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ACADEMIC PRESS, INC. NEW YORK SAN FRANCISCO LONDON

NEURONAL ACTIVITY PATTERNS DURING RAPID-EYE-MOVEMENT SLEEP: RELATION TO WAKING PATTERNS

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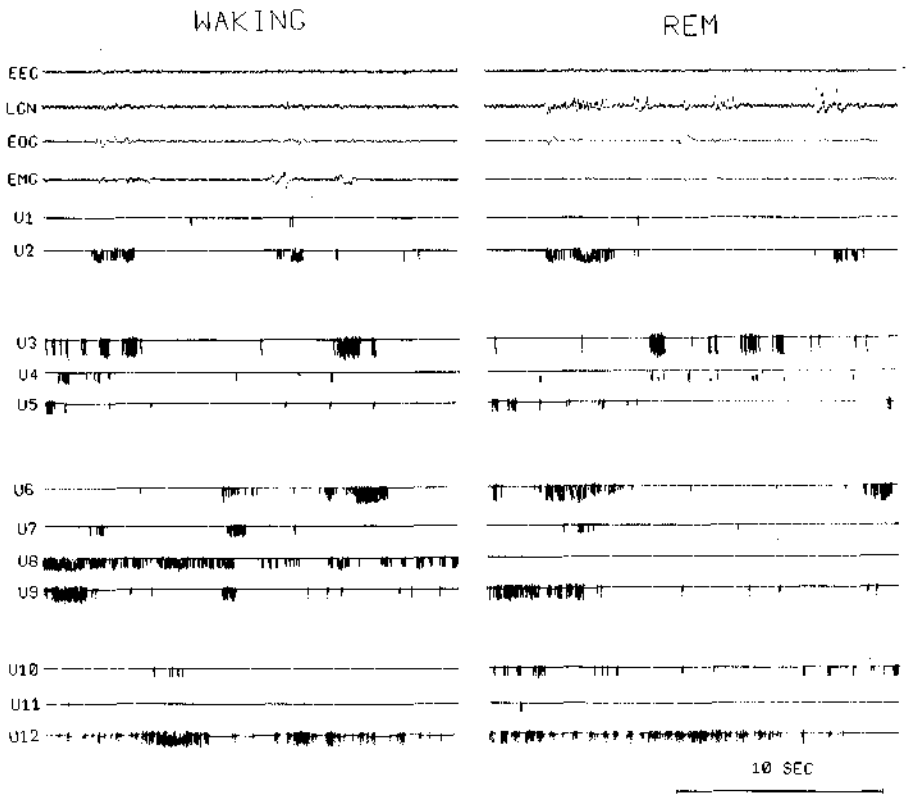
Neuronal unit spike activity as detected by extracellular electrodes has been studied during waking, slow wave sleep (SWS) and rapid-eye-movement sleep (REMS) in a variety of brain sites. A consistent finding has been that a majority of cell types exhibit an increased neuronal discharge rate in REMS and in waking when compared with SWS. Indeed, REMS rates usually equal or exceed waking rates, and REMS has been described as a state characterized by intense excitation of brain unit activity. This observation, first reported by Huttenlocher (1961) for medial midbrain cells, has been extended to the cerebral cortex (Evarts, 1962, 1964; Noda & Adey, 1970), thalamus (Sakakura, 1968; Mukhametov, Rizzolotti, &Seitun, 1970; Mukhametov, Rizzolotti, & Tradardi, 1970), certain limbic sites (Noda, Manohar, & Adey, 1969; Findlay & Hayward, 1969) and most brainstem neurons (Kasamatsu, 1970; Bizzi, Pompeiano, & Somogyi, 1964; Hobson & McCarley, 1971). Other cell types have been found to exhibit reduced activity in REMS compared with SWS, but a similar reduction also occurs during waking, that is, the REMS-waking similarity applies (Jacobs S McGinty, 1971). Initially, these observations were interpreted as supporting concepts that SWS and REM sleep were dissimilar states and that sleep did *not* constitute

a simple resting condition in terms of cellular discharge (Evarts, 1967). In this paper we want to emphasize another aspect of this phenomenon. Studies of the patterns of unit activity during REMS may indicate to us the nature of brain functions that are manifested during this state, assuming we can recognize the functional significance of the observed spike patterns.

Consider the amazement of the proverbial visitor from space, viewing the behavior of mammals and interpreting the significance of REM sleep. He would note that mammalian organisms periodically enter a state in which most motor neurons are paralyzed by a tonic inhibitory process (Pompeiano, 1967). Simultaneously, many other brain neurons begin to behave as if the animal were awake, exhibiting spike train patterns normally associated with waking behaviors or functions. During waking (W), cells in sensory pathways are active in a predictable fashion, exhibiting variations in activity that are determined by the changing sensory flux. It is thought that the characteristics of sensory receptors, pathways and synaptic interactions can account for these activity variations. Similarly, cells associated with motor behavior exhibit tight correlations with specific ongoing movements. But in the REMS state, these same sensory and motor cells exhibit variations in activity that seem to be grossly similar to those found in W, but the sensory flux and motor behavior that "explained" these variations no longer occur. Some examples of motor-related cellular activity in waking and REMS are shown in Figure 1. *During REMS some intrinsic brain process may be modulating cellular behavior.* From the vantage point of the cellular neurophysiologist, it seems entirely plausible that during REMS cells are involved in activities related to the regulation of behavior, possibly including learning, memory, or homeostatic functions.

