***SLEEP*: PAST, PRESENT AND FUTURE — Originally published in 1980**

Sleep, 2(4):453–460

Pubertal Changes in Daytime Sleepiness

*,†Mary A. Carskadon, *,†Kim Harvey, ‡Paula Duke,
†Thomas F. Anders, ‡Iris F. Litt, and *,†William C. Dement

**Sleep Research Center, †Department of Psychiatry and Behavioral Sciences, and ‡Department of Pediatrics (Adolescent Medicine), Stanford University School of Medicine, Stanford, California*

Summary: Nineteen children (8 girls, 11 boys) were evaluated in a total of 47 three-day sessions across three summers. Children were ranked according to Tanner's stages of secondary sexual characteristics. Nocturnal sleep was recorded from 2200 to 0800 hr each night. Multiple sleep latency tests were given at 2 hr intervals from 0930 each day. Nocturnal sleep time and REM sleep time remained constant across Tanner stages. Slow wave sleep time declined progressively across Tanner stages, with a 40% reduction from prepuberty to maturity. Daytime sleepiness was significantly greater in subjects at Tanner stages 3 and 4 than at Tanner stages 1 and 2. Subjects at Tanner stage 5 tended to be as sleepy as Tanner stage 3 and 4 subjects but did not differ significantly from the less mature subjects. No gender differences were found in daytime sleepiness for children at similar Tanner stages. More mature children were significantly sleepier at 1330 and 1530 than in the late afternoon and evening.
Key Words: Sleepiness—Puberty—Adolescence—Maturation—Tanner staging.

Several sleep laboratory studies (Williams et al., 1972, 1974; Karacan et al., 1975) have evaluated nighttime sleep during puberty and have found few striking changes in sleep structure. These studies and surveys of sleep habits (Katchadourian, 1977; Anders et al., 1978) have noted a marked reduction of sleeping time during adolescence. If these changes in habitual sleeping time do not represent a declining biological need for sleep, it is possible that a cumulative sleep debt leads to adolescent daytime sleepiness.

Daytime sleep tendency in pubertal subjects has not been as carefully evaluated as nocturnal sleep. A study of sleep and daytime behavior at the Stanford Sleep Research Center has recently begun a controlled assessment of changes that may be related to pubertal status. By holding constant the opportunity to sleep at night, we have attempted to determine whether pubertal changes in daytime sleepiness may occur in the absence of reduced nocturnal sleep.

Accepted for publication March 1980.

Address reprint requests to M. A. Carskadon at Sleep Research Center, Department of Psychiatry and Behavioral Sciences, Stanford University School of Medicine, Stanford, California 94305.

METHODS AND SUBJECTS

Nineteen normal children with no personal or family history of sleep disturbance participated in the study performed during three consecutive summers. Eight girls (10.9–15.8 years) and 11 boys (10.2–15.7 years) were studied. Five girls and 8 boys were evaluated for three years; 1 girl and 1 boy were studied two years; and 2 girls and 2 boys were observed one year. Pubertal status of secondary sexual characteristics was determined at physical examination in the second and third study years using a standardized assessment system developed by Tanner (1962). This system employs five stages of sexual maturity based on evaluations of breast and pubic hair development for girls and pubic hair and genital development in males. Stage 1 indicates a lack of secondary sexual characteristics (prepubertal), and Tanner stage 5 represents adult sexual maturation. Tanner stages for year 1 were estimated using norms for the timing of secondary sexual development (Barnes, 1975), which generally resulted in either no change or subtracting one number from the second year Tanner stage. The distribution of subjects evaluated at each Tanner stage was as follows: stage 1, eight subjects, repeat measures on four subjects, total $n = 12$; Tanner stage 2, total $n = 10$; Tanner stage 3, nine subjects, repeat measures on one, total $n = 10$; Tanner stage 4 = six subjects, repeat measures on two, total n = eight; Tanner stage 5 = six subjects, repeat measures on one, total n = seven.

