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Cumulative Effects of Sleep Restriction on Daytime Sleepiness

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ABSTRACT

Sleep and daytime sleepiness were evaluated in 10 young adult subjects to determine whether restricting nocturnal sleep by a constant amount produces cumulative impairment. Subjects were studied for 12 consecutive days, including 3 baseline days with a 10-hr time in bed, 7 days with sleep restricted to 5 hrs, and 2 recovery days. In 5 subjects, recovery included a 10-hr time in bed; in the remaining subjects, recovery included a 5-hr time in bed with a 1-hr daytime nap. Sleepiness was measured using two self-rating scales and the multiple sleep latency test. During sleep restriction, nocturnal stage 2 and REM sleep were reduced and slow wave sleep was unaffected. Stanford Sleepiness Scales showed an immediate increase in daytime sleepiness that reached a plateau after 4 days. An analog sleepiness rating scale showed increased sleepiness after 2 restricted nights and leveled off after the fourth restricted night. The multiple sleep latency tests showed no effect of sleep restriction until the second day, followed by a progressive increase in sleepiness that persisted through the seventh sleep restriction day. During the recovery period, daytime sleepiness returned to basal values on all three measures following one full night of sleep; with a daytime nap, no further cumulative effects of sleep restriction were seen.

DESCRIPTORS: Sleep restriction, Daytime sleepiness, Multiple sleep latency tests.

The effects of restricted nocturnal sleep on sleep structure, mood, and performance have been evaluated under a number of experimental conditions. For example, Wilkinson, Edwards, and Haines (1966) and Webb and Agnew (1975) examined the effects of acute (1 or 2 nights) sleep restriction. Dement and Greenberg (1966) assessed a 6-night sleep restriction regime. In 1974, Webb and Agnew evaluated 60 days of sleep restriction. Finally, a number of studies have observed the effects of a gradual reduction of nocturnal sleep time (Johnson & MacLeod, 1973; Friedmann, Globus, Huntley, Mullaney, Naitoh, & Johnson, 1977; Mullaney, Johnson, Naitoh, Friedmann, & Globus, 1977).

In experiments that examined sleep structure, findings were generally similar regardless of specific experimental procedures. Briefly, nocturnal sleep restriction (to > 4 hrs of sleep) results in a significant reduction of stage 2 and REM sleep. Slow wave sleep stages (3+4) tend to maintain basal levels or increase slightly. There is a decline in wakefulness within the sleep period, including a reduced sleep onset latency. The latency to slow wave sleep also tends to decline, while the latency to REM sleep shows a tendency to remain stable or decline slightly. A few subjects have been reported with very brief REM latencies during sleep restriction, as in Webb and Agnew, 1974.

Mood and performance test findings have been less consistent. In acute sleep restriction studies, Wilkinson, Edwards, and Haines (1966) found that performance was unaffected by a single night of sleep restriction until sleep time was reduced to 2 hrs or fewer. These authors observed performance decrements after 2 nights of sleep restriction to 5 hrs or fewer. In the Webb and Agnew (1974) 60-day restriction (5.5 hrs per night) study, a cumulative deficit occurred in only one performance measure (vigilance); mood remained unchanged across the 60 days. The 2 subjects evaluated by Johnson and MacLeod (1973) showed impaired performance

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when sleep was restricted to 5.5 hrs in one and 4 hrs in the other. Mood scales showed these subjects to be more fatigued and irritable and less happy during the sleep restriction. In the gradual sleep reduction study of Friedmann et al. (1977), no performance decrements were seen, even at 4.5 hrs of sleep. Mood scales showed that these subjects were more fatigued and less vigorous as sleep reduction progressed.

Only one of these experiments has specifically assessed the effects of sleep restriction on daytime sleepiness. Friedmann et al. (1977) used the Stanford Sleepiness Scale (Hoddes, Zarcone, Smythe, Phillips, & Dement, 1973) as an introspective measure of sleepiness. They found a gradual overall increase in sleepiness over the course of the sleep reduction schedule. Other studies have reported indirect signs of increasing sleep tendency. Johnson and MacLeod (1973), for example, reported oversleeping and napping in their subjects. Mullaney et al. (1977) also reported more frequent oversleeping and napping as sleep was reduced to fewer than 6.5 hrs. In their descriptive summary of the gradual sleep reduction studies, Johnson, Naitoh, Moses, and Lubin (1977) state that "subjective fatigue was the limiting factor in determining tolerability of gradual sleep restriction. At their lowest TSTs [total sleep times], all subjects said they were too tired to continue . . ." (p. 134). In contrast, reports of drowsiness from the subjects who slept 5.5 hrs for 60 days (Webb & Agnew, 1974) showed an overall decline during the sleep restriction period. One subject, however, was dropped from this study in the third week when he could not tolerate the schedule without daytime naps.

