Sleep Patterns Following 205 Hours of Sleep Deprivation

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The aim of the present study was to compare sleep patterns prior to and following prolonged total sleep deprivation (205 hr) in 4 subjects. Following 205 hr of deprivation, the percentages of Stage 4 and the rapid-eye-movement stage of sleep were increased while the percentage of Stage 2 sleep was decreased on all 3 recovery nights. On the first 2 recovery nights, marked alterations in rapid-eye-movement sleep were noted in addition to the increases in rapid-eye-movement stage percentage, including 2 sleep onset rapid-eye-movement periods, decreased rapid-eye-movement latencies, and decreased rapid-eye-movement intervals between earlier rapid-eye-movement periods. These alterations were most marked in the subject who experienced the greatest psychologic disturbance during the deprivation period. Differences in Stage 4 and rapid-eye-movement stage rebounds as well as the possibility of a relationship between certain psychologic disturbances and rapid-eye-movement pattern alterations are considered.

In the years following the discovery of rapid eye movement (REM) sleep* by Aserinsky and Kleitman,[1] a number of experiments were conducted in which subjects were totally[2–5] or partially[6, 7] sleep deprived or selectively deprived of Stage REM[8–12] or of Stage 4[13] sleep. Following each of these deprivation studies, the all-night electroencephalogram (EEG) sleep patterns of the subjects were continuously monitored.

After several days of total sleep deprivation, subjects showed marked increases above base line levels in Stage 4 sleep on the first recovery night, while REM sleep

*The terms REM sleep, Stage REM, and REM periods are used interchangeably throughout this paper.

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was not increased until the second and third recovery nights.[2,5] These findings indicated that Stage 4 sleep was recovered before REM sleep, suggesting a greater preference or need for Stage 4 sleep. Studies in which subjects were partially sleep deprived further supported this hypothesis with results of increasing amounts of Stage 4, within the sleep period allowed, as nights of partial sleep deprivation progressed.[6,7]

However, in a later, more prolonged (264 hr) total sleep deprivation study, Gulevich *et al*[4] reported that REM sleep as well as Stage 4 was increased on the first recovery night compared to postdeprivation base line levels.[3,4] The authors concluded that the more lengthy period of sleep deprivation in their study accounted for the difference in results on the first recovery night compared with those reported by Berger and Oswald[2] and Williams *et al.*[5]

Thus the results of the study by Gulevich *et al*[4] suggested that after prolonged sleep deprivation there is an increased pressure for both REM and Stage 4 sleep. The aim of the present study was to investigate and compare the sleep patterns prior to and following prolonged sleep deprivation (205 hr) in 4 subjects.

METHODS

The process for subject selection in this study has been previously described.[14] Briefly, 4 healthy, young adult male subjects 21 years or older were selected. Payment was as follows: no payment, $100, $250, or $400, respectively, for remaining awake 6, 7, 8, or 9 days. Prior to the start of the sleep deprivation period, 3 days were allowed so that the subjects could adapt to the hospital environment. During each of these 3 days, base line psychologic and physiologic measurements were recorded. In addition, sleep was continuously monitored by EEG, electromyographic (EMG), and electrooculographic (EOG) recordings.[15] The subjects slept in sound-attenuated, air-conditioned rooms. After preparation of the subjects for sleep, 9 hr were allowed from lights out until lights on in the morning.

Following 205 hr of sleep deprivation, the subjects again slept in the sleep laboratory for 3 consecutive nights. Recording methods were as previously described. On the first night following the deprivation period, subjects were allowed to sleep for 12 hr. This allowed a comparison of the first 9 hr of sleep with that of the base line nights and permitted determination of the sleep patterns following this time interval. On the second and third recovery nights, 9 hr were allowed from lights out to lights on.

Six to nine months after the deprivation period, 3 of the 4 subjects (J.L. was not restudied) again slept in the laboratory for 3 consecutive nights each for the purpose of long-term follow-up.

