Pharmacology Biochemistry & Behavior, Vol. 8, pp. 89–91. Printed in the U.S.A.

BRIEF COMMUNICATION

Cortical EEG Power Spectra Associated with Sleep-Awake Behavior in the Rat[1]

GERALD A. YOUNG,[2] GEORGE F. STEINFELS AND NAIM KHAZAN

Department of Pharmacology and Toxicology, School of Pharmacy

AND EDMUND M. GLASER

Department of Physiology, School of Medicine, University of Maryland, Baltimore, MD 21201

(Received 14 October 1977)

YOUNG, G. A., G. F. STEINFELS, N. KHAZAN AND E. M. GLASER. *Cortical EEG power spectra associated with sleep-awake behavior in the rat.* PHARMAC. BIOCHEM. BEHAV. 8(1) 89–91, 1978. – Power spectral analyses were used to study cortical EEG activities during sleep-awake behavior in the rat. EEG spectra, both long-time and sequential short-time, derived from EEG during the states of wakefulness, sleep, and REM sleep were qualitatively and quantitatively different. The degree of inter- and intrasubject variability between these spectra was minimal. This experimental model with the rat should allow quantitative delineation of cortical EEG changes produced by psychotropic drugs.

EEG   Power spectra   Sleep-awake behavior

WE have reported on the electroencephalographic (EEG) and behavioral effects of narcotic agonists and antagonists [1, 2, 3, 5, 7, and 8]. The behavioral states of sleep, rapid eye movement (REM) sleep and wakefulness during normal sleep-awake behavior and drug-modified EEG and behavior were identified by the corresponding changes in EEG and electromyographic (EMG) recordings of the rat [4]. In an effort to further quantitate these EEG correlates associated with sleep-awake behavior, we have used spectral analysis techniques. The present study reports the results.

PROCEDURES

Five adult female Sprague-Dawley rats, 250–300 g, were used. For bipolar EEG recordings, stainless steel screws (size 0-80 × 1/8 inch) were implanted over the frontal cortex (2 mm anterior and 2 mm lateral to bregma) and the ipsilateral parietal cortex (3 mm posterior and 2 mm lateral to bregma). An additional screw was placed 6 mm posterior and 2 mm lateral to bregma and served as the indifferent electrode. For EMG recordings, pairs of stainless steel wires were inserted into the temporalis muscles. All electrodes were soldered to a miniature Continental connector which was attached to the skull with Eastman 9–10 glue and dental acrylate [2].

Each rat was maintained in an individual cage that was equipped with a swivel cable connector for EEG and EMG recordings. EEG and EMG were recorded on a Grass Model 7D polygraph. The EEG was filtered to pass frequencies between 1 and 35 Hz, while the integrated EMG was filtered to pass frequencies between 10 and 75 Hz. In addition, six-hour segments of EEG were recorded on FM tape with a Hewlett-Packard Model 3960-A recorder. One channel recorded a time code that was generated with a Datatron Model 3950 Translator/Generator.

Behavioral states of sleep, REM sleep and wakefulness during normal sleep-awake behavior were identified by the corresponding changes in EEG and EMG recordings. Processing of these EEG samples was accomplished as follows. EEG samples of 41 sec in duration representing the three behavioral states were obtained from data stored on FM tape and digitized at a sampling rate of 100/sec with a Digital Electronics Corporation PDP-8/I computer. Fast Fourier Transformations were performed with an IBM 370/145 computer to obtain power spectral densities at frequencies from zero to 30 Hz. These were estimated at 0.1 Hz intervals by means of rectangular smoothing over 41 neighboring frequencies. In addition, power spectral densities of successive 5.12 sec EEG specimens were obtained from the same 41-sec EEG samples. There was a 4-sec overlap in the successive EEG specimens.

[1] Supported by NIDA Grant DA-01050.

[2] Reprint requests to: Gerald A. Young, Department of Pharmacology and Toxicology, University of Maryland School of Pharmacy, 636 West Lombard Street, Baltimore, Maryland 21201.