Each summer the subjects stayed at the Stanford Summer Sleep Camp for at least three days, during which nocturnal sleep and daytime behavior were evaluated. Each Sleep Camp session involved 3 or 4 children who were continuously observed by student technician/counselors. Games and entertainment were provided during intervals in the testing schedule.

On each night, total bedtime was 10 hr, from 2200 to 0800 hr. Sleepiness was assessed using a sleep latency test (Carskadon and Dement, 1977) six times each day at 2 hr intervals beginning at 0930. The electroencephalogram (EEG), electrooculogram (EOG), and electromyogram (EMG) were recorded and scored (using a 30 sec scoring epoch) in the standard manner (Rechtschaffen and Kales, 1968). Subjects were recorded in individual, sound-attenuated, darkened bedrooms. At the start of each sleep latency test, subjects were instructed to "please lie quietly, keep your eyes closed, and try to fall asleep." Sleep latency was measured as the elapsed time from lights out to the first 30 sec epoch of stage 1 sleep (see Carskadon and Dement, 1979, for a discussion of sleep-onset criteria). On the first day of each session, children were permitted to sleep until 20 min after lights out; on subsequent days, the sleep latency tests ended after three consecutive epochs of stage 1 sleep or an elapsed time of 20 min. The first day's tests were used to screen for the occurrence of sleep-onset REM periods that indicate the presence of narcolepsy (Mitler et al., 1979).

Observations from each child and each year were analyzed separately, yielding a total n of 47. This procedure avoided the problem of a chronological or year-to-year bias. Nocturnal sleep data were averaged within subjects across the second and third nights of each session. Comparison of sleep data grouped by Tanner stages was accomplished using one-way analysis of variance. Multiple sleep latency test scores (latency to stage 1 sleep) were taken from the third day and were described using survival curve methodology, which determined the proportion of subjects remaining awake at each half-minute interval from the start of the tests. Differences among survival curves for the Tanner stages were evaluated using the nonparametric Kolmogorov-Smirnov statistical comparison. A 0.05 two-tail significance level was used throughout.

RESULTS

Selected nocturnal sleep parameters for each Tanner stage group are summarized in Table 1. Total sleep time showed no significant variation across Tanner stages. Slow wave (stages 3 and 4) sleep time declined progressively from Tanner stage 1 to stage 4 ($F = 5.83$; $df = 4, 42$; $p < 0.001$), with an overall decrease of over 40%. No individual subject has been recorded across the five Tanner stages. In 3 female subjects recorded at Tanner stages 2–4 or 2, 3, and 5, average slow wave sleep times for the three years confirmed this trend. In addition, slow wave sleep time appeared to be unaffected by sleep obtained on the first day's sleep latency tests. Mean slow wave sleep time on the second night was 116 min and on the third night 112 min. Stage 2 sleep time increased significantly ($F = 2.52$; $df = 4, 42$; $p < 0.05$) across the five Tanner stages, while REM sleep time was unchanged.

On the first day of sleep latency testing of each Sleep Camp session, no subject showed sleep-onset REM periods. Sleep latency test scores from the third day of testing, grouped by Tanner stage, are shown in Fig. 1. Children at Tanner stages 1 and 2 rarely fell asleep on the multiple sleep latency tests and never fell asleep in fewer than 9 min. At Tanner stages 3 and 4, the children fell asleep with significantly greater speed and frequency on the daytime sleep latency tests. The sleep latency test curve for children at Tanner stage 5 was not significantly different from the curves for Tanner stages 1 and 2, but they clearly tended toward more rapid and more frequent sleep onsets. Similar curves computed for chronological

TABLE 1. *Selected nocturnal sleep parameters across Tanner stages*

Sleep parameter	Tanner stage				
	1 ($n = 12$)	2 ($n = 10$)	3 ($n = 10$)	4 ($n = 8$)	5 ($n = 7$)
Total sleep time (min)					
Mean	542	545	550	544	536
SD	33	25	16	30	26
Stage 2 sleep time (min)					
Mean	241	261	272	277	280
SD	36	20	35	24	41
Slow wave sleep time (min)					
Mean	137	127	105	90	79
SD	40	24	31	28	17
REM sleep time (min)					
Mean	117	114	126	122	112
SD	20	20	18	11	11

Means and standard deviations given in minutes.

