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Sleep Loss in Young Adolescents

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Summary: Effects of one night's sleep loss on nocturnal sleep, performance, and sleepiness were evaluated in 12 subjects (8 boys, 4 girls) whose ages ranged from 11.7 to 14.6 years. The magnitude and direction of sleep stage changes after sleep loss were comparable to similar findings in older subjects. Performance test decrements occurred for two measures during sleep deprivation. The performance decrements appeared to be related to episodes of sleep during the performance tests. Subjective measures of sleepiness showed a significant increase during sleep loss, with a complete recovery to basal levels after one night of sleep. The subjective ratings of sleepiness during sleep loss also showed a marked short-term dependence on preceding activity levels. Multiple sleep latency tests showed a marked reduction of sleep onset latency from 0530 throughout the day of sleep loss. In contrast to the subjective measures, sleep latency test scores did not vary with activity levels during sleep loss and did not recover to basal levels until the afternoon of the first recovery day. In general, there were no marked differences in the sleep loss response of young adolescents as compared to published reports of sleep loss in older subjects. **Key Words:** Sleep loss—Sleepiness—Adolescents.

Since the early work of Patrick and Gilbert (1896), the effects of sleep deprivation in humans have been evaluated in many experiments. As emphasized by Horne (1978) in a recent review, most of this work has been performed using a very circumscribed group of experimental subjects—young adult men. We have found only two studies (Geller et al., 1969; Copes and Rosentswieg, 1972) in which children were sleep deprived; one study assessed electroencephalograms (EEGs) in children with epilepsy, and the other examined motor performance. Horne (1978) and other reviewers of the field (Naitoh, 1976) have suggested that data from a broader spectrum of subjects may improve our understanding of sleep deprivation effects, the function of sleep, and individual differences in response to sleep loss. Accordingly, we have examined sleep, performance, and daytime sleepiness in a group of young adolescents undergoing a night of sleep loss and have attempted to make comparisons with findings in adults when possible.

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METHODS

Subjects

Twelve youngsters taking part in the Stanford Summer Sleep Camp (Carskadon et al., 1980) agreed to participate in the present study. The experiment, approved by the Stanford University Medical Committee for the Use of Human Subjects in Research, was fully explained; informed consent was obtained from the subjects and their parents. On the first day of the study, subjects were given brief physical examinations and staged according to Tanner's (1962) maturational staging criteria. Tanner stages are based on pubic hair growth and breast development in girls, and pubic hair growth and genital development in boys. The stages are progressive from 1, which indicates pre-pubertal development, to 5, which indicates adult maturation. Table 1 lists the age, gender, and Tanner stage of the 12 subjects. Tanner stage for pubic hair growth is listed for subjects in whom the breast or genital development stage differed from that for pubic hair growth. [Tanner (1962) suggests that the pubic hair growth stages are most reliable when a single determination is made.] All subjects were in good health, drug-free, and without a personal or family history of sleep disorders.

Procedures

The study was performed on groups of 3 or 4 subjects who lived in the sleep laboratory for 6 consecutive days. The Stanford Summer Sleep Laboratory is located in a small dormitory on the Stanford campus. In addition to the sleep laboratory, this facility provides a very comfortable living situation for subjects, including food preparation and dining areas, comfortable lounges, and diverse recreational areas.

Figure 1 illustrates the overall experimental protocol. Subjects arrived in the

TABLE 1. *Young adolescent subjects*

Subject	Gender	Age	Tanner stage
1	M	11.9	1
2	M	12.2	1
3	M	14.6	1
4	M	11.7	2
5	M	14.1	3
6[a]	M	14.1	4
7	M	14.1	4
8[a]	M	14.0	5
9	F	13.9	3
10	F	13.9	3
11	F	13.8	4[b]
12[a]	F	13.3	5[c]

[a] For 3 subjects, the study ended after the second recovery night and before daytime testing on the second recovery day. Data from these subjects are included only for nocturnal sleep stages.

[b] Tanner stage for breast development in this subject was 3.

[c] Tanner stage for breast development in this subject was 4.