0091-3057/78/0801-0089$00.60

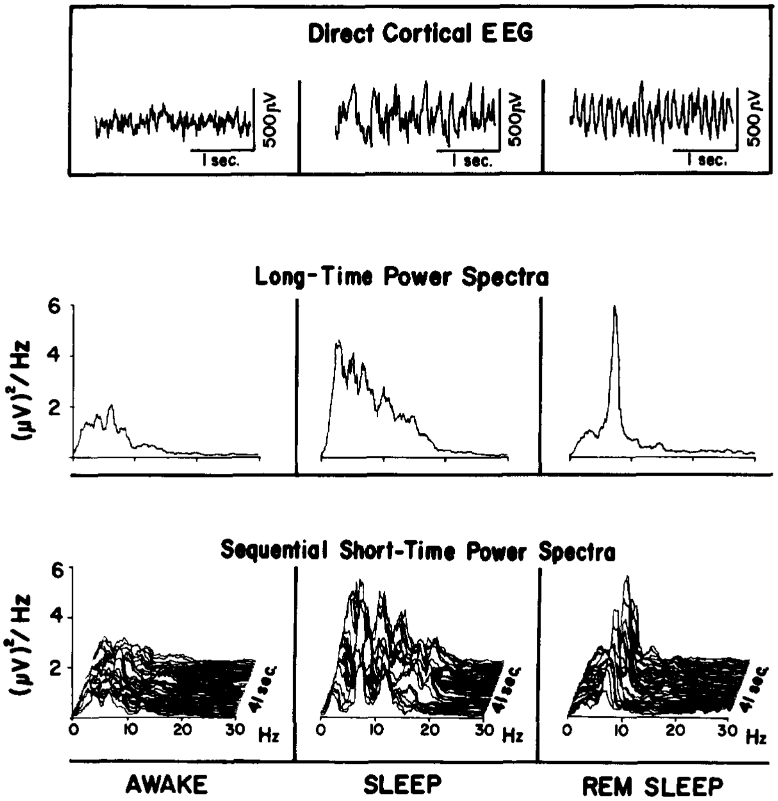

FIG. 1. Direct cortical EEG recordings are shown in the top panel during the awake, sleep, and REM sleep states. Long-time power spectra derived from 41-sec EEG samples during the three behavioral states are shown in the middle panel. Spectral power [$(\mu V)^2$/Hz] is presented as a function of frequency (Hz). Sequential short-time power spectra derived from the same EEG samples are shown in the bottom panel.

RESULTS

EEG and EMG recordings collected during the behavioral states of sleep, REM sleep and wakefulness in the rat are easily distinguishable from one another [1–5, 7, 8]. Cortical EEG tracings during these three states of behavior and their corresponding power spectra are shown in Fig. 1. As seen at the top of this figure, EEG recordings during wakefulness were associated with relatively low-amplitude high-frequency waves. The sleep EEGs consisted mainly of relatively high-amplitude low-frequency waves. REM sleep EEGs exhibited a predominance of 6–9 Hz waves (theta waves). Long-time power spectra derived from the 41-sec EEG samples related to wakefulness, sleep, and REM sleep are also shown in Fig. 1. The awake state was associated with substantially less total spectral power than either sleep or REM sleep. Sleep was associated with a predominance of spectral power in the lower frequency range (zero to 5 Hz) and a gradual diminution of spectral power in the 5–20 Hz range. REM sleep was associated with a predominant peak of spectral power in the 6–9 Hz range. Sequential short-time spectra derived from overlapping specimens of cortical EEG are shown in the bottom of Fig. 1. The awake state was associated with much less total power than that associated with sleep or REM sleep. Sleep was associated with relatively consistent spectral peaks in the zero to 5 Hz range, while spectral peaks in the 5–20 Hz range apparently varied unsystematically in amplitude and location. REM sleep was associated with spectral peaks in the 6–9 Hz range that were confined to a narrow frequency bandwidth, but of flucuating power.

The degree of variability of the power spectra associated with the three behavioral states of the rat is presented in Fig. 2. The top of the figure depicts the degree of variability in power spectra of a single rat. The relative power (% of total power) is shown as a function of frequency at 1 Hz intervals; standard errors of the mean are shown as an indicator of variability between EEG samples. The power spectra at the bottom of the figure indicate the amount of intersubject variability between five rats. Since sleep was associated with the largest amount of total power, the power associated with wakefulness and REM sleep was calculated as being relative to that of sleep, with sleep being 100%.

DISCUSSION

The rat has been used extensively in studies related to experimental psychology and psychopharmacology. Relatively little information is available concerning EEG power spectra during sleep-awake behavior with freely-moving rats prepared with chronic EEG electrodes. This report, therefore, describes the power spectra derived from the rat's cortical EEG during different states of consciousness. In the awake state the EEG spectra consisted mainly of power in the zero to 10 Hz range; there was much less total power than during sleep and REM sleep. In