However, we have speculated beyond the scope of existing data. We have suggested that neurons exhibit discharge patterns in REMS grossly similar to those in waking, but this comparison has not been given detailed consideration. We must in fact, formulate a set of basic questions. What are the similarities and differences between the behavior of cells during waking and REMS? More specifically, can unit discharge rates, interval patterns in spike trains, temporal patterns in the onset and offset of spike trains in REMS be compared with those seen during specific waking behavioral events or processes, such as certain sensory stimuli, drive states, or motor behaviors? Is it possible to recognize neuronal activity sequences in REMS that indicate that the brain is literally reconsidering recognizable unique sensory inputs or motor



1. *Polygraph recordings from waking and REMS comparing patterns of spike activity of pontine tegmental neurons. Units (U) 2, 3, 5, 6, 7, 9, 10, and 12 exhibited bursts of spike discharge in relation to head movements in waking and during REMS, but little activity in quiet waking or SWS and were identified as FTG neurons. Note that, in these samples, bursts and pauses in spike discharge of individual FTG neurons tended to exhibit the same temporal patterns in both states.*

outputs? Or do spike trains in REMS exhibit properties never seen in W, suggestive of specialized functions? Although we are far from definitive answers, these questions will be considered in the following discussion.

We will describe the results of experiments in which the behavior of single cells sampled from *a* specific population is recorded during certain waking behaviors and in REMS. We hope both to recognize the significance of the waking activity

of the cells and to compare its characteristics with those observed in REMS. In attempting to design experiments which would yield answers to our questions, we must first decide which samples of waking should be selected for comparison with REMS. The most common point of view is that REMS should be compared with preceding waking, because only previously acquired information can be processed. REMS is usually thought of as having some recuperative or homeostatic function. Therefore, most behavioral studies, and the unit studies described here, relate REMS periods with previous W periods. Logically, however, it is possible that REMS activities could be more highly correlated with subsequent events, that REMS has preparatory functions. We will describe data supporting the latter point of view.

Motor "Behavior" During REMS

The medial pontine reticular formation contains a class of scattered "giant" neurons which exhibit bursts of phasic activity during REMS and during the pre-REM PGO waves; the "FTG" neurons, which have been studied by Hobson and his associates (see Hobson, this volume). These cells have been found to have the following additional properties. During SWS and quiet waking these cells exhibit little spontaneous activity. During active waking thesa cells exhibit bursts of activity that are correlated with specific head movements. For example, a particular cell may exhibit a burst of spikes during head turning in one direction, head extension, or head lowering. Most cells discharge in relation to a single type of movement. Movement-related cellular discharge could be induced by either passive or active head movement and was attenuated by head restraint.

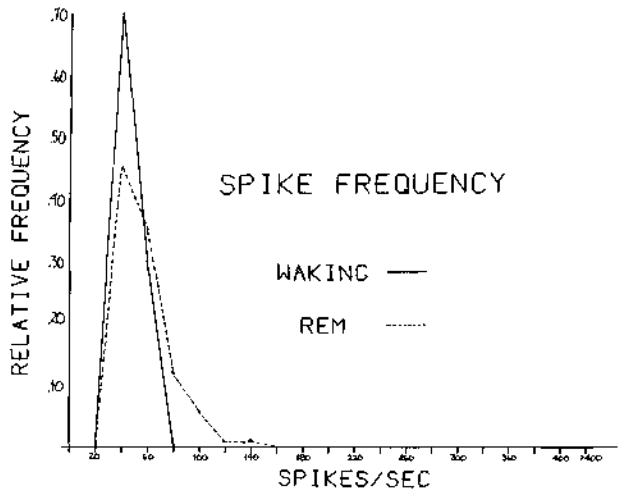
The latter facts suggest that movement-related discharge in FTG cells is a corollary to primary movement or movement command, or may be related to proprioceptive or vestibular movement correlates rather than the initiation of movement. Nevertheless, these cells exhibited discharges which indicate the occasion of specific movements and could be used to compare overt waking motor behavior and covert REMS motor "behavior." We have compared two aspects of spike train samples from waking and REMS. First, the interval histogram function was used to examine the internal structure of the spike train burst. Second, the duration of bursts and inter-burst pauses and the intra-burst spike frequency were analysed to indicate the duration, frequency, and rate of waking and REMS "behavior." These techniques are explained further below.