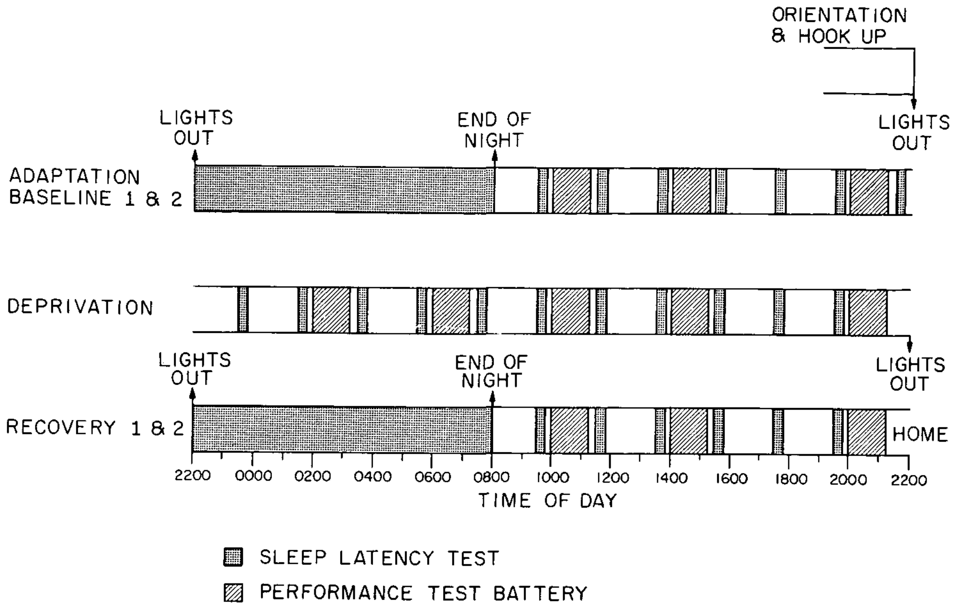

FIG. 1. Experimental procedures are outlined schematically, showing the temporal placement of nocturnal sleep episodes, performance test batteries, and sleep latency tests.

laboratory at approximately 1900 for an orientation session that included a complete description of all procedures. Electrodes were applied in the standard manner (Jasper, 1958; Rechtschaffen and Kales, 1968) to record referential EEG from central (C3 or C4) and occipital (01 or 02) placements, electro-oculogram (EOG) from left (LOC) and right (ROC) outer canthi, and electromyogram (EMG) from on and beneath (mental/submental) the chin. These electrodes remained in place throughout the study, with individual electrodes replaced as necessary to maintain recording quality. On either the first or second night of the study, respiration during sleep was recorded using nasal thermistors and thoracic and abdominal strain gauges.

The study included an adaptation day followed by two baseline (BSLN) days, a one-day sleep deprivation (SD) period, and two recovery (REC) days. On adaptation, BSLN, and REC days, subjects were in bed 10 hr each night, from 2200 to 0800. For all sleep periods and performance tests, subjects were in individual rooms. Recordings were performed using Grass Model 7 polygraphs at a paper speed of 10 mm/sec. EEG was recorded with a low frequency cutoff of 1.0 cps and a high frequency filter of 35 cps. Records of all sleep periods were scored in 30-sec epochs according to standard criteria (Rechtschaffen and Kales, 1968).

Performance tests were administered in three batteries each day, at 1000, 1400, and 2000. During SD, batteries were added at 0200 and 0600. The performance-testing batteries included four tests given in the same order during each battery. Subjects were not informed of test results and were discouraged from discussing the tests with one another.

An abridged form of the Wilkinson Addition Test (Wilkinson, 1968) was given first in each battery. This 30-min test consisted of columns of five two-digit numbers. Subjects were instructed to add "as many problems as you can, working as quickly and carefully as possible." The subjects were also instructed to tap a switch when they completed each problem. EEG, EOG, and output from this switch were monitored polygraphically throughout the test, and subjects were awakened or reminded to continue working if longer than 1 min passed between switch signals. Speed of performance was scored as the number of problems attempted; accuracy was assessed as the percentage of problems completed correctly.

The second test in each battery was an abridged form of the Williams Word Memory test (Williams et al., 1966). Each test contained a list of 25 4-letter words selected in a semi-random manner so that no word was repeated on any test. The words were pronounced and spelled at 10-sec intervals, and subjects were instructed to write each word on a separate page of a small tablet. At the end of the entire word list, a technician entered the room and paged through the list with each subject, at the rate of 5 sec per word. If a word was misspelled, the child was required to write the word correctly. The technician then left the room with the tablet, and the child was instructed to "write down in any order as many of the words as you remember from the list" on a blank sheet of paper. Five min, during which EEG and EOG were monitored, were allotted for recall. If signs of sleep were seen during this time, the subject was awakened. The score on this test was the number of words correctly recalled.

