STUDY ON THE SLOW RHYTHM FOUND IN THE PULSE AND RESPIRATION INTERVALS OF RABBITS

I. ON THE METHOD OF ANALYSIS AND THE MAINTENANCE OF THE SLOW RHYTHM*

Hideto MATSUMOTO**

Department of Physiology,
Faculty of Veterinary Medicine,
Hokkaido University, Sapporo, Japan

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Considerable fluctuations are found in the continuous records of pulse and respiration intervals, even when animals are placed in a quiet condition. These fluctuations have been reported by many investigatiors, and discussed with respect to their physiological significance. Noteworthy reports concerned with the fluctuations of pulse intervals should be mentioned. At first, FLEISCH and BECKMANN (1936) and CERLETTI (1946) found the relatively regular periodic undulations having periods ranging from 20 to 40 seconds by means of the "Pulszeitschreiber" in rabbits. They called it "Puls-Langwellen". Then, SATO (1951) and KATO (1956) also found similar fluctuations in rabbits and dogs on the cardiotachograms which were devised by MATSUDA (1948); and they called it "Slow Rhythm".

On the other hand, it has been reported that the periodic undulations of the respiratory level, which have been well investigated, were found frequently to be associated with fluctuations of their intervals [6,10].

Recently, further investigations were carried out by means of time series analyzing procedures of these phenomena; these fluctuations of pulse intervals[4,13], respiration intervals[9] and both intervals[12] were analyzed in detail.

While the fluctuations have been attributed to some central nervous mechannism, recently there are interpretations for this phenomenon, based on the view of an effect of the automatic control mechanisms[4,13]. Furthermore, these reports suggested that there was considerable possibility of being able to reveal the mechanisms regulating pulse, respiration and other concerned activities.

Although these reports brought much valuable information in this field, there is still considerable need for research to obtain basic information. So the present

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** Present address: *Department of Chemistry, Third Research Division, National Institute of Animal Health, Kodaira, Kitatama, Tokyo, Japan* author proceeded to examine the analytical procedures, the maintenance of slow rhythms and their characteristics in untreated healthy rabbits.

In this paper, the nomenclature of slow rhythm was used after SATO and KATO who named the quasi-periodic fluctuations of pulse intervals obtained by their experiments. In addition to that, the slow rhythms were considered to induce the fluctuation of respiration intervals which had similar periods to those of pulse intervals, and which were limited to those of periods below 30 seconds.

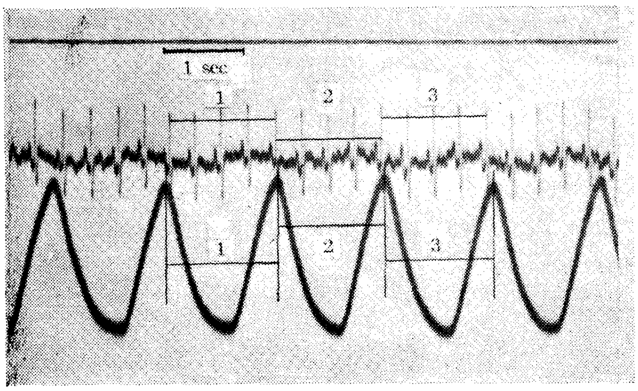
MATERIALS AND METHODS

Untreated healthy rabbits fixed in prone position in a metal cylindrical apparatus were used as experimental animals. From these animals, ECG by means of bipolar lead and pneumograms by means of the Pitot tube were recorded simultaneously on electromagnetic oscillograph papers.

Pulse intervals were obtained using the time of several R–R intervals approximately corresponding to the respiration intervals. Since this measurement was employed, it is natural that respiratory arrhythmia and similar fluctuations having shorter periods than the respiratory arrhythmia, could not be detected.

Respiration intervals were obtained by measuring the time between each summit of inspiratory phases (Fig. 1).

FIG. 1. *Method of Determination of Pulse and Respiration Intervals*



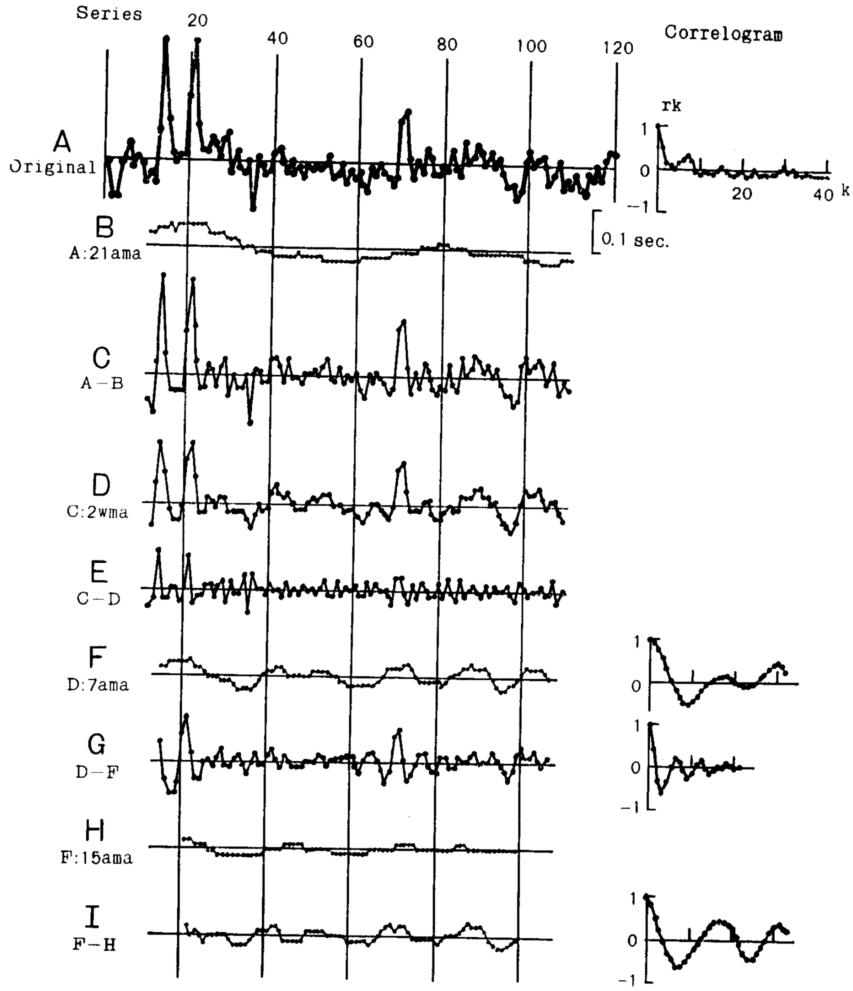
Notes: Upper record is electrocardiogram.
Lower curve is pneumogram (inspiration upward).