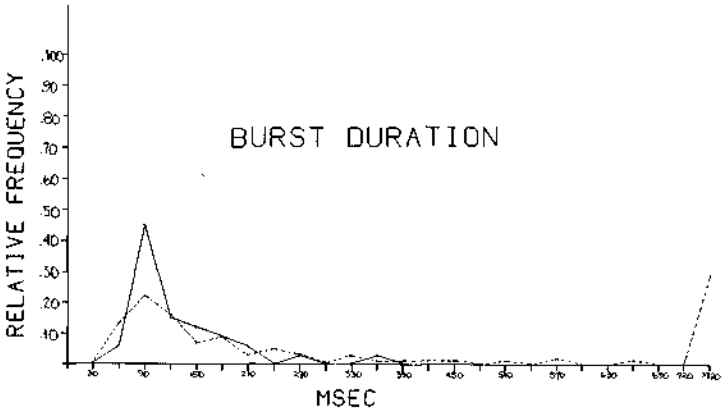
Perhaps the most thorny problem was the finding of useful criteria for choosing waking samples for comparison with REMS. Since we were aware that spike trains from waking samples reflected the specific head movements occurring during the samples, we were faced with the option of choosing samples during certain specific behaviors such as feeding, grooming, and guided head turning, or more varied behaviors such as exploration. We settled on the use of 120 second samples representing a variety of behaviors, usually the samples yielding the highest waking rate.

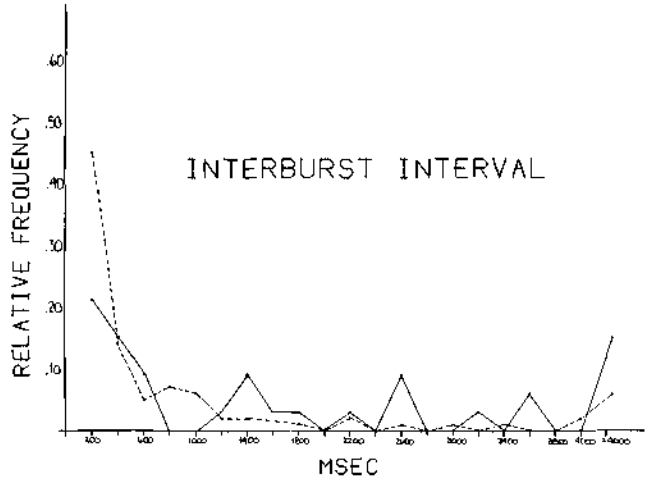
Burst Patterns

As shown in Figure 1, FTG neurons exhibit bursts of spikes alternating with pauses in activity. We reasoned that the duration of these bursts and pauses and the rate of spike activity within bursts were a reflection of the sequencing and rate of movements. If REMS bursts correspond to covert movement, then the duration of the burst should be similar to those during waking. Bursts were defined as any sequency of three of more spikes with no intervals exceeding 50 milliseconds. For each 120 second sample, the list of burst durations, inter-burst intervals, and average intra-burst spike frequencies were sorted to provide relative frequency distributions as illustrated for one cell in Figure 2. This figure indicates that the shapes of the three distributions were similar in waking and REMS. In order to carry out quantitative comparisons, the relative frequency distributions for each parameter and each cell were divided into portions consisting of short intervals or durations or low frequency components, intermediate components, and long intervals or durations or high frequency components. The proportions of the distribution in each component were averaged for all cells for both waking and REMS samples and were then compared statistically. The results are summarized in Table 1.

These comparisons indicate that the general pattern of motor activity, the durations of "movements," the intervals between "movements," and the rates of the "movements" (burst frequencies) are similar in waking and REMS. For example, the proportions of burst frequencies between 40 and 120 spikes per second were virtually identical in waking and REMS, and proportions of intermediate burst durations and intervals were also similar. Some differences appeared at the extremes of the distributions. A significantly larger proportion of both long duration burst (> 720 ms) and short inter-burst intervals (< 200 ms) were observed in REMS. These differences are


SPIKE FREQUENCY
WAKING
REM
RELATIVE FREQUENCY
SPIKES/SEC


BURST DURATION
RELATIVE FREQUENCY
MSEC


INTERBURST INTERVAL
RELATIVE FREQUENCY
MSEC

		Intra-burst frequency	
Waking	< 40 s/s	41-120 s/s	> 120 s/s
REMS	.35 .29	.63 .65	.02 .04
		Burst duration	
Waking	< 60 ms	61-210 ms	> 720 ms
REMS	.13 .20	.61 .53	.02[a] .09[a]
		Inter-burst interval	
Waking	< 200 ms	201-600 ms	> 4000 ms
REMS	.35[b] .47[b]	.24 .21	.13 .11

[a] $P < .05$, two-tailed "t" tests

[b] $P < .02$, two-tailed "t" tests

The table compares the mean proportions of selected portions of relative frequency distributions of burst durations, inter-burst intervals, and intra-burst spike frequencies for waking and REMS. The averages were derived from 11 cells. See text for a detailed explanation. Intra-burst frequencies are given in spikes per second (s/s) and durations and intervals are given in milliseconds (ms).

illustrated in the example seen in Figure 2. However, they do not represent a large proportion of the overall sample. Tendencies for more short duration bursts in REMS and high intra-burst frequencies were not significant.