The third test in each battery was a listening attention task, specifically prepared to assess vigilance in children (Carskadon, 1979). Twenty passages about animals from the *World Book Encyclopedia* were edited so that each contained 70 key words. When read onto tape, the passages had an average length of 10 min (range = 9 min, 36 sec to 10 min, 15 sec). Two types of key word were presented on each tape. The word "because" was repeated 20 times on each passage. The second key word was repeated 50 times per tape and was chosen to represent the major theme of the passage, such as dog, cat, or horse. A signal marker for each key word was introduced on a separate track of the tape. When the taped passage was played over a loudspeaker, the subject was instructed to press one of two switches when he heard "because" and the other when he heard the second key word. An index card, on which were typed the key word–switch alignments, was attached to the switches during the test. The output from the switches was seen on the polygraph as pen deflections in opposite directions, depending on the key word being signaled. EEG, EOG, and the key word signal from the second track of the tape were also recorded. If the subject missed three consecutive responses, he was awakened or reminded to tap. This task was scored for the total number of key words missed.

The final test of the batteries was a serial alternation task, developed as a modification of the Lubin et al. (1974) serial counting task. For this task, subjects were instructed to tap the two switches "regularly and alternately at a steady pace" for 15 min. EEG, EOG, and switch signals were recorded during the task. Subjects were awakened or urged to continue tapping the switches if a gap of 30 sec was seen. A cumulative score of the number of seconds for which subjects failed to tap the switches was compiled from the paper records, hand-scored for all gaps exceeding 2 sec.

Subjective ratings of daytime sleepiness were obtained at 30-min intervals during all waking periods, including immediately before each sleep period. The subjective rating scales included the Stanford Sleepiness Scale (SSS) (Hoddes et al., 1973) and an analog sleepiness rating scale (Carskadon and Dement, 1981). Knowledge of previous ratings was unavailable at each subsequent rating, and subjects were discouraged from discussing ratings with one another. The analog sleepiness rating scale consisted of a 100 mm line on which the left extreme was labeled "very wide awake" and the right extreme "very sleepy." During orientation, subjects were instructed to consider the extremes as the most wide awake or sleepiest they recalled ever having been, and to draw a vertical mark through the horizontal line at a point that corresponded to how they felt with respect to these personal extremes. The scale was scored by measuring the distance (in mm) of the vertical mark from the left extreme. Thus a score of 0 corresponded to maximum alertness and a score of 100 to maximum sleepiness.

The multiple sleep latency test (SLT) was used as an objective measure of daytime sleepiness. The test was given 6 times each day, at 2-hour intervals from 0930. Six SLTs were added during SD. Vigorous activity was suspended 15 min before each SLT. Five min before each test, subjects were asked to lie in bed and perform several calibrating maneuvers (eyes open, eyes closed, etc.) to ensure that a suitable signal was obtained. EEG and EOG were monitored continuously during the SLTs. At the start of each test, subjects were requested to "lie quietly, keep your eyes closed, and try to fall asleep," bedroom lights were extinguished, and doors closed. On the adaptation day, SLTs lasted 20 min whether or not the subjects fell asleep. On subsequent days, the SLTs lasted until three consecutive epochs of sleep occurred or a maximum of 20 min. The SLT score was the interval from lights out until the first 30-sec epoch of sleep or 20 min if no sleep occurred.

Meals were served at 0815, 1200, and 1800 each day; snacks were permitted *ad lib*. Caffeinated beverages were forbidden throughout the study. Recreational activities included volleyball games for about 30 min after lunch and supper, and bowling for about 45 min at 1600. Shorter breaks were spent playing more sedentary games or watching television. With the exception of SLTs and testing batteries, each subject was accompanied and observed at all times by a technician. During the night of sleep loss, subjects were treated to special activities to help keep them awake. These activities included feature-length movies (interrupted as necessary to comply with the testing schedule), bonfire and marshmallow roast, sunrise-viewing expedition, breakfast at a local restaurant, and other mild entertainments. No threats or abuse were used to maintain wakefulness.

