Heart rate (HR) fluctuation in the rat as a function of arousal

HEARTRATE FLUCTUATIONS IN THE RAT AS A FUNCTION OF AROUSAL

By

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Heart rate (HR) fluctuations corresponding to each one of the four cortical EEG patterns separated by visual inspection were investigated using seven white rats under the unanesthetized, unrestrained condition. The overall finding obtained for the spontaneous electrocardiographic (ECG) activity was that although HR might vary with the subject, the pattern of ECG activity in subject over the four EEG patterns remained stable: HR was a function of arousal. Further, the transient disturbance and increased variability of HR were seen during the "paradoxical" sleep pattern.

Recently, much attention has been directed to wide variety of changes that occur among the various physiological functions during sleep, particularly to those during the "paradoxical" period of sleep (the rapid eye movement (REM) phase of human sleep). Generally speaking, it has been reported that during this REM sleep phase characterized by a low voltage relatively fast pattern in the EEG and rapid eye movements, marked skeletal musculature relaxation appears, with breathing tending to become irregular and HR showing transient acceleration (Dement & Kleitman, 1957a; Dement & Kleitman, 1957b; Snyder, 1964). However, the implications of these findings are not clear to date.

More recently, Swisher (1962) has pointed out a sleep pattern analogous to the REM sleep phase in the rat. This sleep pattern was characterized by a constant 6–8 cps waves, and the existence of these waves has been accepted among several investigators (Dillon & Webb, 1965; Hall, 1963; Iwahara, et al, 1967).

At the same time, the attempts of classification of the cortical EEG patterns have been made among them and the "paradoxical" sleep has been differentiated from sleep dominated by large, slow EEG potentials (analogous to non-REM sleep). However, for the manifestations of the spontaneous, autonomic activities corresponding to these EEG patterns, it seems that they are not sufficiently investigated.

The purpose of the present study was to investigate how the spontaneous ECG activities varied according to the various EEG patterns in the rat. So, for evaluating the ECG records the patterns were separated into four groups as shown in the results.

METHOD

Subjects: The Ss were seven male white rats, weighing from 210 to 350 gm., about 7 mo. of age.

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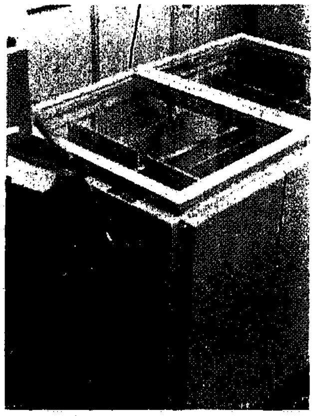

Fig. 1. Shielded box for polygraphic recording.

Apparatus: In order to obtain the polygraph records of animals, a hand-made shielded box (66 × 96 × 70 cm in size) was used (Fig. 1).
The polygraphic recordings were made by means of a Nihon-Kohden ME–92B type electroencephalograph and simultaneously recorded on magnetic tape using a Nihon-Kohden SDR–41 type data recorder. The data of the EEG and ECG were processed by a Nihon-Kohden ATAC–402 type medical data processing computer.

General procedure: Data were collected after the animals had fully recovered from the injury they had received by the operation of electrode implantation (about a week postoperatively).

Polygraph records were made by the unanesthetized, unrestrained animal. After a period of 1-2h during which the animal became accustomed to the box, the data were obtained.

Operative procedure: The electrode implantation was performed under ether or nembutal anesthesia.

Electrodes for EEG recording were small screws implanted in the skull, usually one in the frontal area and one in the occipital area. As reference electrode, another screw was drilled into the nasal bone.

Paired copper wires, kept 5–10 mm apart, were used as the electrodes for electromyographic (EMG) recording and inserted into the nuchal muscles.

Electrode for ECG recording was made of a copper plate (about 3 mm in diam.). It was fixed to the skin of left thorax. The lead wire from it was passed subcutaneously to the back.

Treatment of the data: HR was the value obtained by converting heart beats within a 10-sec period from the EEG pattern concerned, which was occurring with relative stability, into beats/min (B/m) unit. Such ten samples of heart beats per each EEG pattern were selected at random per each animal.