The present study focuses on an objective measure of daytime sleepiness during the course of a 7-day sleep restriction regime. The multiple sleep latency test provides a periodic sample of the tendency to fall asleep (Carskadon & Dement, 1979) and will be compared to subjective rating scales. A major question addressed by the study is whether successive nights of sleep restriction result in a progressive increase of daytime sleepiness or whether sleepiness quickly reaches a plateau or even declines with continued sleep restriction. In addition, this study assesses the response of daytime sleepiness to two schedules of recovery sleep.

Subjects and Methods

Subjects were selected from healthy young adult volunteers. Sleep habits questionnaires were used to rule out persons with irregular sleep habits or complaints of sleep disorders. The volunteers reported habitual sleep times of 7 to 9 hrs nightly. The study was performed in 2 runs of 5 subjects. The first group included 2 women and 3 men (ages 17–24, mean age = 20); the second group included 3 women and 2 men (ages 18–23, mean age = 20). All volunteers agreed to refrain from alcoholic beverages, caffeine-containing beverages, and psychoactive drugs throughout the study.

The experimental runs lasted 12 consecutive days, during which subjects lived at the sleep laboratory and were under continual observation. The first 10 days were identical for both runs of the study. On the first 3 nights (BSLN) subjects were put to bed at 2200 and permitted to sleep until 0800. This 10-hr bedtime was selected for baseline days to reduce the possibility that subjects were partially sleep deprived at the start of the sleep restriction procedure. Bedtime on the 7 sleep restriction (SR) nights that followed was 0300, and subjects were awakened at 0800, thus restricting nocturnal sleep to 5 hrs. By restricting sleep to the second half of the night, daytime tests during sleep restriction maintained the same relationship to the end of night as during baseline and recovery. In the Group 1 subjects, the 2-day recovery period (REC) was identical to BSLN. In the recovery period (NAP) for Group 2, the 5-hr nocturnal sleep restriction was maintained and a 1-hr nap was permitted at 1130.

Each subject was assigned an individual bedroom for sleeping and daytime testing. Opaque posterboard was placed over windows to provide total darkness for all sleep conditions. Sleep periods were recorded using standard techniques (Rechtschaffen & Kales, 1968) on Grass Model 7 polygraphs placed in a nonadjacent recording room. Recording parameters included electroencephalogram (EEG) from referential central (C_3–A_2 or C_4–A_1) and occipital (O_1–A_2 or O_2–A_1) placements, electro-oculogram (EOG) from right and left outer canthi, and electromyogram (EMG) from mental/submental placements. Sleep recordings were performed with low frequency cutoff at 0.3 Hz, high frequency filter of 35 Hz, and a paper speed of 10 mm/sec. Sleep recordings were scored in 30-sec epochs according to standard criteria (Rechtschaffen & Kales, 1968).

Daytime activities were strictly scheduled throughout the study. Performance tests were given in 3, 75-min batteries each day, at 1000, 1400, and 2000. Each testing battery began with an abridged 30-min form of the Wilkinson Addition Test (Wilkinson, 1968), followed by a word memory test similar to that used by Williams, Gieseking, and Lubin (1966), a 10-min listening attention task (Carskadon, 1979), and a serial alternation task, developed as a modification of the Lubin, Moses, Johnson, and Naitoh (1974) serial counting task. Results of the performance tests will not be detailed in this report.

Sleepiness was tested using 3 measures, the Stanford Sleepiness Scale (SSS), an analog sleepiness rating scale, and multiple sleep latency tests. The SSS is a 7-point Likert rating scale shown by Hoddes et al. (1973) to be sensitive to sleep loss. The scale consists of 7 numbered statements that describe feeling states associated with levels of sleepiness/alertness. The statements are arranged on an equal-interval scale that ranges from 1, "feeling active and vital; alert; wide awake" to 7, "almost in reverie; sleep onset soon; lost struggle to remain awake." In administering this form, the subject was shown the list of statements and asked to write down the number of the phrases describing his current level of alertness. Subjects were not permitted to see scores given at previous ratings. The SSS was administered immediately after waking in the morning and at 30-min intervals throughout the day.