RESULTS

Data from the adaptation day are not included. Data from the two BSLN days have been averaged, and mean BSLN results are used in the analyses. Because of other commitments, three subjects (see Table 1) were unable to complete the second REC day, although their sleep was recorded on the second REC night. Data from these three subjects are included only in the analysis of the nocturnal sleep findings. Data from the BSLN period were compared between boys and girls using t-tests. Because a significant ($p < 0.02$) difference was found for only one variable—latency to rapid eye movement (REM) sleep (boys' mean = 105 min, girls' mean = 66 min)—subsequent analyses were performed on combined data for boys and girls.

Nocturnal sleep data were evaluated using a repeated-measures analysis of variance to compare BSLN, REC-1, and REC-2. Performance test scores from the 1000, 1400, and 2000 batteries were averaged for each subject on each day, and repeated-measures analysis of variance for BSLN, SD, REC-1, and REC-2 was computed for the daily mean values. Similarly, mean daily scores for SLTs given each day and for the SSS, and analog sleepiness ratings given immediately before these SLTs, were compared across BSLN, SD, REC-1, and REC-2 conditions using repeated-measures analysis of variance. The Greenhouse-Geisser (Winer, 1971) correction for repeated measures was applied to these analyses, and the Newman-Keuls (Winer, 1971) test was performed to assess differences between means. A 0.05 rejection region was used throughout.

Nocturnal Sleep

Table 2 summarizes selected nocturnal sleep parameters. Total sleep time and stage 4 sleep time were significantly increased on the first REC night as compared to BSLN and REC-2. The mean stage 4 time on REC-1 was nearly double that of BSLN. Stage 1 sleep time was significantly reduced on REC-1 as compared to BSLN and REC-2, and remained low on REC-2 as compared to BSLN. Stages 2 and 3 sleep did not differ from BSLN on REC-1 or REC-2. REM sleep time was slightly, although not significantly, reduced from BSLN on REC-1; a slight REM rebound was seen on REC-2, with a REM time greater than REC-1 but not significantly different from BSLN. Nocturnal sleep onset latency and stage 4 sleep latency (from sleep onset) were significantly lower on REC-1 than either BSLN or REC-2. Wakefulness after sleep onset showed a nonsignificant tendency to be lower than BSLN on the two REC nights. Finally, REM latency did not vary significantly across the three conditions.

Performance Tests

There was a marked tendency for impairment of all performance measures during SD, although this impairment achieved statistical significance for only two of the measures (Table 3). The number of problems attempted on the Wilkinson Addition Test was significantly lower during SD than the other conditions; and the number of words recalled on the Williams Word Memory Test was significantly reduced during SD. Considerable individual variability was present on all performance measures, with generally greater variability on tests given during the SD period.

A clear relationship between sleep loss and performance was evident from the EEG/EOG recordings of the performance testing batteries. When subjects fell

TABLE 2. *Nocturnal sleep summary*

Variable	BSLN	REC-1	REC-2	F	df	$p <$
Total sleep time[a]	550 (20)	590 (2)	560 (16)	12.65	2,11	.005
Stage 1[b,c]	51 (14)	25 (12)	41 (14)	26.09	2,11	.001
Stage 2	269 (27)	273 (34)	260 (28)	0.87	2,11	NS
Stage 3	33 (16)	38 (12)	32 (11)	0.83	2,11	NS
Stage 4[a]	79 (24)	143 (29)	91 (26)	43.63	2,11	.001
REM[d]	120 (15)	111 (14)	136 (14)	4.51	2,11	.05
Wakefulness after sleep onset	12 (14)	1 (1)	4 (4)	2.89	2,11	NS
Sleep onset latency[b]	24 (12)	2 (1)	25 (14)	12.32	2,11	.005
Stage 4 latency[b]	43 (14)	12 (4)	43 (26)	10.32	2,11	.005
REM latency	92 (31)	119 (62)	79 (35)	1.83	2,11	NS

[a] REC-1 > BSLN and REC-2.
[b] BSLN and REC-2 > REC-1.
[c] BSLN > REC-2.
[d] REC-2 > REC-1.
All values are in min; standard deviations are given in parentheses.
Abbreviations, Tables 2–4: BSLN, baseline; REC, recovery; SD, sleep deprivation.