All EEG sleep records were scored according to the criteria of Dement and Kleitman,[16] which were recently modified as follows by a representative group of sleep researchers:[17]

Stage 1 consists of low-voltage mixed-frequency EEG activity without sleep spindles, K complexes, or REM. In Stage 2 there is low-voltage mixed-frequency activity with spindles of 14–16 cps. In Stage 3, high-amplitude slow waves (2 cps or slower) are present, with some superimposed spindling. In Stage 4, at least half the record is dominated by these high-voltage slow waves. The amplitude criterion used for determining Stage 3 and 4 was 75 microvolts peak-to-peak. During REM sleep there is low-voltage mixed-frequency, Stage 1 EEG activity associated with bursts of REM and a markedly decreased tonus of certain head and neck muscles. In contrast, when a Stage 1 EEG is present at sleep onset, REM does not occur, and the muscle tonus of head and neck muscles is higher than the levels seen during REM periods. Stage 2, 3, 4, and Stage 1 without REMs, are collectively referred to as non-rapid-eye-movement (NREM) sleep.

RESULTS

Observations During the Deprivation Period

These have been described in detail elsewhere[14] and will be only briefly described here. "During the first five days of the experiment there was a gradual increase in fatigue, decline in perceptual, cognitive, and psychomotor capabilities with increasing transient ego-disruptive episodes." On the fifth day, the subjects seemed to get a "second wind" and were better able to cope with their sleeplessness.

Disorientation and misperceptions seemed to be associated with "lapses" which became more frequent with deprivation. Reality testing was impaired between lapses. Regressive behavior was noted increasingly as the experiment continued. Tests for thought disorder showed shifts in thought processes toward more primitive or childlike levels of cognition. However, there was no evidence of schizophrenic thinking.

R.S. showed the only bizarre episode during the sleepless period. After 168 hr, while performing the psychomotor task in a darkened room, he suddenly went "berserk," exhibiting a behavior similar to that of a child with a night terror. It was subsequently learned that he had experienced night terrors as a child. In addition, he admitted that he had experienced some visual hallucinations during the sleepless period prior to this episode. He was calmed down with support from the other subjects and the experimenters and was able to complete the experiment.[14]

Sleep EEG Patterns Before and After Deprivation

Sleep stage changes. It is well known that normal subjects, when first studied in the laboratory, experience an "adaptation" or "first night" effect which consists of greater time spent awake and a lowered percent of REM sleep.[18] In our laboratory the sleep pattern on the third adaptation night is usually taken as the base line night —the night most nearly representative of the individual's normal sleep pattern. However, it was observed that on the third adaptation night subjects had more awakenings, more total wake time, and a slight decrease in the percent of REM sleep than control subjects of the same ages studied in our laboratory. These findings indicated that a first night effect occurred to a certain extent on this night as well as the first adaptation night, and we interpreted the results as being due to anxiety. Since the sleep parameters on the third night were not completely normal, it was felt that for this study the value of the parameters which would be most representative of each individual's normal pattern of sleep would be the average of all 3 base line nights for each subject.

Table 1 lists the percentages for sleep stages for the averages of the 3 base line nights, first recovery night for the first 9 hr, and for the entire 12-hr period. All 4 subjects had marked increases in Stage 4 sleep on the first recovery night, and the mean value for percentage Stage 4 was significantly increased during the first 9 hr of this recovery night as compared to the base line averages. In addition, 3 of the subjects showed marked increases in Stage REM during the first 9 hr on the first recovery night. However, 1 subject (J.L.) showed a decrease in REM percent so that the group mean REM percent was not statistically significant.

When the entire sleep period of the first recovery night was analyzed, the percent of Stage REM increased moderately over that of the first 9 hr, while the percent of Stage 4 decreased moderately (Table 1). In order to determine changes which might have occurred during the last part of the first recovery night, sleep stage percentages were calculated for the last 3 hr of this night (Table 2). Stage REM predominated during this period (52.8%) as compared with 29.4% Stage REM during the first 9 hr.