Results

On the basis of the polygraphic data of seven rats were the EEG records of

P-I

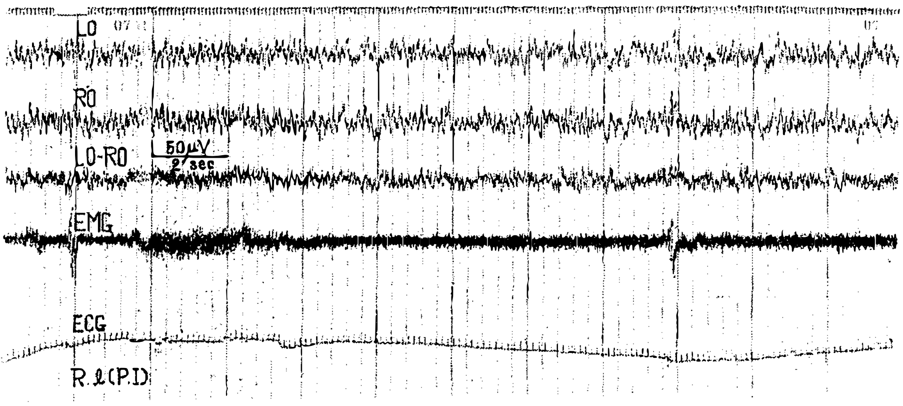

Fig. 2. a

P-II

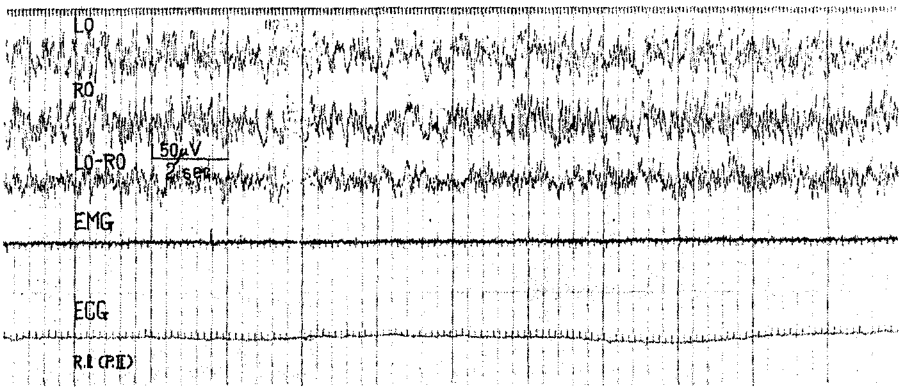

Fig. 2. b

P-III

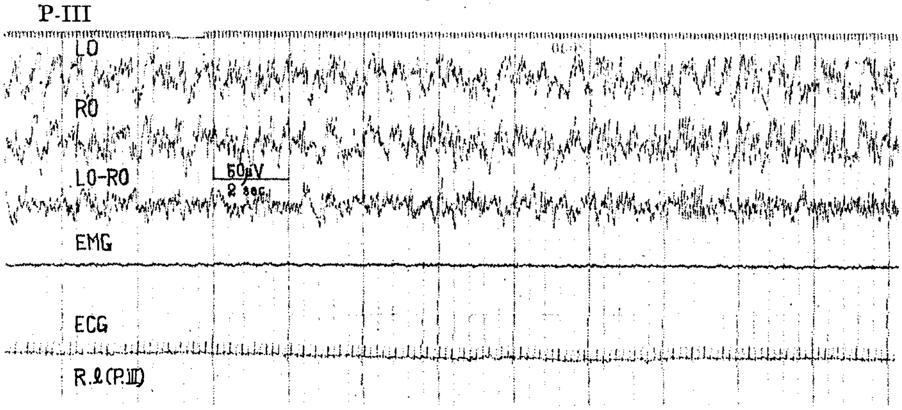

Fig. 2. c

occipital areas classified into four patterns by visual inspection. Then, each EEG pattern of a representative rat was analyzed using the medical computer. Each of these patterns which are shown in Fig. 2 may be roughly described as follows:

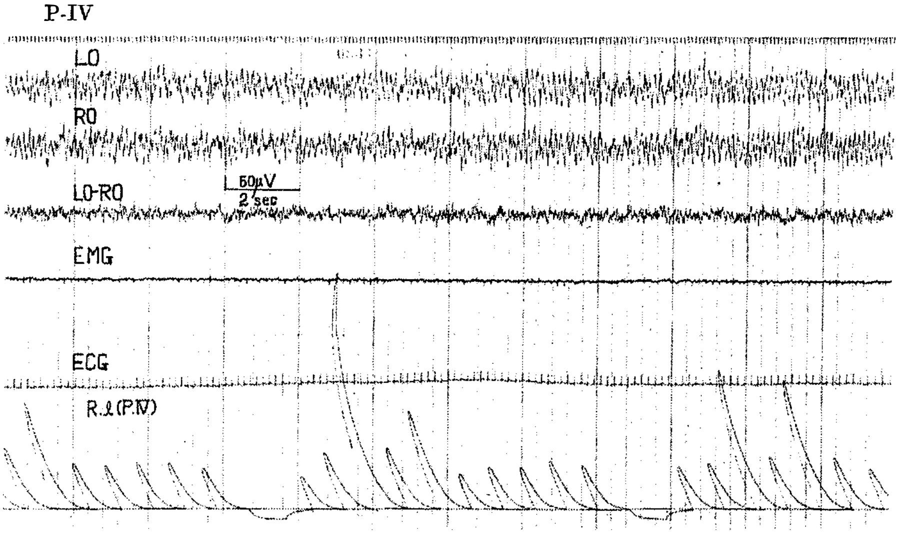

Fig. 2. d

Fig. 2. Polygraph records in a representative rat. Abbreviations: LO; left occipital, RO; right occiptial area. See text for description of four EEG patterns.

Pattern I (P-I) is the relatively regular pattern seen during the waking, resting state, dominated by 6-8 cps (35–40 μ V) waves and approximately 15 cps (35–40 μ V) waves. However, it can be noted that the former waves compose the basic rhythms in this pattern and the latter very often overlapped the former.

Pattern II (P-II) is probably regarded as an EEG pattern corresponding to the drowse phase passing to light sleep phase. This pattern is characterized by the occasional appearance of slow waves and the increase of voltage in each frequency band; that is, high voltage slow waves occur at times, with spindle-like bursts of 9-11 cps (approximately 90 μ V) waves and approximately 16 cps (80 μ V or so) fast waves for the background activity.

Pattern III (P-III) is characterized by high voltage slow waves of 1–4 cps (approximately 90 μ V) with few "alpha" components, regarded as an EEG pattern corresponding to the deep sleep phase.

Pattern IV (P-IV) or the "paradoxical" sleep pattern is dominated by the continuously occurring regular 6–8 cps (35–50 μ V) waves. This pattern looks very much like the P-I, but differs from it in that, compared with the similar waves (6–8 cps waves) in P-I, its voltage in P-IV is slightly higher and P-IV has fewer fast waves than P-I. Besides these two respects, almost complete silence of EMG activity in the neck muscles, transient disturbance of ECG activity, the lowest HR and occasional twitching of the extremities are prominent features seen in this pattern.

In the EEG patterns classified into four large groups as mentioned above, it may be assumed that in terms of levels of wakefulness or alertness a gradual decrease in

Table 1. Mean HRs and variances for each EEG pattern

Pattern / Rat	P-I		P-II		P-III		P-IV	
	Mean	Variance	Mean	Variance	Mean	Variance	Mean	Variance
B5	385.2	876.96	345.6	51.84	336.0	36.00	326.4	57.44
C5	427.2	41.76	415.8	36.36	397.8	216.36	364.2	172.16
a	404.4	831.16	376.8	358.56	365.4	96.84	357.6	44.64
c	408.6	680.04	336.0	21.60	331.8	83.52	315.6	34.56
k	384.0	115.20	365.4	53.64	350.4	80.64	310.2	158.76
l	385.8	93.96	357.6	15.84	357.0	30.60	321.6	73.44
m	352.8	869.76	316.2	65.16	307.2	12.56	294.0	396.0
Total	2748.0	3508.84	2513.4	603.00	2445.6	556.52	2289.6	937.00
Mean	392.57	501.26	3359.05	86.14	349.37	79.50	327.08	133.86
Var.	981.16		961.34		783.95		683.74	

Var. is the variance for each pattern.

arousal level from P-I to P-IV occurs.

Table 1 presents the mean HRs and variances of seven animals for each pattern. Here it can be seen that in all animals the highest HR was in P-I, with its gradual decrease from P-I to P-IV and the lowest HR in P-IV. It seems, however, that there is no large difference in HR between P-II and P-III. Fig. 3 shows the means and standard deviations of HRs for EEG patterns.

For the purpose of further clarifying these data, by confirming that there was a nonsignificant difference among variances of 70 samples of HRs for each pattern (chi-square=2.86, df=3, P>.50) by the Bartlett test, an analysis of variance and the follow-up trend analysis were attempted. Table 2 summarizes the results.