TABLE 3. *Performance test summary*

Variable	BSLN	SD	REC-1	REC-2	F	df	$p <$
Wilkinson Addition							
Number attempted[a,b]	105 (22)	87 (27)	118 (21)	132 (22)	10.22	3,8	.005
Percentage correct	89.5 (7.2)	79.0 (15.3)	85.6 (8.6)	88.7 (7.3)	2.31	3,8	NS
Williams Word Memory							
Number recalled[a]	11.7 (2.3)	8.4 (2.5)	12.7 (2.6)	12.3 (2.8)	6.41	3,8	.02
Listening Attention							
Number missed	8.0 (5.6)	11.8 (7.7)	10.0 (5.7)	6.7 (5.0)	1.60	3,8	NS
Serial Alternation							
Cumulative time without tapping (sec)	5.6	74.6	5.1	3.8	3.15	3,8	NS

[a] BSLN, REC-1, and REC-2 > SD.
[b] REC-2 > BSLN.
Standard deviations are given in parentheses.

asleep during performance tests, whether for brief episodes or longer episodes that reached criterion for arousals, performance test scores were markedly reduced; if no sleep occurred, there appeared to be very little decrement in test scores. For example, the mean number of problems attempted on the Wilkinson Addition test during SD batteries in which subjects did not fall asleep was 106, which is virtually identical to the mean baseline value. The relationship to sleep episodes was most obvious for the listening attention task and the serial alternation task on which a precise parallel between sleep and performance errors was observed on the polygraphic records. Figure 2 illustrates this relationship on the listening attention task.

No sleep was recorded on any performance tests during adaptation or either REC day. All test scores achieved basal values on the first REC day at the 1000 testing battery.

Sleepiness

Mean daily scores for sleepiness measures are listed in Table 4. The subjective rating scales showed a significant increase in perceived sleepiness during SD. The SSS and analog rating scale, as illustrated in Fig. 3, were highly related throughout the study, with a mean correlation coefficient of 0.83 ($p < 0.001$, zero mu t-test) across the 9 subjects who completed the study. As Fig. 3 shows, the subjective sleepiness rating scores were quite variable during SD, and this variability appeared to be related to the daytime activities. Thus subjective sleepiness scores were consistently higher after performance testing batteries than following episodes when greater physical activity was permitted. Subjective sleepiness scores achieved BSLN levels immediately after one full recovery night of sleep.

Multiple sleep latency test scores also showed a significant response to SD (see Table 4), although the pattern of response on this test differed from the subjective rating scales. As Fig. 4 illustrates, SLT scores declined progressively during the night of sleep loss and reached a low value at 0530. In contrast to the labile subjective rating scores, SLT scores remained fairly stable at low values through the remainder of SD, with virtually no response to preceding activity levels.

The recovery pattern of SLT scores also differed from that of the subjective sleepiness rating scales. Although the overall daily mean score of REC-1 did not differ significantly from BSLN, it was lower than the REC-2 mean. On a test-by-test basis (see Fig. 4), mean REC-1 SLT scores remained significantly below BSLN (t-test for related means) at 0930, 1130, and 1530. SLT scores on the second REC day did not differ from BSLN.

DISCUSSION

The twelve young adolescent subjects appeared to tolerate a single night's sleep loss with few problems. In spite of extreme sleepiness, all subjects cooperated with the testing procedures. One 12-year-old boy became very frustrated and began to cry when he was repeatedly awakened during the 0600 performance testing battery on SD. Nevertheless, he refused an offer to terminate the study and

