated sodas on weekends. Apart from the weekly variation, higher caffeine intake was associated with shorter nocturnal sleep duration ($t = -3.33$; $P = .001$), longer WASO ($t = 2.019$; $P = .044$), and longer daytime sleep ($t = 2.771$; $P = .006$). When interaction terms were included in the model, the effect of WASO was found to be highly significant ($t = 2.63$; $P = .008$).

Sleep Times and Duration

Mean bedtime was at 10:57 PM, and mean wake time was at 7:14 AM. A multiple regression model (age, sex, cubic polynomial of day of week) fitted to the sleep-onset times explained 6.8% of the variance ($F(11,3910) = 25.8$; $P < .001$). It showed that bedtimes became delayed with increasing age, from 10:39 PM at age 12 to 11:10 PM at age 15 ($t = 8.56$; $P < .001$). Older children also delayed bedtimes longer on weekends than younger children did ($t = -2.21$; $P = .027$). The latest bedtimes occurred on Saturdays (mean: 11:50 PM), and the earliest were on Tuesday (10:37 PM), a difference of 73.3 minutes (Fig 2). A

TABLE 1. Mean Caffeine Intake

	Coffee	Tea	Soda.h	Soda.l	Condiments	Medications	Total
Unit size	6 oz	8 oz	12 oz	12 oz	1 cup	1 tablet	
Mean units/d	0.06	0.06	0.17	0.68	0.06	0.03	1.06
Percent of units	5.3	6.1	16.2	63.9	5.6	2.9	100
Caffeine (mg)/unit	135	50	55	40	40	100	420
mg/d	7.6	3.2	9.4	27	2.3	3.1	52.7
Percent of caffeine	14.5	6.1	17.8	51.3	4.5	5.9	100