On the second recovery night (Table 3) both the mean Stage REM and Stage 4% were elevated over base line levels, ($p < 0.01$ for Stage REM, not significant for

Stage 4). On the third recovery night both Stage REM and Stage 4 were still increased above base line; however, not significantly. The percents for both of these sleep stages for the third recovery night were less than the respective figures on the second recovery night.

Thus, increases over base line in both

Table 1. Sleep Stage Percentages

	Sleep stages						
	REM*		1	2	3	4*	
Subject	(%)	(min)	(%)	(%)	(%)	(%)	(min)
3 BASE LINE NIGHTS AVERAGE (9 HR TOTAL LAB TIME)							
R.S	17.9	76	3.0	67.7	10.1	1.2	5
H.D.G.	28.7	142	1.3	45.1	16.2	9.0	45
H.H.	19.9	88	1.7	59.4	11.1	7.9	35
J.L.	21.1	108	1.4	48.9	15.6	12.9	66
Mean	21.9	104	1.8	55.3	13.2	7.8	38
RECOVERY NIGHT 1 (1ST 9 HR)							
R.S.	35.0	191	0.4	34.5	18.2	11.9	63
H. D. G.	40.5	217	0	15.8	10.3	33.4	180
H.H.	27.7	153	0.2	33.4	13.5	25.2	134
J.L.	14.6	90	0	20.9	21.0	43.5	232
Mean	29.4	163	0.2	26.2†	15.7	28.5‡	152
RECOVERY NIGHT 1 (12 HR TOTAL LAB TIME)							
R.S.	38.2	269	1.0	37.6	14.3	8.9	63
H.D.G.	47.0	347	0	15.8	12.4	24.8	183
H.H.	34.8	251	0.3	36.3	10.0	18.6	134
J.L.	22.2	164	0	25.7	18.9	33.2	245
Mean	35.5	258	0.3	28.9	13.9	21.4	164

* With all sleep stages, the percentages and the absolute values (min) showed the same trends.
† $p < .01$ (t-test used as statistical test of significance).
‡ $p < .05$.

Table 2. Sleep Stage Percentages for Extended Sleep on Recovery Night 1*

	Sleep stages						
	REM		1	2	3	4	
Subject	(%)	(min)	(%)	(%)	(%)	(%)	(min)
R.S.	46.7	78	3.0	47.9	2.4	0.	0
H.D.G.	72.2	130	0	13.9	12.2	1.7	3
H.H.	54.4	98	0	45.6	0	0	0
J.L.	41.1	74	0	37.8	13.3	7.2	13
Mean	52.8	95	0.7	35.4	6.9	2.2	4

* Values are for sleep stages from the last 3 hr.

Table 3. Mean Sleep Stage Percentages

	Sleep stages (%)				
	REM	1	2	3	4
Base line night 3	21.9	1.8	55.3	13.2	7.8
Recovery night 1 (first 9 hr)	29.4	0.2	26.2*	15.7	28.5†
Night 2	34.2*	1.6	28.0†	16.1	20.0
Night 3	26.5	0.9	41.8	15.9	14.9
Long-term follow-up	23.0	3.3	51.1	14.3	8.3

* $p < .01$.
† $p < .05$.

sleep stages (REM and 4) were seen on each recovery night. The greatest increase in Stage 4 sleep was on the first recovery night, while the peak REM increase occurred on the second recovery night. On all 3 recovery nights, the increases in Stage REM and Stage 4 sleep were accompanied by a decrease in Stage 2 sleep. The decrease in Stage 2 was significant on the first 2 recovery nights, but not on the third night when the value more closely approximated base line levels. The shifts in sleep stages on the 3 postdeprivation nights are illustrated in Fig 1.