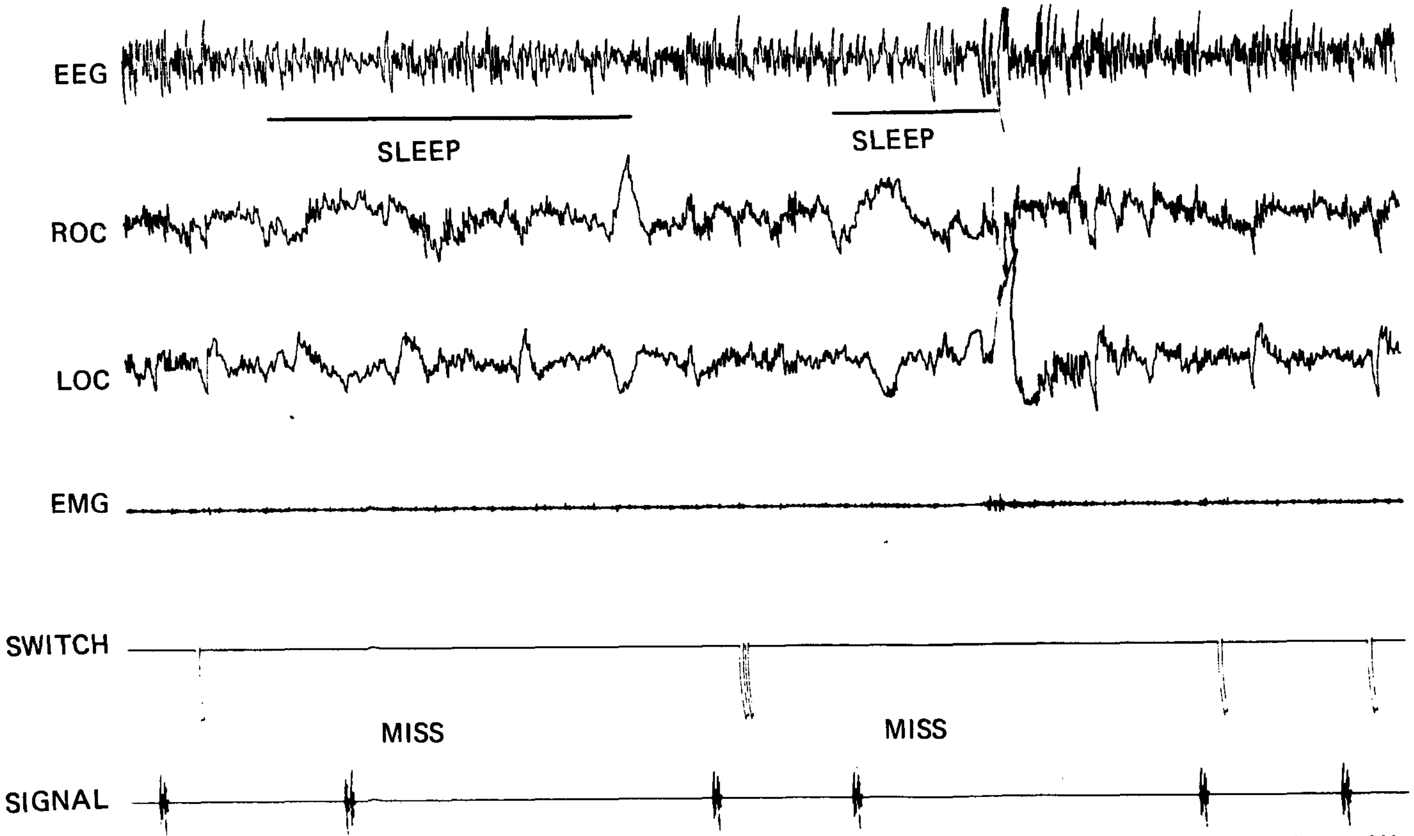

FIG. 2. Polygraphic output from the listening attention test shows the correspondence of sleep episodes with performance failures in one 12-year-old boy during the 0600 SD testing battery. Switch indicates the subjects' responses to keywords, which are shown on the channel marked signal. Two instances when EEG sleep corresponded to missed responses are shown.

TABLE 4. *Daytime sleepiness summary*

Variable	BSLN	SD	REC-1	REC-2	F	df	$p<$
Stanford Sleepiness Scale (SSS)[a]	2.7 (0.4)	3.8 (0.6)	2.6 (0.5)	2.5 (0.6)	6.67	3,8	.02
Analog Sleepiness Rating (mm)[a]	37.4 (14.9)	52.7 (16.5)	37.3 (18.1)	34.1 (16.7)	4.28	3,8	.05
Sleep Latency Test (min)[a,b]	16.8 (4.0)	1.2 (1.0)	13.1 (4.0)	17.6 (3.2)	46.13	3,8	.001

[a] BSLN, REC-1, and REC-2 > SD.
[b] REC-2 > REC-1.
Standard deviations are given in parentheses.

continued to cooperate with all procedures. Most of the subjects appeared to consider the study a challenge and an adventure; a great deal of individual support and encouragement was provided to the subjects by the Sleep Camp staff members assigned to accompany each child.