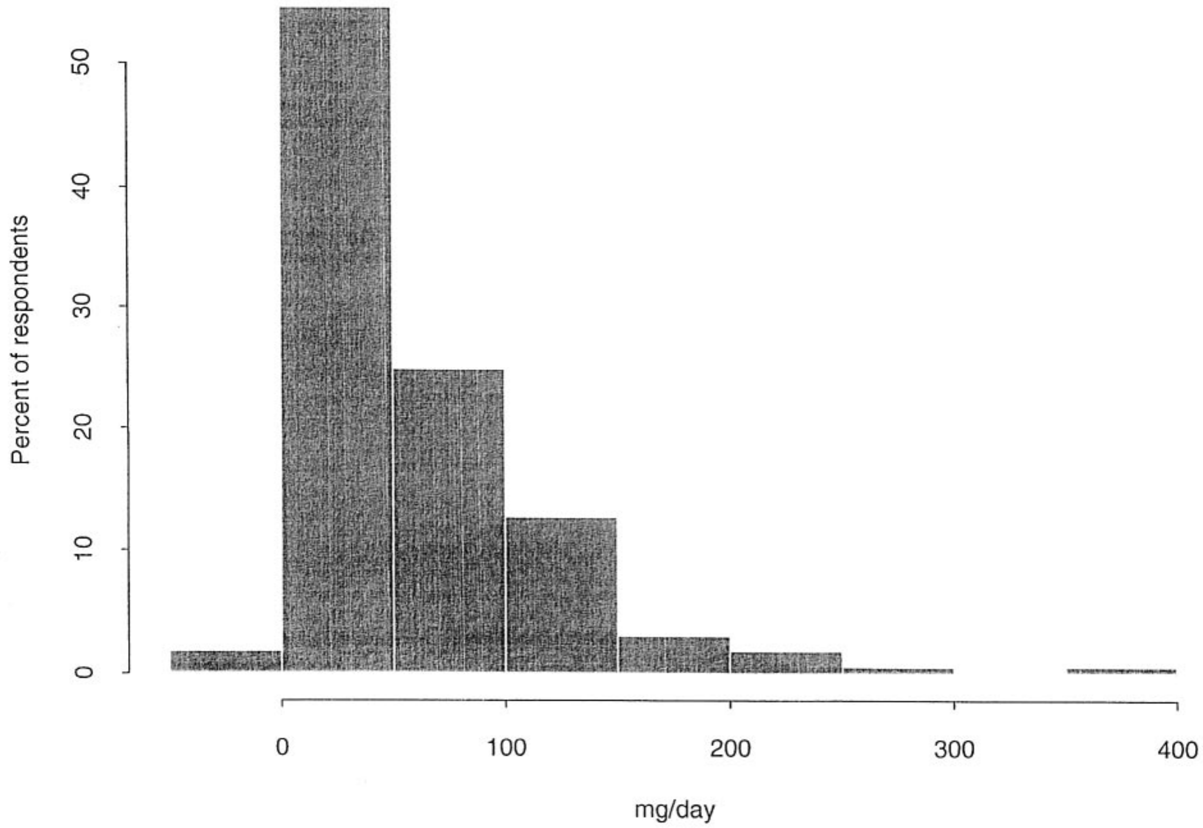

Fig 1. Distribution of 2-week mean caffeine consumption ($N = 191$).

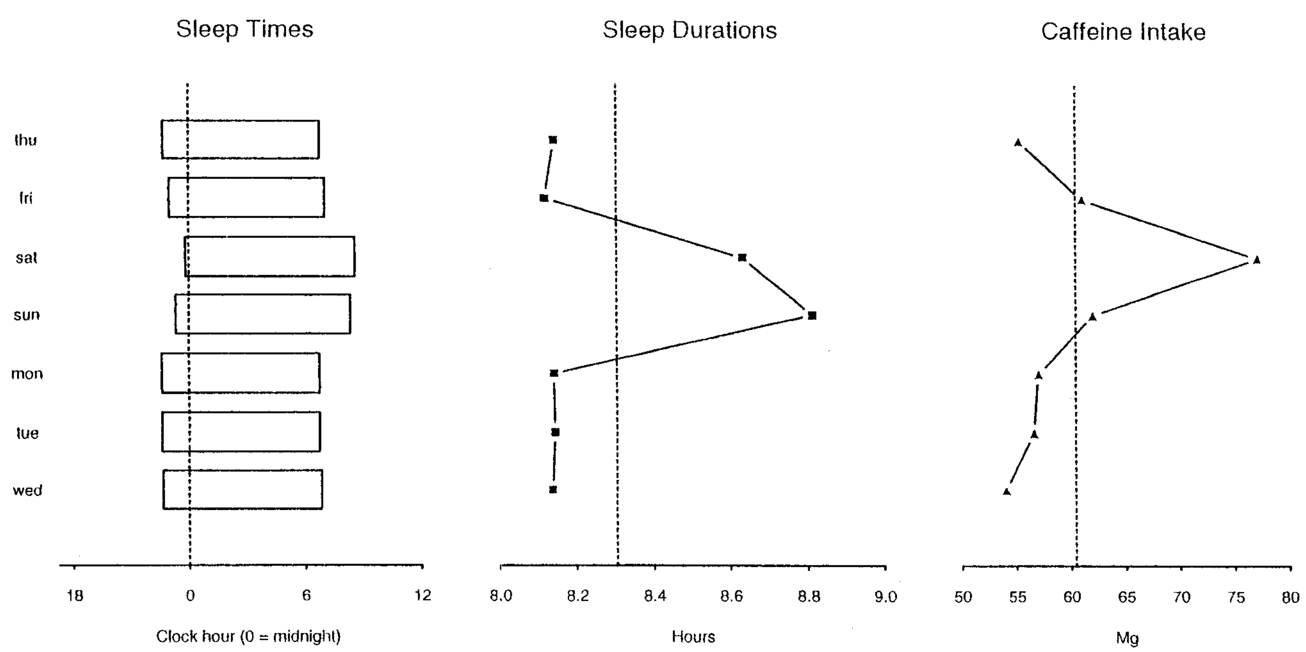

Fig 2. Left panel: mean sleep intervals by day of week. The intervals extend from mean reported times of sleep onset to mean sleep offsets. Sleep intervals end on the day designated on the left. Middle panel: mean durations of sleep ending on the day shown on the left, in hours/day. Because the durations were reported directly by the respondents, they do not precisely equal the sleep intervals in the left panel. Dotted line: mean, weekly sleep duration. Right panel: mean caffeine intake by day of week, in mg/d. Caffeine intake was calculated from units of coffee, soda, etc. that were consumed, using the caffeine/item values in Table 1. Dotted line: mean caffeine intake.

regression model of times of sleep offset explained 14.3% of the variance [$F(14,3905) = 46.34$; $P < .001$] and showed no effects of age, sex, or day of week.