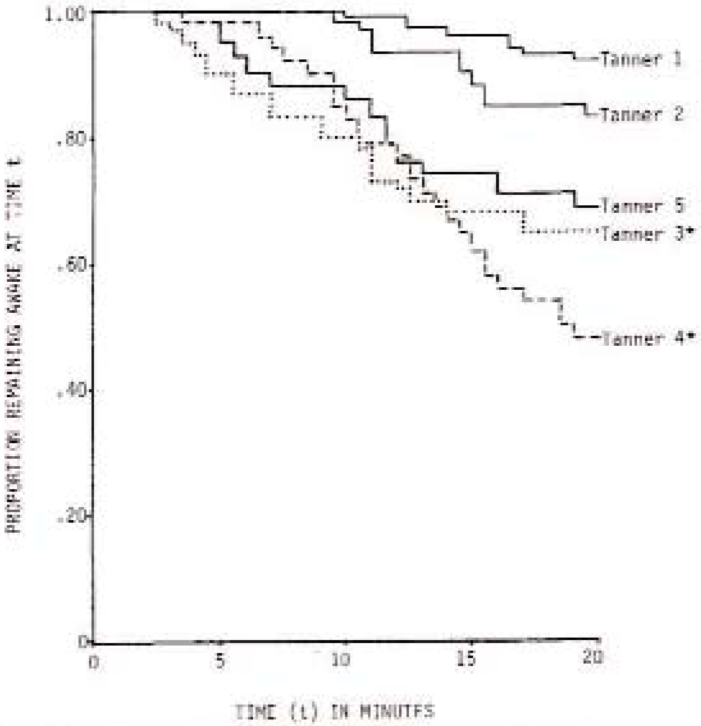

FIG. 1. Relation of sleep latency test scores to Tanner stage. Sleep latency test scores from the third day are plotted for Tanner stage groups. The horizontal axis represents the elapsed time from "lights out" to stage 1 sleep onset. The vertical axis gives the proportion of the group who remained awake at a given time (t) after lights out. Thus, for example, Tanner stage 1 subjects did not fall asleep on 92% of the tests, while Tanner stage 4 subjects remained awake the full 20 min on only 48% of the tests. Asterisks indicate a significant difference from stage 1 and 2 curves.

age revealed no significant age-related differences, although there was a trend for the oldest group to fall asleep more often.

The sleep latency test data were also analyzed for gender differences. The sleep latency curves (Fig. 2) show no significant gender differences at any Tanner stage. (Tanner stages 1 and 2 were combined because few girls were included in the Tanner stage 1 group.)

A final analysis of sleep latency test data examined the effects of time of day. Latencies from each of the six daily sleep latency tests are illustrated in Fig. 3 for subjects at Tanner stages 1 and 2 (T 1–2) and stages 3–5 (T 3–5). The more mature group had a significantly greater tendency to fall asleep than the group of subjects at Tanner stages 1 and 2 on the tests given at 1330 and 1530. For the Tanner 3–5 subjects, across-day comparisons demonstrated that the sleep tendency was significantly greater at 1330 and 1530 than at 1730 and 1930; the two morning tests in this group fell between these extremes but did not differ significantly. In the Tanner 1–2 subjects, there were no across-day differences.