A comparison of nocturnal sleep findings with those from sleep deprivation studies in adults reveals few differences. We compared our findings to four similar studies (Williams et al., 1964; Horne, 1976; Nakazawa et al., 1978; Carskadon and Dement, 1979) that involved a total of 31 men and 2 women who ranged in age

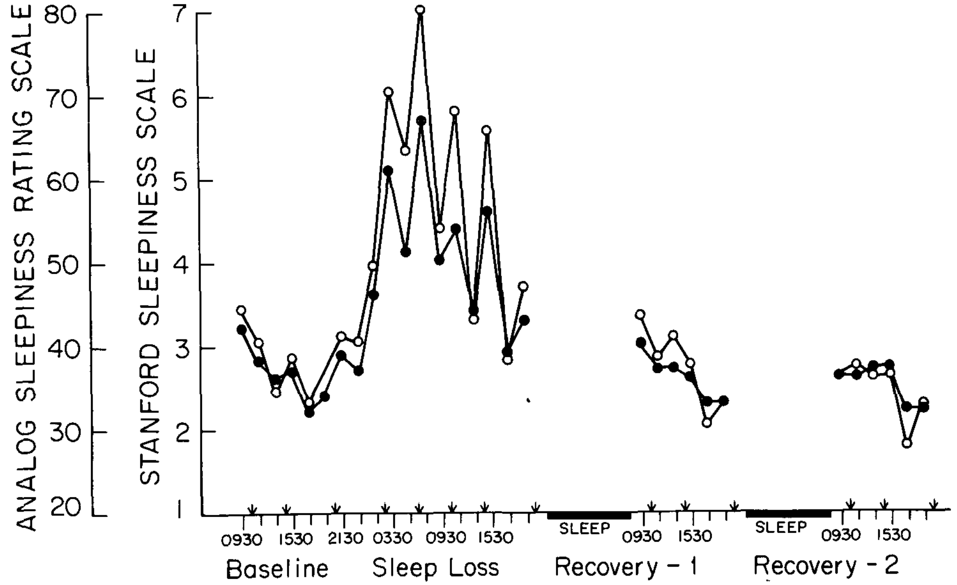

FIG. 3. Mean SSS (filled circles) and analog sleepiness (open circles) are shown for ratings taken before each SLT. A high correlation of these ratings was found in each subject. Arrows indicate performance testing batteries. During SD, subjective sleepiness ratings increased after performance tests.

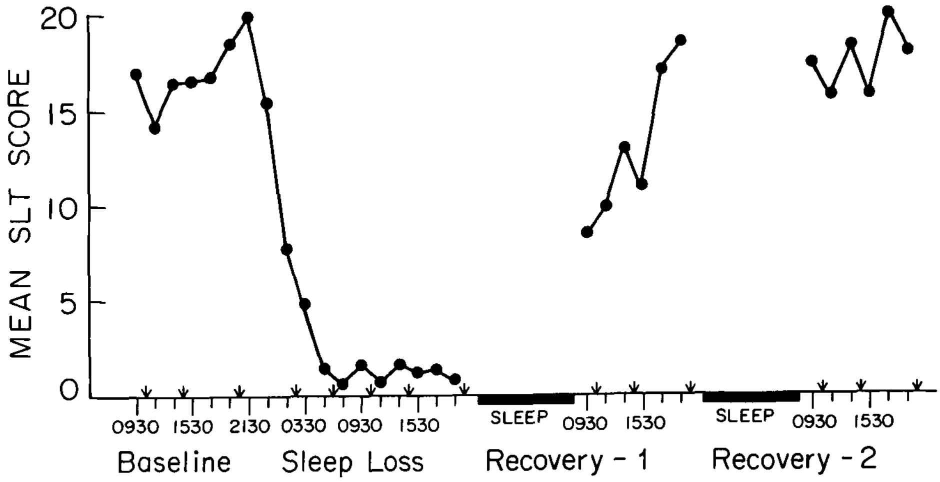

FIG. 4. Mean SLT scores are shown for the 4 conditions. Performance batteries are indicated by arrows. SLT scores remained stable at low values from 0530 on SD and throughout the SD period. REC-1 SLT scores were lower than BSLN at 0930, 1130, and 1530.

from 18 to 35 years, undergoing one or two SD nights. The direction and magnitude of sleep stage changes during recovery nights were very similar across all five experiments.