The analog sleepiness rating scale was administered at the same time as the SSS. This scale was developed to enable younger subjects to self-rate sleepiness/alertness in a manner requiring less verbal facility than the SSS. The scale consists of a 100 mm horizontal line on which the right extreme is labeled "very sleepy" and the left is labeled "very wide awake." Subjects were instructed to consider the line as a continuum with their own recollected personal extremes on either end. Subjects were instructed to draw a vertical mark through the line at a point that best approximated their current level of sleepiness/alertness. The scale was scored by measuring the distance (in mm) of the vertical mark from the left extreme. Thus a score of zero corresponds to maximum alertness and a score of 100 indicates maximum sleepiness.

Multiple sleep latency tests (SLTs) were given at 2-hr intervals beginning at 0930 each day. On days with a 2200 bedtime, the last SLT was given at 1930; on days with bedtime at 0300, the last SLT was given at 0130. All vigorous physical or mental activity was suspended at least 15 min before each SLT. Five min before the test, subjects were asked to lie in bed and perform several simple calibrating maneuvers (e.g. open eyes, close eyes, look right, look left) to ensure that an excellent signal was obtained. The SLT started when subjects were asked to "please close your eyes, lie quietly, and try to fall asleep," lights were extinguished, and bedroom doors closed.

Polygraphs were monitored continuously during SLTs for signs of sleep onset. The maximum length of each test was 20 min. On the first study day, subjects were permitted to sleep for the full duration of the tests. This procedure was used to rule out subjects who may have had unrecognized narcolepsy, wherein rapid sleep onsets and early appearance of REM sleep are diagnostic signs (Richardson, Carskadon, Flagg, van den Hoed, Dement, & Mitler, 1978). Because no subjects showed signs of narcolepsy, chin EMG was not recorded during SLTs after the first baseline day. On subsequent days, the SLTs were terminated after 3 consecutive 30-sec epochs of sleep (usually stage 1). The criterion value for sleep latency on the SLTs was the elapsed time from lights out to the first 30-sec epoch scored as stage 1 sleep. (A discussion of the choice of this criterion is given in Carskadon & Dement, 1979, and Carskadon, 1979.) Reduced sleep latencies on the SLTs are taken as a sign of increased daytime sleepiness.

Results

Comparison of basal data from the two groups using *t*-tests for independent means revealed no significant differences. Therefore, the data were combined to assess the effects of sleep restriction. A repeated-measures analysis of variance was used to compare data from the third baseline (BSLN-3) and the first (SR-1), fourth (SR-4), and seventh (SR-7) sleep restriction days. Analysis of these days was chosen for several reasons. The third baseline day was selected under the assumption that basal values for nocturnal sleep and daytime sleepiness measures would have reached stable values by day three. The 3 sleep restriction days were chosen for analysis to reduce the complexity of the analysis while maintaining the ability to assess cumulative changes. Comparisons among intervening days were made when appropriate to clarify the results. Newman-Keuls analysis was used to identify significant differences among mean values in the analysis of variance procedures. For SLTs and subjective sleepiness ratings, the average daily score was calculated from data that were available every day (i.e. only data collected between 0800 and 2130). A value of 20 min was used for SLTs on which subjects did not fall asleep. SLTs were also evaluated using the non-parametric Kolmogorov-Smirnov test as applied to survival curve presentation of sleep latency test scores. The SLTs will be displayed using survival curves in which the percentage of subjects remaining awake is plotted as a function of sleep latency. Analysis of the recovery period relied on *t* test comparisons within and between groups. A .05 rejection region was employed throughout.

Nocturnal Sleep

Selected nocturnal sleep data are listed in Table 1. In agreement with similar studies, sleep time, sleep latency, wake time after sleep onset, stage 1, stage 2, and REM sleep were significantly reduced throughout the sleep restriction period, with no cumulative effects apparent over the 7 nights. Slow wave sleep stages 3 + 4 generally remained at basal levels, with a slight increase on the fourth sleep restriction night. REM latency showed a nonsignificant tendency to decline with sleep restriction. One female had REM latencies of 7, 11, and 4 min on the last 3 SR nights, and 5.5 and 3 min on the NAP-1 and NAP-2 nights.