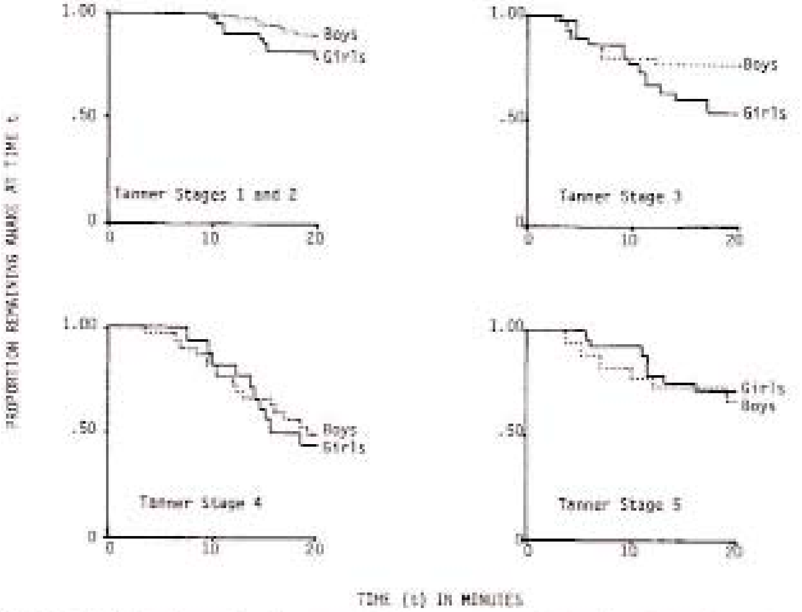

FIG. 2. Relation of sleep latency test scores to Tanner stage and gender. Data from Fig. 1 are displayed by grouping the subjects according to gender and Tanner stage. The curves demonstrate no differences attributable to gender.

DISCUSSION

The nocturnal sleep data showed a number of interesting results. First, given the stable bedtimes and arising times, total nighttime sleep did not vary across Tanner stages. This finding suggests that reduced habitual sleep time reported by adolescents may be related more to environmental factors (social, academic, and peer pressures) than to a declining "need" for sleep. The slow wave sleep findings, which demonstrated an almost linear decrease across Tanner stage, superficially contradict the findings of Williams et al. (1972, 1974), who reported a slight increase in stage 4 sleep from preadolescence to midpuberty. The Williams group, however, based bedtimes on habitual sleeping hours and reported percentage amounts of sleep stages. Thus, the absolute changes in slow wave sleep were similar to the data reported here, but reflect an "increase" of stage 4 when reported relative to total sleep time.

Before discussing the multiple sleep latency test findings, it is important to address the issue of whether this measure is a valid reflection of daytime sleepiness. One might suggest that the decreased sleep latencies simply represent a learned response to the test situation. If this were the case, we would expect to see sleep latencies decrease across days, from the first to the third day, and from year to year. Figure 3 illustrates that the sleep latencies do not become progressively shorter across the days. We have also found no consistent trend for shorter sleep latencies from the first to the third testing days. (The opposite trend seems to be