Previous sleep deprivation studies noted the frequent occurrence of spindles on recovery nights just prior to, concomitant with, or following REMs.[3,5] This was noted in all 4 of our subjects and was most prevalent on the first night following the deprivation period.*

Changes in REM intervals and lengths. In addition to the changes in sleep stage percentages between base line and recovery nights, alterations were noted in 2 measures: the time from sleep onset to the first REM period, and the interval between successive REM periods. In 2 subjects (R.S. and H.D.G.) the first REM periods of the night were noted only minutes after sleep onset, whereas the usual interval between sleep onset and the first REM period ranges from 70 to 100 min. On the first recovery night for R.S., REM sleep occurred only 6 min after sleep onset, while on the second recovery night for H.D.G., the first REM period occurred only 8 min after sleep onset.

In most cases, all subjects had marked decreases over base line averages in the interval between sleep onset and the first REM period on the first 2 recovery nights (6 intervals decreased, 1 increased, and 1 stayed the same). Table 4 lists the intervals between, and lengths of, the first 3 REM periods for base line nights and the first 2 recovery nights. Although there was considerable individual variation, the intervals between the first and second as well as the second and third REM periods were decreased from base line levels. Later REM period intervals were more nearly the same as those on base line nights. Of the 4 subjects, 3 had increases in percent REM on the first 2 recovery nights. Of these, 2 showed longer REM periods at the first of the recovery nights, while for the third subject, longer REM periods came later in the night. J.L. was the only subject who had little or no REM rebound. He was

*Since a 40-sec epoch was scored in our study, short interruptions of REM by spindles were not necessarily reflected in REM percent.

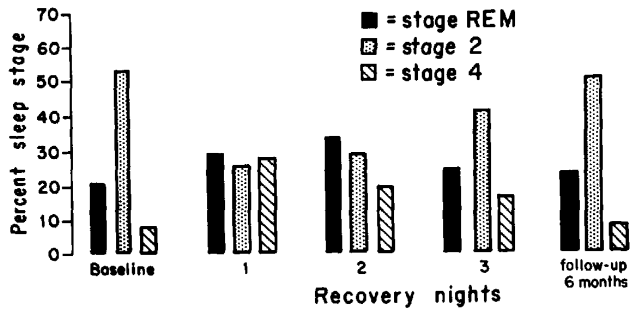

Fig 1. *Sleep deprivation and sleep stages.* **Mean values for 4 subjects except for long-term follow-up which represents 3 subjects. Stage REM and Stage 4 are increased on all 3 recovery nights at expense of Stage 2. Peak increase occurs on first recovery night for Stage 4 and on second recovery night for Stage REM. By third recovery night, figures more closely approximate base line (predeprivation) levels. On long-term follow-up, sleep stage percentages are similar to base line.**

also the only subject who did not show a shortening in his early REM intervals; moreover, he did not show a lengthening in his first 3 REM periods.

The sleep record of subject R.S. was qualitatively different from the other 3 subjects on the first recovery night. The other subjects quickly fell asleep and rapidly progressed to Stage 4 sleep of lengthy duration. R.S., however, had a markedly short latency from sleep onset to the first REM period (6 min). In addition, during the first 4 hr of sleep he had 4 REM periods rather than the fairly continuous Stage 3 and 4 manifested by the other subjects. During the first third of the 9 hr sleep period, R.S. had 71 min of Stage REM, compared to 10, 18, and 53 min of Stage REM for the other subjects. The differences in sleep cycles before and after the deprivation period, and the differences between R.S. and the other subjects are illustrated in Fig 2 and 3.

Sleep EEG Patterns—Long-Term Follow-up

Table 3 and Fig 1 compare the original base line sleep stage percentages for 3 of the subjects with the sleep measurements obtained when they were monitored again from 6 to 9 months following the sleep deprivation. All 3 subjects had sleep patterns on follow-up which were quite similar to their predeprivation recordings.