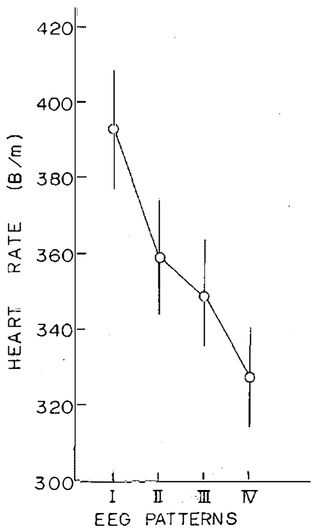

Fig. 3. Mean HRs and standard deviations of HRs for EEG patterns on 7 rats.

Table 2. Analysis of variance of the HR data
(Trend analysis)

Source	S S	df	M S	F
Between Patterns	155583.08	3	51861.03	59.46***
linear	148732.07	1	148732.07	170.53***
quadratic	2206.41	1	2206.41	2.53
cubic	4644.60	1	4644.60	5.33*
Within pattern	240716.04	276	872.16	

***: P<.001, *: P<.05

The F value associated with the pattern differences was highly significant (F=59.46, df=3/276, P<.001). A trend analysis of these data showed a highly significant linear trend (F=170.53, df=1/276, P<.001), as well as a significant cubic component (F=5.33, df=1/276, P<.05). Therefore, it will be seen that the relation of spontaneous ECG activity to the EEG patterns from P-I to P-IV is considered as a function of arousal, but not linear.

Next, as seen in Table 1, it seems that there is a considerable difference between the variance for each pattern and the mean of intra-individual variances. Therefore, the F value among these averages was sought. Then, the F value proved significant (F=4.26, df=69/6, P<.05). This result appears to be closely related to individual differences in HR.

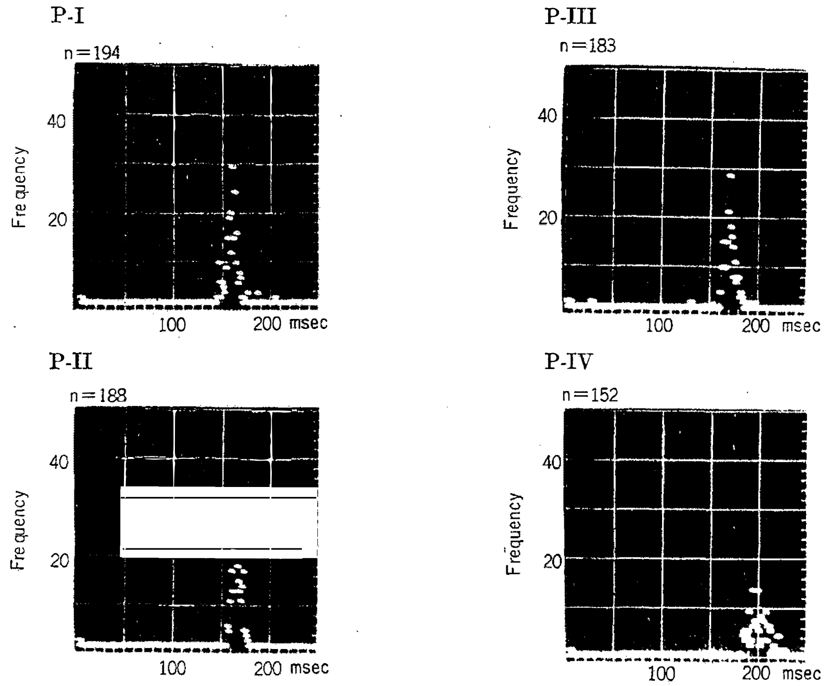

Fig. 4. Time interval histograms (Non-Sequential) between heart beats to each EEG pattern for a representative rat. N is the number of heart beats within a 30-sec period.

Fig. 4 illustrates the time interval histograms (Non-Sequential) of a representative animal showing the time intervals between heart beats, and the numbers of heart beats within a 30-sec period for each EEG pattern. It also shows the progressive prolongation of the time intervals between heart beats from P-I to P-IV, with the gradual decrease of HR. Moreover, it should be noted that the histogram of P-IV has a strinkingly different distribution from the others. This histogram suggests a transient distrubance of ECG activity in the "paradoxical" sleep pattern.

Discussion

The present study indicates that the gradual falling of arousal level as expressed by the EEG patterns from P-I to P-IV was accompanied with the gradual decrease of HR in the rat, particularly with its striking decrease in the "paràdoxical" sleep pattern, at the same time that the transient disturbance characteristic to this pattern was elucidated from the data obtained by the computer. It may be said from the former result that HR is a function of arousal. This functional relation was, however, not linear.