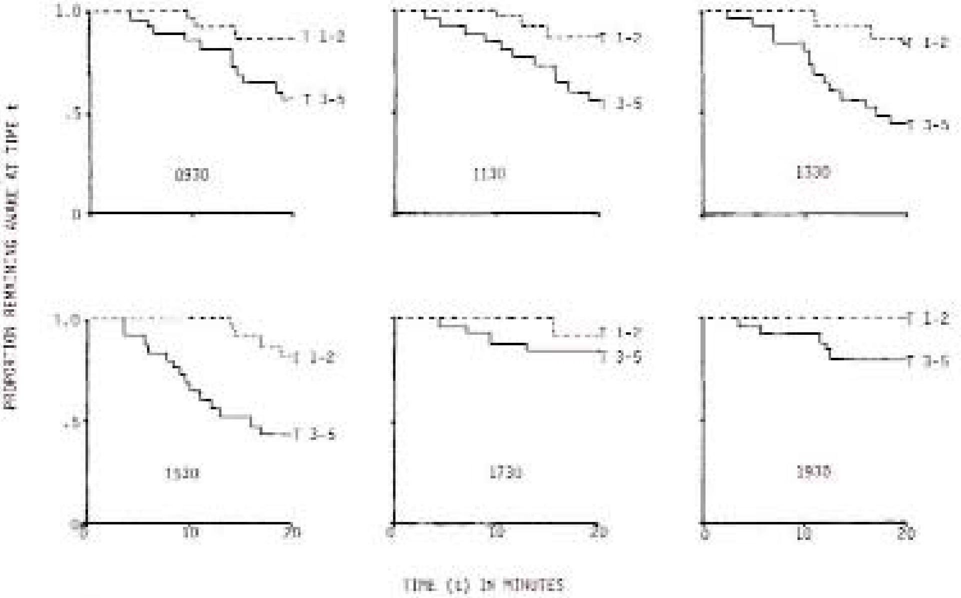

FIG. 3. Sleep latency test scores across days. Data from Figs. 1 and 2 are displayed by grouping results according to the time of day of the sleep latency test in subjects at Tanner stages 1 and 2 and subjects at Tanner stages 3–5. Tanner 3–5 subjects fell asleep faster across days, although the differences were significant only at 1330 and 1530 hr. No significant time-of-day differences were found in the Tanner 1–2 subjects. In Tanner 3–5 subjects, sleep onsets occurred earlier and more frequently on the tests at 1330 and 1530 hr than at 1730 or 1930 hr.

true in several children whose sleep was restricted on nights before coming to Sleep Camp.) Finally, in children whose Tanner stage rating stayed constant for two or three years, there was no tendency for shorter sleep latencies from one year to the next.

Several studies support the face validity of the multiple sleep latency test as a measure of sleepiness. Carskadon and Dement (1979) showed a marked decrease of sleep latencies during sleep deprivation, followed by a gradual recovery to basal values. A similar finding has been reported in children undergoing sleep loss (Carskadon et al., 1978). Sleep restriction also affects multiple sleep latency test scores (Carskadon et al., 1977), resulting in latencies intermediate between baseline values and those seen during total sleep loss. Finally, in patients with narcolepsy and sleep apnea syndromes who complain of excessive daytime sleepiness, the multiple sleep latency tests consistently confirm the complaint (Dement et al., 1978; Richardson et al., 1978).

The present study showed a marked tendency for children to demonstrate daytime sleepiness at a specific time of pubertal development, i.e., with the maturation to Tanner stage 3. This change in daytime sleepiness did not appear to be related to nocturnal sleep time, which remained constant across Tanner stages. Certain variations of nocturnal sleep structure paralleled the developmental stages and may be related to daytime sleepiness. For example, the tandem decline of slow wave sleep and daytime sleep latencies in association with maturation might support a "restorative" role of slow wave sleep. A relationship among nocturnal sleep structure changes, sleepiness, and hormonal changes, such as the pubertal augmentation of nocturnal gonadotropic hormone secretion (Boyar et al., 1972), should also be considered.

The time-of-day sleep latency test findings in Tanner 3–5 subjects parallel those seen in older adolescents (Carskadon and Dement, 1979), adult control subjects (Richardson et al., 1978), and elderly individuals (Carskadon et al., in press). In each of these groups there is a tendency for greater sleepiness in the early and midafternoon than in the morning or evening. Pubertal maturation appears to be accompanied by a reduction in the capacity for the type of sustained daytime alertness seen in younger children. Perhaps an afternoon siesta would improve daytime functioning in older individuals.

The relationship between pubertal status and daytime sleepiness may have implications for prospective studies of the development of narcolepsy, in which sleepiness is a cardinal symptom. One might speculate that the transition to Tanner stage 3 may be a particularly vulnerable time in the development of narcolepsy. Sours (1963) has shown that narcolepsy usually has an age of onset near the time of puberty. Perhaps there is an additive effect in which the pubertal increase of daytime sleepiness results in the overt expression of a previously latent excessive sleep tendency.