Sleepiness

As shown in Table 2, the three measures of sleepiness were significantly affected by sleep restriction. The pattern of effects differed somewhat among the three measures. Figure 1 illustrates the SR sleepiness data as percentages of the baseline mean values. The SSS showed a significant increase in subjective sleepiness on the first SR day and an increase from the first to the fourth SR days. No change was found from SR-4 to SR-7. For the analog sleepiness rating, no effect was seen until the second SR day ($p<.01$; *t* test for related means), and there was no further significant increase in sleepiness to the seventh SR day. Multiple sleep latency test scores did not differ from basal values until the

TABLE 1
Nocturnal sleep—Comparison of baseline and sleep restriction

	Mean Values (min) (SDs in Parentheses)			
Sleep Variables	**BSLN-3**	**SR-1**	**SR-4**	**SR-7**
Sleep Time	527**(42)	285(7)	288(7)	295(3)
Sleep Latency	33**(33)	10(7)	7(5)	3(3)
Wake After Sleep Onset	28 *(40)	1(1)	1(1)	0(0)
Stage 1	57**(21)	21(8)	15(9)	12(7)
Stage 2	280**(34)	127(29)	114(33)	126(24)
Stages 3+4	81(34)	81(29)	94+(29)	83(30)
REM	108**(29)	56(18)	64(20)	73(17)
REM Latency	101(40)	83(28)	78(28)	71(41)

Symbols identify significant F values with repeated-measures analysis of variance. Newman-Keuls analysis showed the following significant differences among means.

**BSLN-3>SR-1, SR-4, and SR-7; $p<.01$.

*BSLN-3>SR-1; $p<.01$. BSLN-3> SR-4 and SR-7; $p<.05$.

+SR-4>BSLN-3, SR-1, and SR-7; $p<.05$.

TABLE 2
Daytime sleepiness—Comparison of baseline and sleep restriction for SSS, Analog Sleepiness Rating, and SLT

	Mean Values (SDs in Parentheses)			
Sleepiness Variables	**BSLN-3**	**SR-1**	**SR-4**	**SR-7**
Stanford Sleepiness Scale** (Average from 0800–2130)	2.4(.5)	2.7(.4)	3.2(.3)	3.4(.3)
Analog Sleepiness Rating* (Average from 0800–2130)	32.3(9.8)	37.9(7.8)	44.7(6.4)	48.9(6.2)
Multiple Latency Test+ (Average of 6 given each day)	16.7(3.1)	14.3(5.6)	10.3(5.5)	7.0(4.0)

Repeated-measures analysis of variance showed significant differences for each measure.

**SSS: $F(3/27)=16.34, p<.01$. Newman Keuls: SR-1>BSLN-3 ($p<.05$); SR-4>B-3 ($p<.01$); SR-4>SR-1 ($p<.05$); SR-7>BSLN-3 and SR-1 ($p<.01$).

*Analog Sleepiness Rating: $F(3/27)=13.71, p<.01$. Newman Keuls: SR-4> SR-1 ($p<.05$); SR-4>BSLN-3 ($p<.01$); SR-7>SR-1 and BSLN-3 ($p<.01$).

+SLT: $F(3/27)=27.54, p<.01$. Newman Keuls: BSLN-3>SR-4 and SR-7 ($p<.01$); SR-1>SR-4 and SR-7 ($p<.01$); SR-4>SR-7 ($p<.01$).

second day of sleep restriction ($p<.001$, Kolmogorov-Smirnov). The SLT scores showed a prolonged effect of sleep restriction, as the only sleepiness measure on which the seventh SR day differed from the fourth. Figure 2 illustrates the progressive change in SLT scores during the SR period. Nonparametric analysis (Komogorov-Smirnov) of the survival curves confirmed the analysis of variance for the SLTs. Inspection of the data showed no obvious relationship between the individual sleepiness scores and nocturnal sleep structure changes during the sleep restriction period.

Recovery

Nocturnal sleep parameters in Group 1 subjects showed that stage 1 sleep remained low on the first 10-hr recovery night, and REM sleep time increased above the basal value. In addition, there was a nonsignificant ($p<.10$) trend for total sleep and slow wave sleep to increase above baseline on the first REC night. On the second REC night, no values differed significantly from baseline.

In the second group, whose recovery period included a 1-hr daytime nap, the nocturnal sleep values continued the trends evident during the SR period. On the daytime naps, subjects were asleep an average of 55 (SD=4) min. All subjects had REM sleep (mean=20 min; SD=18 min) on the daytime naps; in 4 of 5 subjects, REM sleep appeared within 15 min of sleep onset on both NAP days. All subjects but 1 had slow wave sleep on the daytime naps (mean=11 min; SD=9 min).