As seen in Fig. 3, the slopes of the decreases of HRs from P-I to P-II and P-III to P-IV are steeper than those from P-II to P-III and the results of a trend analysis of HRs for four EEG patterns does not only show a highly significant linear trend, but also the existence of a significant cubic component. Perhaps, this latter result, indicating that the overall HR trend departs significantly from linearity, is related to the small difference in HRs between P-II and P-III. Further, in general, the neck muscle potentials in P-II were much the same as the magnitude of those found in sleep characterized by large, slow EEG potentials.

From the above-stated findings, it appears that the flucutations of the autonomic and somatic activities in these two patterns may be relatively small. Niimi et al. (1968) also points out that the tendency of the decreases in negativity of basal skin potential in man was strikingly smaller during ordinary sleep in comparison with that during paradoxical sleep.

Concerning the somatic activities during the "paradoxical" sleep in the rat, Swisher has demonstrated the existence of the frequent twitches in vibrissae and extremities, the shifts in muscle tone. But Hall's observations during this period differed from Swisher's in that no changes in the neck muscle potentials could be detected. Hall's result agrees well with our own: during the periods marked by very regular 6–8 cps waves in recordings made from the occipital area, we observed very low neck muscle potentials without prominent changes in the EMG activity.

On the other hand, it has been made clear that the autonomic activities in this phase in man also make the different, peculiar manifestations from those in the others (Snyder, 1964). Among them, basal skin potential and skin potential response (or, reflex) have been in some degree elucidated in man, phenomenally (Broughton, et al, 1965; Johnson & Lubin, 1966; Niimi, et al, 1968). The autonomic activities in this type of sleep in the rat seem, however, to have not sufficiently been investigated.

As stated above, the fact that HR in this pattern shows a strikingly small number of heart beats and an increased variability quite different from those in the others, may reveal, as Levitt (1967) also points out, that this pattern is qualitatively different from the others, in biological function.

References

Broughton, R.J. et al. 1965 The electrodermogram (Tarchanoff effect) during sleep, *Electroenceph. Clin. Nuerophysiol.*, **18**, 691–708.

Dement, W. and Kleitman, N. 1957a Cyclic variations in EEG during sleep and their relation to eye movements, body motility, and dreaming, *Electroenceph. Clin. Neurophysiol.*, **9**, 673–690.

Dement, W. and Kleitman, N. 1957b The relation of eye movements during sleep to dream activity: an objective method for the study of dreaming, *J. exp. Psychol.*, **53**, 339–346.

Dillon, R.F. and Webb, W.B. 1965 Threshold of arousal from "activated" sleep in the rat. *J. comp. physiol. Psychol.*, **59**, 446–447.

Hall, R. 1963 "Activated" sleep in the rat. *Science.*, 139, 800.

Iwahara, S. et al., 1967 EEG patterns during natural sleep in the rat and their multivariate analyses. *Bull. Fac. Educ.*, (Tokyo University of Education)., **13**, 41–57. (in Japanese)

Johnson, L.C. and Lubin, A. 1966 Spontaneous electrodermal activity during waking and sleeping. *Psychophysiol.*, **3**, 8–17.

Levitt, R.A. 1967 Paradoxical sleep: activation by sleep deprivation, *J. comp. physiol. Psychol.*, **63**, 505–509.

Niimi, Y. et al. 1968 Skin potential activities as a function of stages of sleep. *J. Physiol. Soc. Jap.*, **30**, 231 244. (in Japanese)

Snyder, F. et al. 1964 Changes in respiration, heart rate, and systolic blood pressure in human sleep. *J. Appl. Physiol.*, **19**, 417–422.

Swisher, J. 1962 Manifestations of "activated" sleep in the rat. *Science*, 138, 1110.

Zusammenfassung

Die den vier kortikalen EEG Formen entsprechenden Herzfrequenzen wurden mittels der sieben unänesthesierten, ungehalten Ratten untersucht.

Aus den Resultaten folgt, dass ein allmähliche Abstieg des Erregungsniveaus, das in den EEG Formen von P-I zu P-IV (vom Wach-zum Schlafzustand) ausdrückt wurde, mit sich eine allmähliche Abnahme der Herzfrequenz an allen Tieren bringt. Anderseits traten auf Grund der transitorischen Störungen auffallende Unregelmässigkeiten der Herzfrequenz während des "paradoxen" Schlafs auf.

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