DISCUSSION

In this study, after 205 hr of total sleep deprivation, there were marked increases over base line levels in both Stage 4 and Stage REM on all 3 of the recovery nights measured. The finding of increased Stage 4 is in agreement with the short-term total deprivation studies of Berger and Oswald[2] and Williams *et al.*[5] The percent of Stage 4 on the first recovery night closely approximated in our study those of the other two studies (Berger and Oswald, approximately 27%; Williams *et al*, 24%; our study, 28.5%). In addition, Stage 4 was increased in our study on the next 2 recovery nights as well as the first recovery night, although to a lesser degree on the later nights. This finding cannot be compared with other studies since Stage 4 percent was not reported for later recovery nights.

Table 4. REM Period Intervals and Lengths

Subjects	Sleep onset to REM 1	REM Intervals (min)* 1–2	REM Intervals (min)* 2–3	REM Lengths (min) 1	REM Lengths (min) 2	REM Lengths (min) 3
BASE LINE AVERAGES						
R.S.	83	70	84	7	14	16
H.D.G.	84	131	126	22	36	56
H.H.	69	88	109	10	23	22
J.L.	105	94	125	8	22	24
Mean	85.2	95.8	111.0	11.8	23.8	29.5
RECOVERY NIGHT 1 (1ST 9 HR)						
R.S.	6	78	70	30	22	26
H.D.G.	59	93	109	26	59	74
H.H.	75	79	70	8	10	22
J.L.	145	75	84	10	11	12
Mean	71.2	81.2	80.8	18.5	25.5	33.5
RECOVERY NIGHT 2						
R.S.	72	121	82	39	15	20
H.D.G.	8	97	104	13	37	38
H.H.	56	104	64	37	21	12
J.L.	49	123	88	21	12	33
Mean	46.2	111.2	84.5	27.5	21.2	25.8

* Intervals were measured between the beginning of one interval and the beginning of the next interval.

After 2–5 days of sleep deprivation, no increase, in fact a decrease, in REM sleep on the first recovery night was found. Williams *et al*[5] found a slight decrease in REM percent from 21.6 on the second base line night to 19.4 on the first recovery night. In the study of Berger and Oswald,[2] REM percent on the first recovery night was only one-third that of the predeprivation night (7.4 versus 22.5, respectively). In order to compare our results with those of Berger and Oswald, we analyzed an amount of sleep time on our first recovery night equal to that in their study (446 min). Percent of Stage REM for this sleep interval was 30.0 versus the 7.4 noted in their study.

Our results showing an increase in the percent of REM sleep after prolonged sleep deprivation is in agreement with more recent findings of Gulevich *et al*[4] for their subject who was sleep deprived for 10 days. Our data, however, was reported in a different form from their study. They reported parameters based on the entire sleep period of 14 hr on the first recovery night. Using the entire period resulted in a diluted Stage 4 percent that appears lower than it actually is when compared to base line measures based on 8–9 hr sleep time. Also, since a large part of REM time occurs in the latter part of the night, REM percent on their first recovery night appears higher than it would be if a 7–9 hr time period were recorded instead of 14 hr. In addition, it

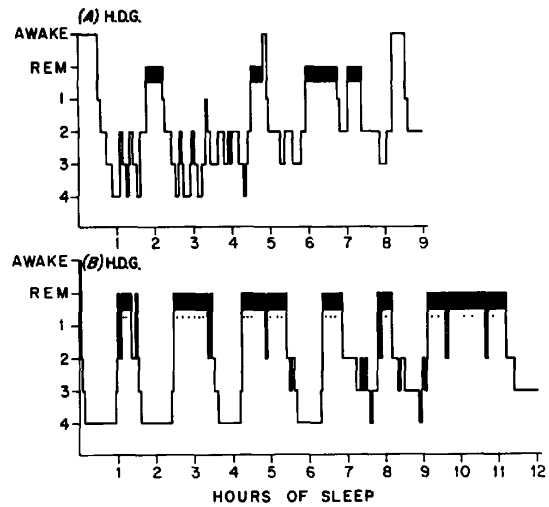

Fig 2. Sleep cycles before (A) and after (B) deprivation in H.D.G. (A) is third base line night and (B) is first recovery night. After deprivation there is marked increase in Stage 4, moderate increase in Stage REM; the interval from sleep-onset to first REM period is decreased and there are less overall shifts of sleep stage. Dots under REM periods on (B) indicate interruptions of REM sleep by spindle activity which lasted less than 2 min.