In summary, the findings of this study suggest that daytime sleep tendency in adolescents increases in the absence of any change in nocturnal total sleep time. Thus, the stereotypic increase of sleep tendency in adolescence appears to be related to two major factors: (1) a maturational augmentation of daytime sleepiness and (2) partial sleep loss associated with curtailment of total sleep time. The physiological basis of the former is unclear at this time; the latter appears to result from environmental factors.

ACKNOWLEDGMENT

This research was supported in part by grants from the Spencer Educational Foundation, William and Flora Hewlett Foundation, NIMH Award MH 31845, and NIMH Award MH 05804 to Dr. Dement.

REFERENCES

Anders TF, Carskadon MA, Dement WC, and Harvey K. Sleep habits of children and the identification of pathologically sleepy children. *Child Psychiatry Hum Dev* 9:46–63, 1978.

Barnes HV. Physical growth and development during puberty. *Med Clin North Am* 59:1305–1317, 1975.

Boyar R, Finkelstein J, Roffwarg H, Kapen S, Weitzman E, and Hellman L. Synchronization of augmented luteinizing hormone with sleep during puberty. *N Engl J Med* 287:582–586, 1972.

Carskadon MA and Dement WC. Sleep tendency: An objective measure of sleep loss. *Sleep Res* 6:200, 1977.

Carskadon MA and Dement WC. Effects of total sleep loss on sleep tendency. *Percept Mot Skills* 48:495–506, 1979.

Carskadon MA, Harvey K, and Dement WC. Total sleep loss in children: Sleep tendency and performance. *Sleep Res* 7:127, 1978.

Carskadon MA, Harvey K, Dement WC, and Anders TF. Acute partial sleep deprivation in children. *Sleep Res* 6:92, 1977.

Carskadon MA, van den Hoed J, and Dement WC. Sleep and daytime sleepiness in the elderly. *J Geriatr Psychiatry*, in press.

Dement WC, Carskadon MA, and Richardson GS. Excessive daytime sleepiness in the sleep apnea syndrome. In: C Guilleminault and WC Dement (Eds), *Sleep Apnea Syndromes*. Alan R Liss, New York, 1978, pp 23–46.

Karacan I, Anch M, Thornby JK, Okawa M, and Williams RL. Longitudinal sleep patterns during pubertal growth: Four-year follow-up. *Pediatr Res* 9:842–846, 1975.

Katchadourian H. *The Biology of Adolescence*. WH Freeman, San Francisco, 1977.

Mitler M, van den Hoed J, Carskadon MA, Richardson GS, Park R, Guilleminault C, and Dement WC. REM sleep episodes during the multiple sleep latency test in narcoleptic patients. *Electroencephalogr Clin Neurophysiol* 46:479–481, 1979.

Rechtschaffen A and Kales A (Eds). *A Manual of Standardized Terminology, Techniques, and Scoring System for Sleep Stages of Human Subjects*. UCLA Brain Information Service/Brain Research Institute, Los Angeles, 1968.

Richardson GS, Carskadon MA, Flagg W, van den Hoed J, Dement WC, and Mitler MM. Excessive daytime sleepiness in man: Multiple sleep latency measurement in narcoleptic and control subjects. *Electroencephalogr Clin Neurophysiol* 45:621–627, 1978.

Sours J. Narcolepsy and other disturbances of the sleep-waking rhythm: A study of 115 cases with a review of the literature. *J Nerv Ment Dis* 137:525–542, 1963.

Tanner JM. *Growth at Adolescence*. 2nd ed. Oxford, Blackwell, 1962.

Williams RL, Karacan I, and Hursch CJ. *EEG of Human Sleep: Clinical Applications*. Wiley, New York, 1974.

Williams RL, Karacan I, Hursch CJ, and David GE. Sleep patterns of pubertal males. *Pediat Res* 6:643, 1972.