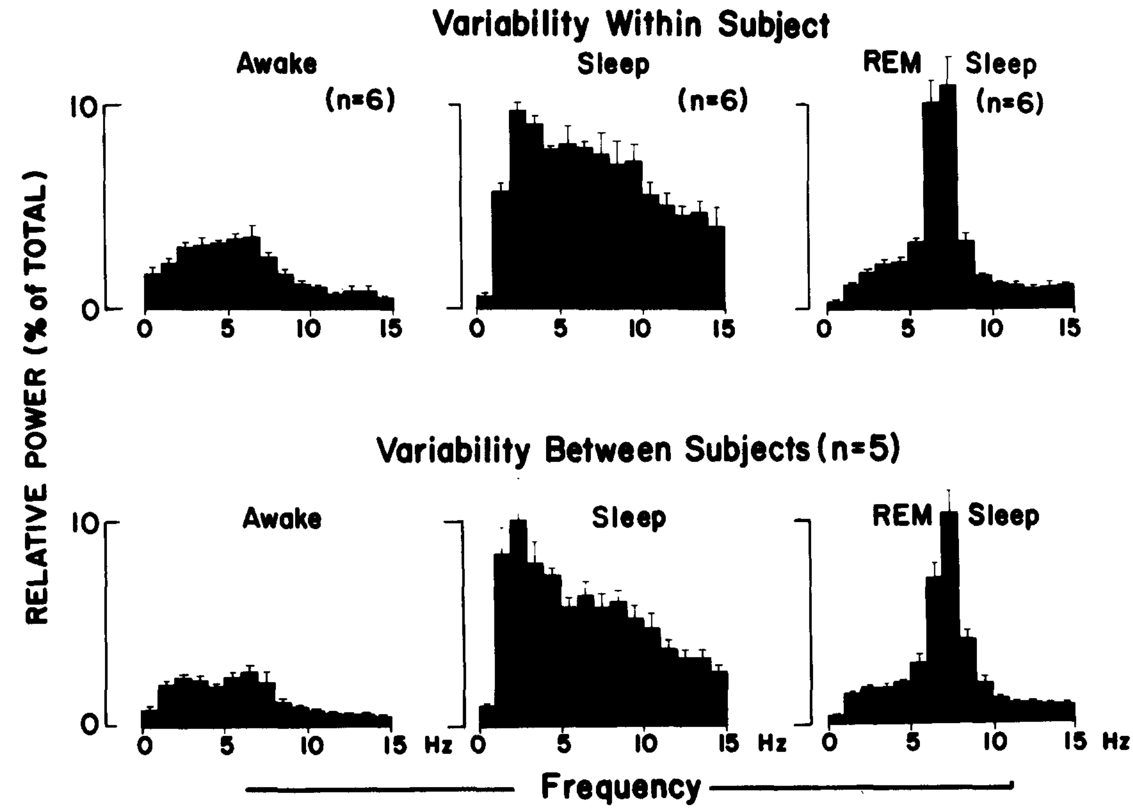

FIG. 2. Power spectra derived from cortical EEG are shown at the top of the figure during the awake, sleep, and REM sleep states. Each spectrum is the average of six, each of which was derived from a 41-sec cortical EEG sample. The relative percent of total spectral power is shown as a function of frequency at 1 Hz intervals. Standard errors of the mean are indicated. Grouped data from five rats is shown at the bottom of the figure. For each rat average power spectra were derived from three 41-sec cortical EEG samples during each of the three behavioral states. These spectra from each of the five rats were then averaged relative to the total power associated with sleep, sleep being 100%. Standard errors of the mean are indicated.

the sleep state there was a predominance of spectral power in the zero to 5 Hz range with a gradual dimunution of power as frequency increased from 5 to 20 Hz. In the REM sleep state there was predominance of power in the 6 to 9 Hz range. Having characterized the EEG power spectra associated with normal sleep-awake behavior in the rat, precise EEG changes which may result from exposure to abnormal behavioral conditions or to effects of psychoactive drugs [6] can be delineated.

REFERENCES

1. Colasanti, B. and N. Khazan. Agonistic properties of narcotic analgesics and antagonists on the electroencephalogram and behavior in the rat and their reversal by naloxone. *Neuropharmacology* 12: 619–627, 1973.
2. Khazan, N. The implication and significance of EEG and sleep-awake activity in the study of experimental drug dependence on morphine. In: *Methods in Narcotics Research (Modern Pharmacology-Toxicology, Vol. 5)*, edited by S. Ehrenpreis and A. Neidle. New York: Marcel Dekker, Inc., 1975, pp. 173–215.
3. Khazan, N. and B. Colasanti. EEG correlates of morphine challenge in post-addict rats. *Psychopharmacologia* 22: 56–63, 1971.
4. Khazan, N., J. R. Weeks and L. A. Schroeder. Electroencephalographic, electromyographic and behavioral correlates during a cycle of self-maintained morphine addiction in the rat. *J. Pharmac. exp. Ther.* 155: 521–531, 1967.
5. Moreton, J. E., T. Roehrs and N. Khazan. Drug self-administration and sleep-awake activity in rats dependent on morphine, methadone or l-alpha-acetylmethadol. *Psychopharmacology* 47: 237–241, 1976.
6. Young, G. A., N. Khazan and E. M. Glaser. Computer analysis of EEG changes associated with morphine self-administration in dependent rats. *Pharmacologist* 19: 140, 1977.
7. Young, G. A., J. E. Moreton and N. Khazan. Duration of action of naloxone subcutaneous pellets in blocking the EEG and behavioral effects of morphine in the rat. *J. Pharm. Pharmac.* 28: 658–660, 1976.
8. Young, G. A., J. E. Moreton and N. Khazan. REM sleep distributions in post-addict rats relapsing to morphine self-administration: Effects of naloxone subcutaneous pellets. *Res. Communs Chem. Pathol. Pharmac.* 11: 355–363, 1975.