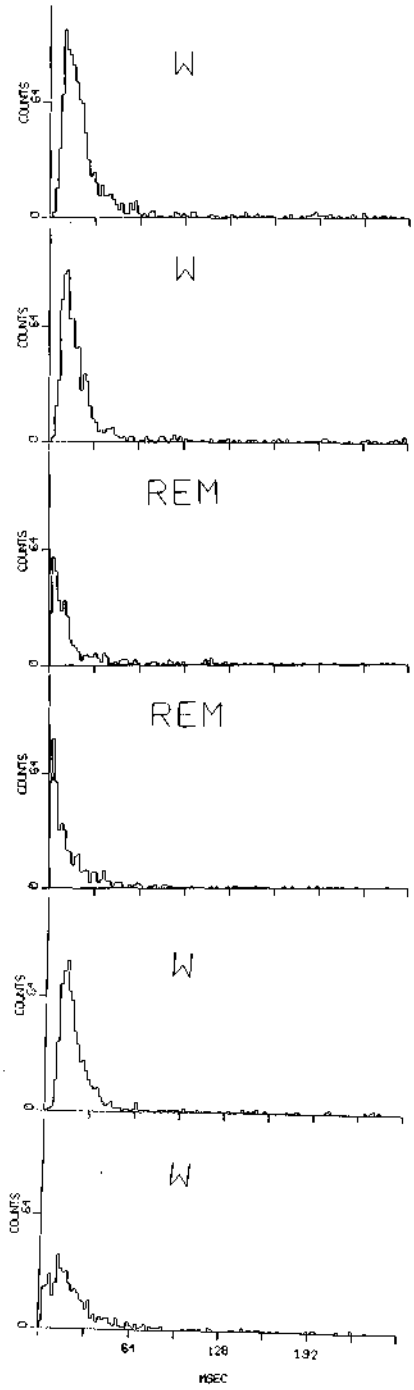
Interval Histogram

The interval histogram provides information about the temporal pattern within the spike train, namely, the relative frequency of various durations of intervals between adjacent spikes. Examples of interval histograms derived from 120 second samples obtained during REMS and from both preceding and subsequent waking are shown in Figure 3. It is apparent that these distributions are shifted to the left in the REMS samples; that is, the relative proportion of short interspike intervals is greater in REMS.

We have quantified the shape of these distributions by calculating the interquartile points, the inter-burst intervals delineating the shortest and longest fourths of all intervals, plus the median interval. Table 2 compares the interquartile points of waking and REMS samples of 12 cells. This comparison confirms the impression given by the example; most FTG neurons have shorter interspike intervals at their interquartile points during REMS.

Commentary

We have examined the hypothesis that activity of FTG neurons reflects centrally-commanded motor activity during REMS as in waking. Since, during REMS, motor activity is prevented by motoneuron hyperpolarization, the inference was based on the patterns of bursts and pauses in FTG neuronal discharge that are correlated with spontaneous waking movements. These patterns, that is, the rate, duration, and pauses in REMS behavior, were found to be generally similar to waking behavior. The result supports the idea that the commanded behavior of FTG cells during REMS is qualitatively similar to their waking behavior. Our interpretation is supported by the data of Jouvet (1962) and Henley and Morrison (1974) who studied cat preparations with restricted dorsolateral pontine lesions. Such cats are thought to exhibit paradoxical sleep episodes *without* motoneuron paralysis. During sleep they exhibit episodes of phasic motor activity suggestive of aggression and flight, that is, behaviors having the appearance of organized motor sequences. On the basis of these


W
COUNTS
64
0
W
COUNTS
64
0
REM
COUNTS
64
0
REM
COUNTS
64
0
W
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64
0
W
COUNTS
64
0
64
128
192
MSEC

Figure 3

Fig. 3. Interval histograms of spike trains from REMS and both preceding (upper samples) and subsequent waking (lower samples). Analyses of two 120-second spike trains from each of the three sample periods are shown. The interval histograms are shifted during REMS to demonstrate an increased proportion of short interspike intervals.

Waking	2	34	
REMs	10	9	S

The table shows which of the 12 samples, REMS or waking, provided the shortest interquartile points indicating faster spike discharge within bursts. Q1 and Q3 refer to the shortest and longest quartiles, respectively, and Q2 refers to the median point.

two kinds of results, we conclude that FTG neuronal behavior in REMS reflects characteristics of "commanded" motor behavior. On the other hand, we observed certain subtle differences between REMS and waking spike trains. In most FTG neurons REMS bursts were of longer duration, and the spike train was characterized by shorter interspike intervals. These differences could have resulted from insufficient selection of samples from waking, samples which neglected long and rapid spike trains. However, since the highest rate waking samples were chosen for analyses, this bias seems unlikely. Another possibility is that the REMS spike trains reflect the differences between the intensity and topography of REMS and waking motor activity, differences which can readily be observed in the cats with dorsolateral pontine lesions.

Motivational Influences

Basic questions affecting the understanding of unit discharge in REMS pertain to the influence of motivational factors. For example, we may ask if various cell types respond to food deprivation during sleep by an altered discharge rate as they are known to respond in waking. This question was explored experimentally (Jacobs, Harper, S McGinty, 1970) by measuring unit discharge rate during SWS and REMS in a

variety of midbrain and hypothalamic sites under two conditions: (1) after 48 hour food deprivation, and (2) following satiation. Each rate measurement was the mean of at least eight 10-second samples. In control studies, rates were obtained from two separate sleeping periods separated by waking time similar to that required for "satiation," but with no food intake. Some sample data and a summary of results are shown in Figure 4.