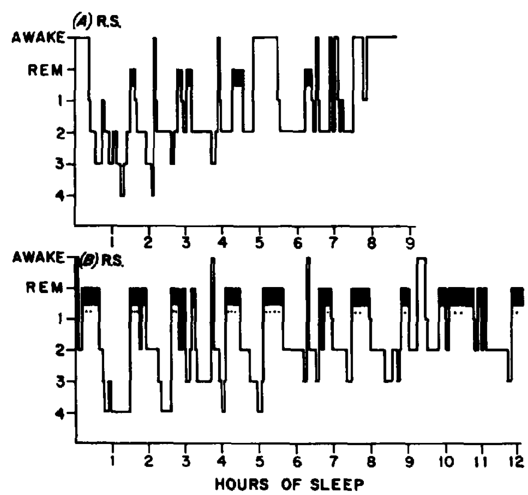

Fig 3. Sleep cycles before (A) and after (B) sleep deprivation in R.S. (A) is third base line night and (B) is first recovery night. As with other subjects, there are increases in Stage 4 and Stage REM following deprivation. In addition, first REM period occurs minutes after sleep onset and there is marked increase in REM sleep during first third of night. Third base line night was final night prior to deprivation and showed increase in wake time throughout night. Dots under REM periods on (B) indicate interruptions of REM sleep by spindle activity lasting less than two min.

is difficult to determine the degree of REM and Stage 4 rebound since their base line measures were 3 single, nonconsecutive nights recorded several weeks to a month after the deprivation period. We have also found in our laboratory that nonconsecutive laboratory nights result in a readaptation or first night effect—ie, a lowering of REM sleep time.[19]

Since, on the first recovery night of their study[4] all of the Stage 4 sleep occurred in the first 6 hr of sleep, the minutes of Stage 4 which they reported could be used to determine the percent if only 9 hr of sleep had been allowed. This yielded 21.0% during Stage 4 compared to the 12.8% which they reported, bringing it closer to the values obtained in previous studies. REM percent could not be determined for 9 hr, however, since much is assumed to have occurred during the last part of the night.

The findings of approximately the same increase in Stage 4 on the first recovery night after both 3–5 days and 8–11 days of sleep deprivation seem significant. They suggest that Stage 4 may not be proportionately increased on the first recovery night following longer durations of total sleep deprivation. This is in contrast to Stage REM where increases only seem to occur after prolonged (8–11 days) total sleep deprivation.

It is of interest that there was such a large REM rebound on the second recovery night in our study, since allowing 12 hr of total sleep also allowed a greater REM rebound on the first recovery night. In order to determine the degree of REM rebound occurring in the last part of the first recovery night we compared the last 3 hr of that night with the last 2 hr allowed normal subjects in addition to their regular night's sleep in a study by Webb *et al.*[20] Our REM was 52.8% versus their finding of 38.2% (our measure was of Hr 9–12 while the findings of Webb *et al* were of Hr 8–10). We felt that the larger percent found in our study is indicative of an additional marked REM rebound in the extra 3 hr allowed as compared with early morning REM percents found in normal subjects.

Of all the subjects, R.S. showed the greatest variation in many sleep parameters. On the third base line night, it was noted that this subject had the greatest sleep alteration, as indicated by more total awake time, greater number of awakenings, and less REM sleep. In other words, the anxiety factor mentioned previously seemed to be greatest in this particular subject. On the first recovery night, the first REM period occurred shortly after sleep onset, lasted for 40 min, and contained numerous REM's. The first REM period usually lasts only for a few minutes (5–10), with only a few REM's. Thus, this particular REM period was unusual, not only because of its occurrence at sleep onset, but also because of its duration and the considerable REM activity present throughout. In addition, the REM time for the first third of the sleep period on the first recovery night was considerably higher (71 min) than that of the base line nights (12 min).