SD was clearly related to decrements in performance. That these decrements reached statistical significance for only two measures reflects the wide variability of the performance test scores, particularly during SD.

In addition, because we were concerned about the tolerance of our younger subjects for long testing sessions, we chose relatively brief tasks that did not involve the monotony and boredom of most tasks used in studies of adult subjects (Wilkinson, 1968).

Although it is difficult to compare the performance results directly to those from studies of adults, it seems that similar kinds of decrements were experienced by the youngsters. For example, the findings in adolescents were compatible with the lapse hypothesis of Williams et al. (1959) who found that SD performance failures were frequently related to reductions in EEG alpha. In the present study, we assume that the episodes we scored as sleep correspond to these episodes of reduced alpha. To a great degree, the drop-off in performance test scores in adolescents appeared to be related to the occurrence of these sleep episodes during the performance tasks. On SD test batteries at 0600, 1000, 1400, and 2000, subjects fell asleep at least briefly on 55% of the tests; longer sleep episodes that reached criterion values for arousal occurred on 24%. Thus we feel that the adolescents' performance decrements in SD can be attributed largely to falling asleep during the tests, much as we had seen in an earlier study of young adults (Carskadon and Dement, 1979).

In sleep loss studies of adult subjects, subjective ratings of sleepiness and fatigue generally increase during sleep loss (Murray et al., 1958; Naitoh et al., 1969; Hoddes et al., 1973; Hord et al., 1976; Glenville and Broughton, 1978; Carskadon and Dement, 1979). A similar augmentation of perceived sleepiness was found in the young adolescent subjects' SSS and analog sleepiness rating scales. We had initially felt that youngsters might find the analog ratings easier to use than the SSS, but there was a consistently high correlation between the self-rating scales.

Perceived sleepiness during SD appeared to fluctuate markedly depending upon preceding activity levels. During performance testing batteries, subjects sat at their desks for approximately 75 min, whereas other breaks were spent with greater physical activity (volleyball games, bowling, etc.). Sleepiness ratings tended to be much higher after performance testing batteries than after the breaks without performance testing. Kleitman (1963) has noted that one way to avoid extreme sleepiness during sleep loss is to maintain physical activity, and we feel that the adolescents' subjective ratings may reflect this phenomenon.

Multiple sleep latency test findings from the young adolescent subjects very closely paralleled those reported in young adults undergoing two nights of sleep loss (Carskadon and Dement, 1979). In both studies, maximal sleep tendency was achieved during the first night of sleep loss, and no recovery was apparent until after a night of sleep. The pattern of recovery for SLT scores was also similar in the two studies, in spite of differences in experimental protocol. That is, sleep latency test scores remained low (relative to BSLN) in the early part of the first recovery day and returned to basal values by late afternoon or early evening. In both groups, the second recovery day SLT scores were comparable to baseline scores.

The pattern of the first recovery day's SLT scores in this study and our previous sleep loss study in young adults (Carskadon and Dement, 1979) suggests that a single night of sleep is insufficient to produce complete recovery. An alternative explanation is that the sleep loss procedure induces a phase delay in the circadian rhythm of sleep tendency. That subjects achieve a basal pattern of SLT scores following the second recovery night would seem to favor the former explanation.

Unlike the subjective ratings, SLT scores during SD did not show any tendency to vary in relation to preceding activity levels. Another difference between SLT scores and subjective sleepiness ratings was the relatively slower recovery of SLT scores on the first recovery day. Nevertheless, there was a significant overall correlation between SLT scores and SSS ($r = -0.57$; $p < 0.001$) and analog sleepiness ratings ($r = -0.52$; $p < 0.001$).

Whether the sleep permitted during the multiple sleep latency tests affected the overall results may be an issue. We feel, however, that these very short periods of sleep and the brief, documented sleep episodes during performance testing did not contribute to any lessening of the sleep deprivation effects. In fact, because we monitored sleep during the tests and awoke the subjects when sleep occurred, we may have limited inadvertant sleep more than has been done in other similar studies.

In summary, we found that the sleep loss response in young adolescents differed very little from published findings in older subjects. This conclusion does not preclude the possibility that such differences may occur in areas of function not evaluated in this study; nor do our findings permit us to make conclusions regarding the response to sleep loss of prepubescent children.

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