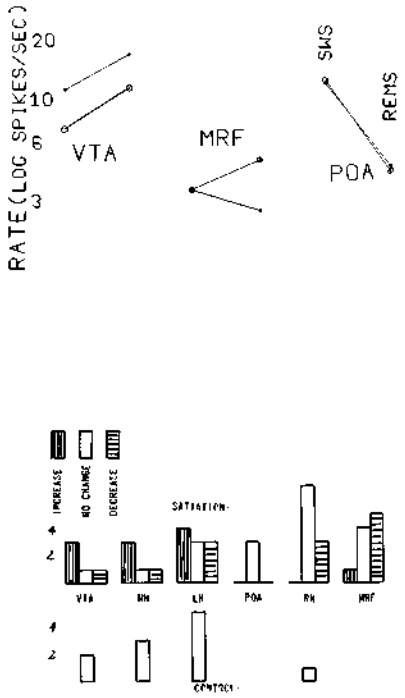

Fig. 4. Changes in firing rate of midbrain and hypothalamic neurons during sleep before (open circles) and after (closed circles) satiation following 48 hours food deprivation. Upper: Examples of firing rate changes in individual neurons from the ventral tegmental area (VTA), midbrain reticular formation (MRF), and preoptic area (POA). The VTA unit was changed in both SWS and REMS, the MRF cell was changed in REMS, and the POA cell was unaffected by satiation. Lower: Summary of number of cells exhibiting statistically significant changes in sleep firing rate in various sites. No changes were observed in control tests (see text for details). Other sites included medial hypothalamus (MH), lateral hypothalamus (LH), and red nucleus.

All 11 cells that were studied in the control condition failed to exhibit significant changes in rate, including six cells which were found to change in the experimental condition. On the other hand, 58% of our experimental cells exhibited significant rate changes in REMS following satiation. In 19 of 24 cells that showed changed discharge rates following satiation, the change was larger in REMS than in SWS. The majority of cells in regions known to be involved in motivational process, including the medial and lateral hypothalamus, midbrain reticular area and ventral tegmental area exhibited significant changes, while most cells in the red nucleus and proptic area were unaffected. The direction of change seen in the medial and lateral hypothalamus produced by satiation was consistent with earlier studies in waking or acute preparations (Oomura, Ooyama, Naka, Yamamoto, Ono, S Koyayashi, 1969). The MRF cell illustrated in Figure 4 declined in rate during REMS following satiation, possibly reflecting a reduced reticular activation. Thus, the direction of change in unit discharge in REMS produced by food deprivation appeared to be the same as in waking.

These results show that the unit discharge rate in REMS reflects a motivational condition in appropriate cells groups. This type of experience does not indicate the source of the motivational influence on rate changes or its behavioral significance. On the other hand, we can conclude that cellular interactions during REMS involving these cells groups will be influenced by these rate changes.

Relationship of REM Sleep and Food Intake

The preceding conclusions present us with a timely opportunity to digress from our emphasis on unit-recording studies, to consider the more general issue of how and when neuronal activity in REMS may influence waking behavior. The question investigated in these experiments (Siegel, 1973, 1975) was whether the amount of REM sleep that a cat had was related to the amount of food it consumed. EMG and EEG measures were recorded continuously while cats were fed *ad libitum* for periods of from five to nine days. The animals were maintained on a 12-hour light-dark cycle. They were individually caged, room temperature was kept constant and the cages were thoroughly cleaned and checked for food spillage every 10 hours. Amounts of REM sleep, SWS, waking and food intake were calculated separately for the lights-on "day" period and the lights-off "night" period.

It was found that the amount of REM sleep in a 12-hour period was significantly correlated with food intake in the *subsequent* 12-hour period (see Table 3). An example of one such relationship can be seen in Figure 5. REM sleep was never significantly correlated with food intake in the previous 12-hour period. Furthermore, no clear relationship could be seen between REM sleep and food intake which occurred within the same 12-hour period. A consistent pattern of correlations was seen in all of the cats. Either day REM or night REM, but never both, showed significant correlations with the food intake in the subsequent 12-hour interval. All but one of the significant REM sleep-subsequent food intake correlations were negative. Therefore, increased amounts of REM sleep were associated with decreased amounts of food intake in the subsequent 12-hour period.

The interval used for prediction did not overlap the subsequent predicted interval. Therefore, the observed correlations could not merely be the result of REM sleep time displacing waking time during which eating might have occurred. All of the significant correlations between REM sleep and subsequent food intake were larger in magnitude than the corresponding correlations between W, SWS, or food intake, and subsequent food intake. Similarly, all of the correlations between REM sleep and subsequent food intake were larger than the correlations between waking or SWS, and food intake when all were within the same interval. Therefore, these data show that REM sleep time is a better predictor of subsequent food intake than either previous food intake, waking or SWS, or concurrent waking or SWS.