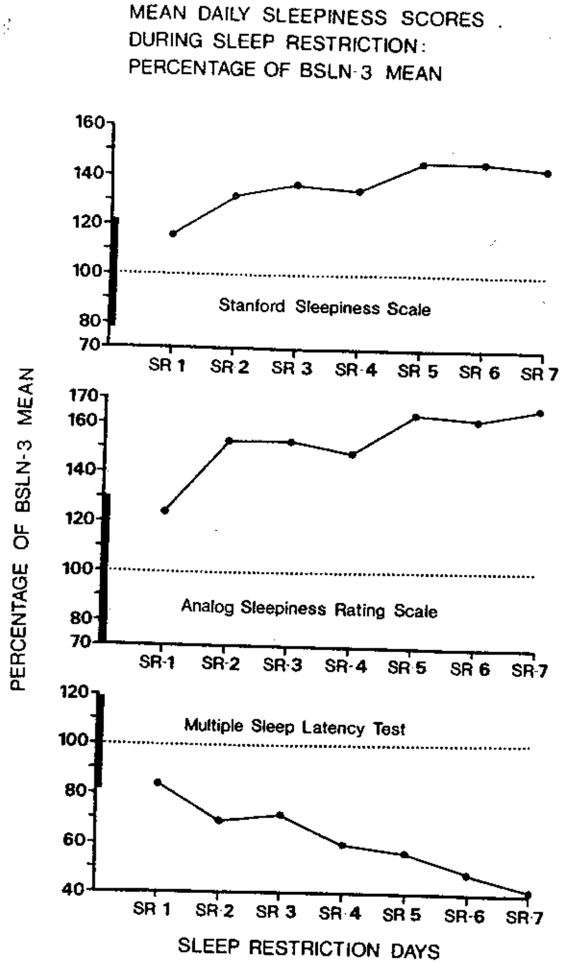

Figure 1. Sleepiness measures for the 7 sleep restriction days are displayed as percentages of the BSLN-3 day mean scores. The SSS scores increased significantly above (sleepier) baseline on the first sleep restriction day and reached a plateau after SR-4. A similar finding was seen for the analog sleepiness rating, which differed from BSLN-3 on the second SR day and reached a plateau after SR-4. Multiple sleep latency test scores were significantly reduced on SR-2 and showed further reductions on each of the sleep restriction days.

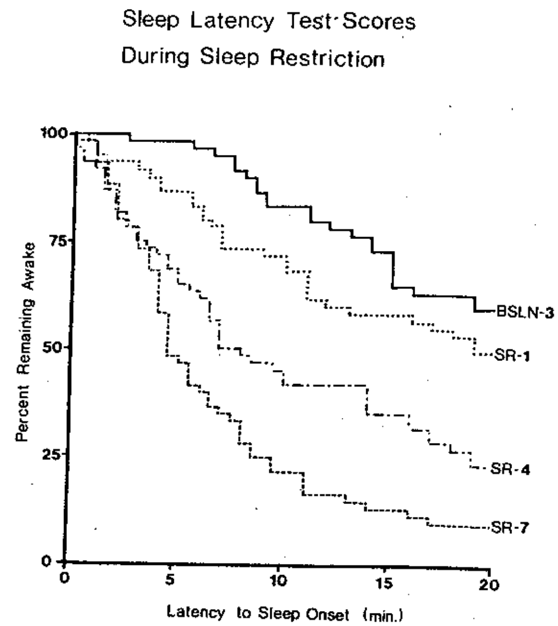

Figure 2. Multiple sleep latency test scores are displayed as survival curves, illustrating the percentage of subjects remaining awake at intervals from lights out (sleep latency). The curve for SR-1 shows a nonsignificant decrease in sleep latency from BSLN-3. On SR-4 and SR-7, subjects fell asleep significantly faster and more often than on BSLN-3. The curve for SR-7 showed a significant increase in sleepiness over the fourth SR day.

In Group 1, the three measures of daytime sleepiness showed a return to basal values on the first REC day (after 10 hrs of sleep) and continued at baseline levels on the second REC day (see Table 3). For Group 2, all three measures indicated that daytime sleepiness was impaired (from basal values) on both NAP days, although there was no change from SR-7 on the SSS or the analog sleepiness scale. The SLT scores revealed an improvement of daytime sleepiness on NAP-2 as compared to SR-7. SLT scores were significantly different between the two groups on the REC/NAP days.