Some alterations in REM sleep following deprivation occurred in all subjects in varying degrees. Marked disturbances in REM patterns occurred in 3 of the 4 subjects. These included marked rebound in percent of REM sleep, 2 sleep onset REM periods, shortening of the intervals between, and increases in the lengths of the first three REM periods. In addition, interruptions of REM periods by spindle activity, particularly during the earlier REM periods, were found in this study as in previous studies.

In contrast to the other 3 subjects who

had large REM rebounds on the first recovery night, J.L. had a marked decrease in REM percent while experiencing an extreme increase in Stage 4 sleep. On the second recovery night his REM percent was approximately the same as that on base line nights. It was subsequently learned that this subject was a Navy deserter who had had a history of some homosexual activities and psychotic behavior. Whether there was any relationship between this subject's clinical picture and his abnormalities in REM pattern is not clear, but the finding may be of interest in future studies.

As mentioned above, R.S. had a REM period shortly after sleep onset as well as a predominance of REM sleep early in the night on the first recovery night. It is possible that this, as well as the other REM alterations he demonstrated, could be related to the psychologic disturbances which this subject exhibited during the sleepless period. Snyder[21] found REM periods occurring shortly after sleep onset in a number of psychotically depressed patients longitudinally studied in the sleep laboratory. In addition, Stern *et al*[22] found significantly shorter REM latencies in patients in the acute phase of schizophrenia than in normals. However H.D.G. also experienced an REM period shortly (8 min) after sleep onset but did not exhibit the clinical disturbances seen in R.S. If sleep onset REM's are a concomitant of psychotic-like disturbances after sleep deprivation, just as they are in the acute phases of schizophrenia and psychotic depression, then it is possible that the sleep onset REM period noted in H.D.G. may have been indicative of an incipient or impending psychotic reaction.

The possibilities of differential recovery patterns of Stage 4 versus Stage REM suggested by the differences in rebound after short- versus long-term deprivation indicate that further research might profitably prolong the recovery period during which sleep is monitored in the laboratory, as well as limiting the length of the recovery nights to that of base line levels. The disturbances in REM sleep patterns found in this study, such as 2 sleep-onset REM periods, as well as shortened REM latencies and intervals early in the recovery sleep period, also offer an enticing area of further research into the possible relationships which might exist between psychiatric disturbances and alterations in REM sleep patterns.

SUMMARY

Four normal, young adult male subjects were continuously monitored for EEG, EMG, and EOG on 3 consecutive nights prior to 205 hr of total sleep deprivation, and again following this deprivation period. Three of the subjects were studied again several months after the initial experiment.

The percentages of Stage 4 and Stage REM sleep were increased while the percentage of Stage 2 sleep was decreased on all 3 nights following the sleep deprivation. The stage shifts were significant for Stage 4 on the first night, Stage REM on the second night, and Stage 2 on both the first and second recovery nights. Although not to the same degree, higher percents of Stage REM and Stage 4 persisted through the third recovery night. On the long-term follow-up all 3 of the subjects had sleep patterns quite similar to those before sleep deprivation.

On the first 2 recovery nights, marked alterations in REM sleep were noted in addition to the increases in Stage REM percentage. There were 2 REM periods close to sleep onset; 3 of the 4 subjects had shortened intervals between sleep onset and the first REM period; and the intervals between the first 3 REM periods on the

first night were decreased. These results suggested that following prolonged sleep deprivation marked alterations in REM sleep are present as well as increases in Stage 4.

One subject who had the greatest clinical disturbance during the sleep deprivation also showed marked abnormalities in REM sleep on the first recovery night. The suggestion of a relationship between his clinical disturbance and REM sleep changes is raised.

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