This strong and specific relationship between REM sleep and subsequent food intake has several implications for studies relating REM sleep to behavior. These include the following: (1) REM sleep may relate more strongly to subsequent behavior than it does to previous behavior; (2) the relevant period of analysis may be the 24 hour circadian cycle and not the 30 minute REM-waking cycle; (3) REM sleep may have a relatively specific relationship to subsequent food consumption apart from any role in consolidation or other "higher" *functions.*

Commentary

The conclusions reached in this study are consistent with a variety of other experimental findings. REM deprivation has been shown to alter thresholds and rates of subsequent brain self-stimulation and food consumption (Steiner & Ellman, 1972; Dement, 1969). These results can be interpreted, in the light

TABLE 3

PERSON PRODUCT-MOMENT CORRELATIONS BETWEEN FOOD INTAKE IN ONE PERIOD AND REM, SWS, W, AND FOOD INTAKE IN THE PRECEDING OR SAME 12-HOUR PERIOD

	DAY FOOD INTAKES, PRECEDING NIGHT				NIGHT FOOD INTAKE, PRECEDING DAY				NIGHT FOOD INTAKE, CONCURRENT SLEEP			DAY FOOD INTAKE, CONCURRENT SLEEP			
SLEEP MEASURES									MEASURES						
CAT	REM	W	SWS	FOOD	REM	W	SWS	FOOD	REM	W	SWS	REM	W	SWS	N
23	−.95[b]	+.84[a]	+ . 73	+ .72	+ .09	−.21	+ .40	+ .27	−.49	+ .33	+ .56	+ .72	−.82[a]	+ .75	7
24	−.34	+.44	−.11	−.03	−.90[b]	+ .40	+ .31	−.28	+ .48	−.72	+ .13	+ .45	+ .11	−.49	a
25(1)	−.98	−.09	+ .38	−.65	−.19	+ .36	−.38	−.67	+ .64	+ .81	−.95[a]	+ .64	−.26	−.06	5
28(1)	−.84[a]	+.73	−.51	−.54	−.38	−.03	+ .11	+ .68	+ .28	−.14	+ .04	−.52	+ .04	+ .04	7
25(2)	−.04	−.14	+ .23	+ .27	+ .80[s]	−.43	−.17	−.40	−,87[b]	+ .63	−.51	−.35	−.06	+ .24	7
28(2)	−.74[a]	+.22	+ .16	−.30	−.24	+ .23	−.13	−.20	−.25	−.37	+ .50	+ .65	−.08	−.15	8

P < .05, two-tailed probablility value P

< .01, two-tailed probability value

REM sleep, SWS and W are computed as a percentage of the 12-hour recording time. N is the number of observations.

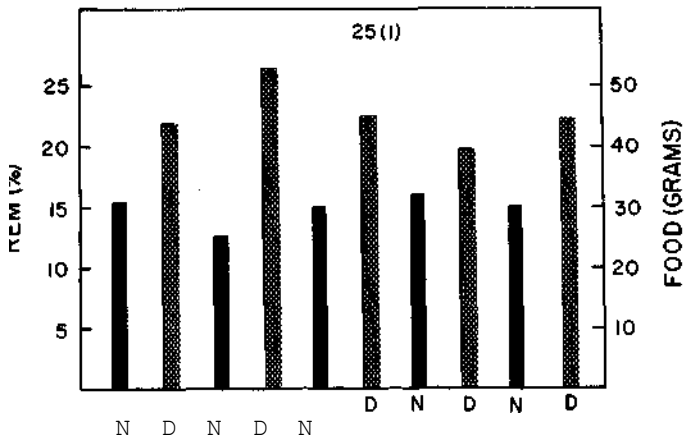

Fig. 5. Data for cat 25. Note that increased amounts of REM sleep (solid bars) are followed by decreased amount of food intake (cross-hatched bars) on the subsequent day.

of our present findings, as evidence for an alteration in motivational levels resulting from the disruption of REM sleep's regulatory influence. The unit recordings by Jacobs et al. (1970), mentioned in the previous section, provide evidence that hypothalamic neurons express their response to food deprivation most strongly during REM sleep.

The importance of circadian influences in the regulation of REM sleep has been seen in a number of recent studies. Time of day, not the amount of prior sleep, has been shown to be the most important determinant of REM sleep occurrence (Taub & Berger, 1973; Sterman, Knauss, Lehman, & Clemente, 1965; Sterman, Lucan, & MacDonald, 1972). Food intake is similarly subject to strong circadian regulation (LeMagnen & Devos, 1970). These results, in conjunction with the present findings, suggest a relationship between the amplitudes of the circadian cycles regulating REM sleep and those regulating food intake, and perhaps other motivated behavior.

The existence of a relationship between REM sleep and subsequent food intake creates problems of interpretation for studies relating REM sleep to learning, and using food as a reinforcement. Many such studies can be interpreted as reflecting postingestional consequences of food intake on REM sleep. Other studies showing changes in REM sleep preceding a change in performance (e.g., Smith, Kitahama, Valatx, & Jouvet, 1974) may, in fact, be reflecting an alteration in motivation rather than retention. A better understanding of the relationship of REM sleep to food intake and food

dependent motivation would be necessary to properly interpret these studies.