Mean daily sleep durations varied from 6.1 to 9.8 hours (mean: 8.3 hours), and the distribution of sleep durations was skewed toward shorter durations (Fig 3). A fitted, linear regression model comprising age, sex, day of week, caffeine intake, and naps explained

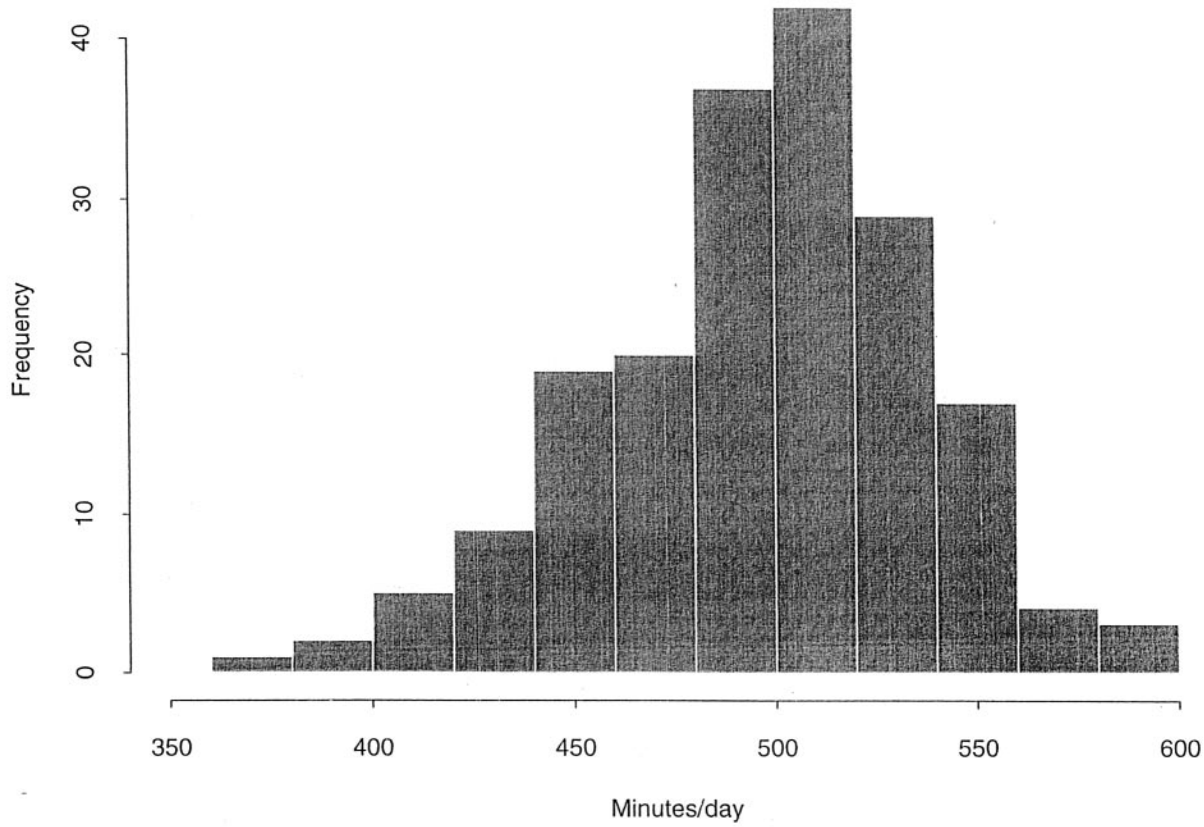

Fig 3. Distribution of 2-week mean sleep duration (N = 191).