Discussion

Nocturnal sleep data confirm the findings of other similar studies. That is, restriction of nocturnal sleep reduces the amount of stages 2 and REM sleep and has little effect on the amount of slow wave sleep. As has been noted in at least one other sleep restriction study (Webb & Agnew, 1974) sleep onset REM periods may occur in an occasional subject. In the present study, short REM latencies (<15 min) were seen in one 18-yr-old female on 5 of the abbreviated nights. No other subject showed similarly brief REM latencies in the nocturnal sleep recordings.

All measures of daytime sleepiness showed an effect of sleep restriction. This effect was seen first on the Stanford Sleepiness Scale and was longest lasting for the SLT scores. The subjects reported no increment of daytime sleepiness after the fourth SR day, although the multiple sleep latency tests continued to show an increasing sleep tendency through SR-7. This discrepancy may be explained by the subjects' reluctance to report negative feelings or by a gradual shift of their basal frame of reference for the subjective scales.

The SLT also appeared to be more sensitive to

TABLE 3

Daytime sleepiness—Comparison of baseline, SR-7, and recovery period for SSS, Analog Sleepiness Rating, and SLT

	Mean Values (SDs in Parentheses)			
		Group 1		
Sleepiness Variables	**BSLN-3**	**SR-7**	**REC-1**	**REC-2**
Stanford Sleepiness Scale	2.7(0.6)	3.4*(0.2)	2.8(0.4)	2.8(0.5)
Analog Sleepiness Rating	36.0(9.6)	49.5*(5.8)	38.4(7.0)	35.3(10.6)
Multiple Sleep Latency Test**	16.2(3.3)	9.1*(4.6)	17.3(2.7)	16.9(3.8)
		Group 2		
	B-3	**SR-7**	**NAP-1**	**NAP-2**
Stanford Sleepiness Scale	2.2^{+}(0.5)	3.3(0.4)	3.1(0.3)	3.2(0.5)
Analog Sleepiness Rating	28.6^{+}(9.4)	48.3(7.1)	44.6(5.3)	47.2(5.6)
Multiple Sleep Latency Test	17.1^{+}(3.3)	4.9(2.0)	7.3(4.1)	8.3^{++}(4.1)

Symbols indicate significant differences when mean values were compared using t tests. (Related-means t test was used for within group comparisons; independent-means test was used for between group comparisons.)

*SR-7 significantly different from BSLN-3, REC-1, and REC-2 ($p<.05$).

$^{+}$BSLN-3 significantly different from SR-7, NAP-1, and NAP-2 ($p<.05$).

$^{++}$NAP-2 significantly different from SR-7 ($p<.05$).

**Group 1 MSLTs significantly different from Group 1 MSLTs on REC-1/NAP-1 and REC-2/NAP-2 comparisons.

interindividual differences than were the subjective rating scales. This sensitivity was most apparent for the recovery periods, wherein the SLT was the only sleepiness measure to distinguish Groups 1 and 2. The SLT clearly showed that Group 1 was less sleepy on REC days than Group 2 on NAP days.

The SLT data during the SR period may be interpreted as showing a cumulative effect on daytime well-being that persists through 7 nights of sleep restriction. There was no evidence to indicate that sleepiness would not progress to very uncomfortable or intolerable levels in all subjects if the sleep restriction had been continued. By the seventh SR day, 3 subjects had SLT scores (average SR-7 SLTs=2.6, 2.8, and 3.2 min) that fall within the suggested range of pathological sleepiness (Dement, Carskadon, & Richardson, 1978).

The recovery data may reflect strategies by which people who are forced to restrict sleep over long periods of time may be able to forestall intolerable levels of daytime sleepiness. The SLT data from the REC period in Group 1 demonstrated that a single full night of sleep completely reversed daytime sleepiness. This finding suggests that an individual who might need to restrict sleep for 5 or 6 nights a week to meet academic or employment demands could recover by a single long night of sleep on the weekend. It is not clear whether such an individual might become more vulnerable to sleep restriction over time. The recovery data from Group 2 demonstrated that a nap is less effective in recovering from sleep restriction. Nonetheless, napping may provide a stop-gap measure against the maximum effects of sleep restriction. In the present case, 2 days with a 1-hr nap appeared to forestall further cumulative effects of sleep restriction. In a number of the gradual sleep reduction studies described earlier (Johnson & MacLeod, 1973; Friedmann et al., 1977), occasional oversleeping and napping occurred and may have contributed to the tolerability of those procedures.

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