Serotonin--Containing Neurons

Neuron classes which are thought to be involved in the active control of sleep have special significance for the problem of information processing during sleep. In particular, we have shown that a group of serotonin-containing neurons exhibits a unique suppression of discharge during REM. Since serotonin may play a role in regulation of biochemical processes related to information processing as well as in sleep (Jouvet, 1967), the unique interruption of release of serotonin during REM is potentially significant. These results are described below.

The recording of raphe unit discharge rate would seem to provide the best method for obtaining a detailed description of the time course of 5HT turnover in relation to behavioral events (see McGinty, Harper, & Fairbanks, 1974, for a review of this approach). Excitation of raphe neurons increases the release and metabolism of 5HT; thus, release of 5HT, like acetylcholine, appears to be initiated by the invasion of the nerve terminal by an action potential. Brief and subtle changes in 5HT release can be estimated from unit recordings. Contemporary biochemical and histochemical methods are limited to estimates of relatively long-term changes and are often incompatible with the study of normal sleep states. Further discussion of the properties of serotonin-containing neurons is found in this volume.

We have studied the discharge patterns of 38 dorsal raphe neurons of the type thought to contain 5HT (McGinty S Harper, 1976). These neurons exhibit a slow regular discharge rate in waking (0.5-5 spike/second), similar to that observed in the anesthetized rat (Aghajanian, Foote, S Sheard, 1968, 1970; Mosko & Jacobs, 1974). Bursts of unit spikes, typical of the pontine neurons described above, are never observed in raphe units. Changes in discharge rate during SWS and REMS are remarkably consistent within this cell population. The mean discharge rate is reduced about 50% in SWS when compared with waking. This change was statistically significant even in most individual neurons, as well as in the group mean.

The most interesting effect was associated with REM sleep. Raphe neurons exhibited a striking suppression of discharge during REM when compared with SWS or waking. The mean rate was reduced 92% compared with W. This change was significant in most individual neurons as well as the groups. Figure 6

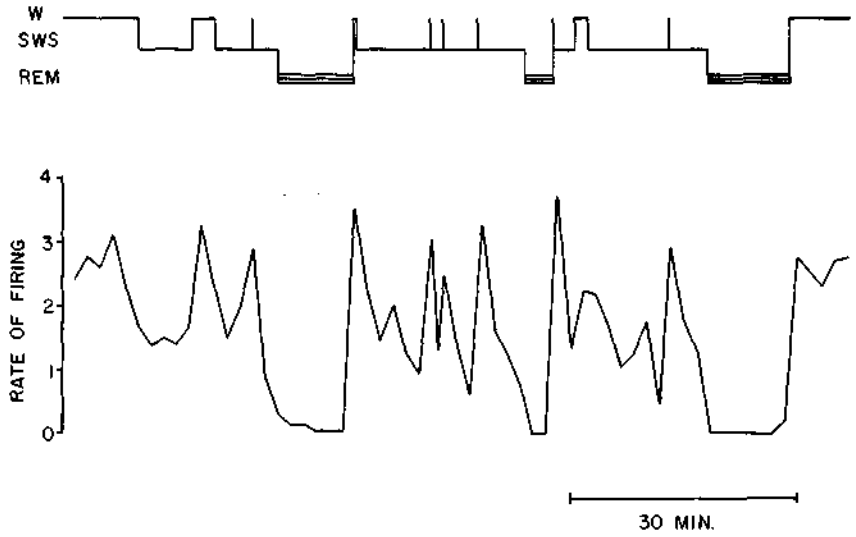

Fig. 6. Firing rate of an Individual dorsal raphe neuron during an extended waking-sleep-waking cycle including three REMS episodes. Note that unit discharge was highest during waking, gradually declined during sustained periods of SWS and virtually ceased during each REMS episode.

depicts these rate changes in a typical cell, and illustrates the stability of this phenomenon during successive SWS-REM cycles.

Commentary

The depression, during REMS, of raphe unit discharge and, by implication, the release of 5HT may have special significance for theories of memory processing during REMS which include a role for protein synthesis. Essman has reported a series of findings (1) correlating retrograde amnesia phenomena, especially that induced by electroconvulsive shock (ECS), with diminished turnover of 5HT (Essman, 1974), and (2) showing that resulting high levels of 5HT are related to inhibition of protein synthesis *in vivo* and *in vitro* (Essman, 1974). Many amnesic treatments, including either anesthesia, hypothermia, hypoxia, as well as ECS, have in common a suppression of 5HT turnover (Essman, 1971). Further, ECS-induced amnesia is attenuated by treatments and methods that prevent elevation of 5HT levels that result from diminished turnover (Essman, 1968).

These findings may explain some memory changes associated with sleep. The poor memory for events occurring during short arousal from sleep, for dream content, and for material learned immediately after arousal from sleep (see the discussion by Ekstrand, this volume) may be explained by a diminished protein synthesis secondary to reduced turnover of 5HT.

In addition, diminished protein synthesis and consolidation of recent memories may be factors that will ultimately contribute to our comprehension of the functions of REMS. Perhaps the *absence* of recent memory consolidation makes possible certain types of information processing operations such as the disposal of useless information.