only 3.8% of the variance in sleep duration ($F(20,3934) = 7.85$; $P < .001$). Of these, the only significant explanatory variable was age, with younger respondents sleeping longer than older ones ($t = -3.456$; $P = .001$). According to the model, mean sleep duration decreased from 507.5 minutes at 12 years to 489.3 minutes at age 15. When the same model was limited to main effects, sleep duration was found to be shorter in boys ($t = -3.992$; $P <$ .001). It was also shorter in subjects who made greater use of caffeine ($t = -3.336$; $P = .001$), as already noted, and it was shorter in subjects whose naps were of shorter duration ($t = 3.388$; $P = .001$). Nighttime sleep durations also varied significantly by day of week ($t = -7.79$; $P < .001$). The longest durations occurred on Saturdays (mean: 518.0 minutes) and Sundays (mean: 528.8 minutes), and the shortest were on Mondays (448.5 minutes; Fig 2).

DISCUSSION

Although food diaries from which caffeine intake could be calculated have been kept before by children,[12] this seems to be the first time that a daily record of sleep and caffeine intake has been kept by American teenagers. We found that they consumed an average of 52.7 mg/d of caffeine, mostly in soft drinks of an ordinary (not high-caffeine) type. This figure does not fully portray the use of caffeine by teenagers, however, as 18.8% of our 191 respondents consumed an average of 100 mg/d or more. Boys are heavier users of caffeine, as previously reported.[12,15] After adjusting for total energy intake, however, caffeine intake may be similar in boys and girls.[12]

Caffeine was consumed on over 70% of surveyed days. Its use increased after Wednesday, peaked on Saturday, then declined, thus partially supporting our hypothesis that caffeine was sometimes used to counteract daytime sleepiness[15] resulting from sleep deprivation on school nights. The increased consumption of soda on weekends might be explained by its availability at weekend social functions.

A weekly cycle in sleep duration and timing, in which the hours of sleep are delayed and extended on weekends, is widely familiar, though it has not often been documented.[19] It may be explained by the fact that the free-running period of the circadian sleep-wake cycle is nearly always longer than 24 hours.[20,21] This results in night-by-night delays of bedtimes and times of sleep onset.[14] Regular school and start times at work, however, require that sleep often be ended before the amount needed can be obtained. Sleep deprivation on school or work nights is the inevitable result. Weekends are free of the need to truncate sleep, providing opportunity to expand the hours of sleep and recover from the effects of sleep deprivation. This can be accomplished without advancing bedtimes; in fact, bedtimes are often further delayed on weekends. In this way, a weekly rhythm arises from the combined effects of the circadian timing system and a mechanism that regulates the duration of sleep.

In the children sampled by us, mean sleep duration decreased from 528.8 minutes (8.8 hours) on Saturday night to 448.5 minutes (7.5 hours) on Sunday night. This is explained by the fact that sleep onset occurred relatively late on Sunday night (11:21 PM), but sleep offset was (had to be) set back for school on Monday morning, from 8:01 AM on Sunday morning to 6:45 AM on Monday morning.

Caffeine consumption was associated with increased WASO, an effect that was found both between and within subjects: high caffeine users had more disturbed (interrupted) sleep, and sleep was more interrupted on nights after increased caffeine use. This finding is at odds with a previous report.[15] The data do not establish whether caffeine disturbed sleep or, conversely, whether teens may have consumed caffeine to counteract the residual effect of interrupted sleep on the following day. The latter is suggested by increased use of caffeine by those reporting more daytime naps. In either case, caffeinated beverages would have had pharmacologic effects in teenagers and not merely thirst-quenching or hedonic effects.

The increasing availability of soft drink dispensing machines in schools is apparently welcomed by students and is profitable to school boards, but our findings suggest that it may be interfering with the nighttime sleep of teenagers. Pending additional studies that confirm or refute these findings, it may eventually become appropriate to limit the caffeine contents of soft drinks or restrict the types of beverages that are promoted to teenagers.

Additional studies should also address some of the shortcomings of the present study. These include limited sample size, insufficient demographic characterization of the sample, limited geographic representation, and lack of objective verification of caffeine intake. Obtaining detailed data from teenaged subjects is, however, likely to be challenging.

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Lewis S. The fog, the bog, the future. *Can Med J.* 2002;166:11

Submitted by Student