DISCUSSION

Sleep investigators from Aristotle to Freud, to present-day unit researchers have been attempting to explain the relationship between mental activity in sleep and waking behavior. In this quest, unit researchers have certain advantages. The foremost of these is that we are able to objectively measure brain activity during sleep and quantitatively relate it to waking activity. We do not have to rely on the subject's recollections of his dream experiences and their transformation into verbal messages during a subsequent W interval. In addition, we can, in principle, assess various elements of the cognitive and motor process, distinguishing excitatory vs. inhibitory processes, aspects of motivation, temporal order effects, and so on. We can also model the influences of drugs, neurological disturbances, and other manipulations that are not readily applied to humans. Unfortunately, the great advantage of being able to observe directly the functional "atom" of the brain is accompanied by the great disadvantage of being as yet unable to fully understand the role of these "atoms" in the complex brain "chemistry" underlying behavior. However, with the proper caution, we feel that it is possible to extract important information by careful observation of both sleep and waking unit activity.

The intriguing possibility of relating unit recording data to psychological concepts of cognitive function in sleep, such as rehearsal, hypothesis testing, integration of experience, or homeostatic adjustment, requires further comment. A primary problem is that neuronal systems are not necessarily "coded" or organized along the dimensions of psychological concepts. At best, neuronal behavior can be correlated with behavioral descriptions, as with the accuracy of a choice in a discrimination learning trial, or with the rate or intensity of a behavior. Psychological concepts such as rehearsal and

consolidation which have been related to REMS must be defined in unambiguous behavioral terms. It is possible that neuro-physiological studies cannot be used at this level of analyses, that the functions of sleep can only be expressed in the complex interrelationships of groups of millions of neurons. Another possibility is that neuronal activity in sleep is exclusively reflecting intraneuronal processes during sleep, such as membrane repair, RNA and protein synthesis and energy transport. If this is the case, intracellular recording and neurochemical studies would be necessary to understand these processes. However, the parsimony of nature, and the similarity of sleep and waking activity in identifiable groups of cells, encourages us to hope that there are meaningful questions that can be asked of single neurons recorded extra-cellularly.

We have not succeeded in relating specific aspects of REMS "behavior" to specific samples of waking behavior. That is, we cannot yet recognize the specific type of motor behavior occurring in REMS. Our preliminary data show that REM behavior does *not* consist of simple rhythmic activities such as eating or grooming. Compared with our waking samples, REMS behavior is more variable. These observations are in agreement with analyses of dream content which usually reveal a mixture of ordinary events and unlikely times, settings, or stimuli. In current studies we are conditioning specific head movements during waking, using hypothalamic stimulation as a reward. We hope that this approach will yield patterned motor behavior which will be reflected in the REM episode. Specific patterned motor behavior will be recognized by analysis of burst structures or time series analyses. We could then assess variables which modulate the probability that a particular behavior will be manifested in REMS, and the nature of modification of patterned motor behavior in REMS. This approach should be of value in interpreting the post-learning enhancement of REM as described by Bloch and his colleagues (see Bloch, this volume).

A finding that patterned motor behavior, conditioned during waking, is manifested in REM would have another benefit. It would strengthen the interpretation that the motor activity represented in FTG neurons does, indeed, reflect centrally commanded or programmed motor outflow. Our current results could be interpreted as resulting from local reflex interaction, rather than centrally coordinated activity. It is conceivable that neurons at each level of the neuroaxis are uncoupled in REM, and operate independently. Similarly, our finding that hypothalamic and midbrain neurons are sensitive to effects of food deprivation is suggestive of interneuronal

coordination, but it is possible that a variety of individual neurons can be sensitive to blood-borne or other non-specific factors associated with food ingestion. Studies of interaction of remote neural elements will help resolve this issue.

SUMMARY

We have studied and compared the discharge patterns of single brainstem and hypothalamic neurons during wakefulness and REM sleep in the cat, in an effort to assess the functional characteristics of REMS. On the basis of these studies we have reached the following conclusions.

1. In neurons associated with motor behavior, REMS discharge patterns closely resemble those in waking, indicating an expression during REMS of normal movement patterns.

2. Neurons exhibit changed discharge rate in response to food deprivation during REMS as they do in waking, indicating a potential influence of motivational mechanisms in REMS.

3. The release of serotonin in the forebrain projection fields of dorsal raphe neurons is greatly decreased during REMS. Decreased release of 5HT has been implicated as a mechanism resulting in failure of immediate memory consolidation and may account for amnesia for dreams.

In addition, we have presented results of a study correlating the amount of REMS in a 12-hour period with food intake in the preceding, same, or subsequent 12-hour period. It was found that the amount of REMS was most highly correlated with subsequent food intake, and that this correlation was not secondary to changes in waking or SWS. This result suggests that REMS may have a stronger relationship to subsequent behavior than it does to previous behavior.

ACKNOWLEDGMENTS

This research was supported by the Veterans Administration Research Project 5590-01 and National Institute of Mental Health Grant #10083. The assistance of Mary Fairbanks and Sandy Sarnoff is gratefully acknowledged.

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