The accuracy of each of the determinations of pulse and respiration intervals was 0.05 seconds.

Then the analysis was made on respective time series composed of each 120 of these measured intervals by the following procedure.

(1) After the subtraction of the sample mean from the individual values of respiration intervals and pulse intervals, the arithmetic moving average using 21 terms was carried out on the series (original series, Figs. 2 and 3 (A)) to yield the series (B). Then the series of the remainders (C) was obtained by subtracting series (B) from the original series (A). Thus, from

FIG. 2. *Procedure of Analysis (pulse)*



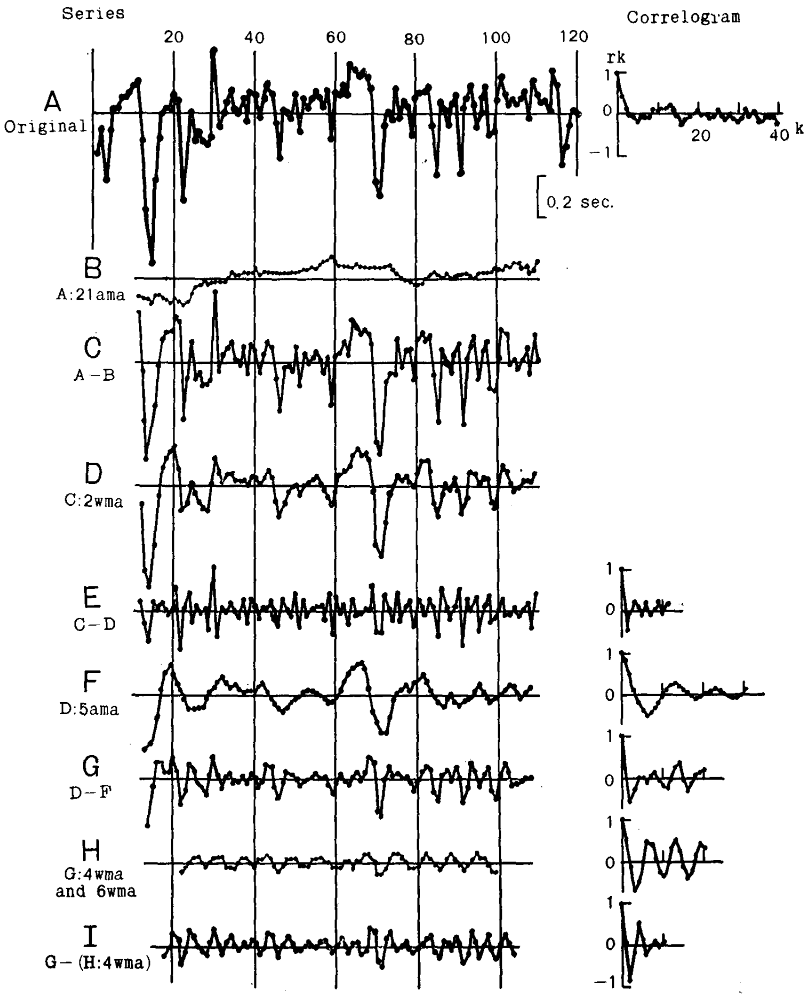
Notes: Average interval of each 4 pulses is 1.33 sec.
ama and wma denote arithmetic and weighed moving average, respectively. See the text of this paper as for r_k and k.

the original series, the components have been removed which have periods longer than 21 terms or about 30 seconds (trend in these series, (B)).

(2) Then 3 terms weighed moving average with weights [1/4, 1/2, 1/4], which was reported by NAKATA (1943), was applied to series (C) to obtain series (D). Then series (E) was obtained by subtracting series (D) from series (C). Thus, series (C) was divided into two series, the one is a series (E) which is composed mainly of components with periods of 2 terms (2 term component) or 3 terms and the other is a series (D) in which the components with periods of 2 or 3 terms are suppressed.

(3) When series (D) still contained more than one dominant component, the series (D) was further decomposed until there was left no significant frequency component, by applying suitable arithmetic or weighed moving averages. The series, F, G, H and I in the figs. 2 and

FIG. 3. *Procedure of Analysis (respiration)*



Notes: Average interval of respirations is 1.33 sec.
ama and wma denote arithmetic and weighed moving average, respectively. See the text of this paper as for r^k and k.

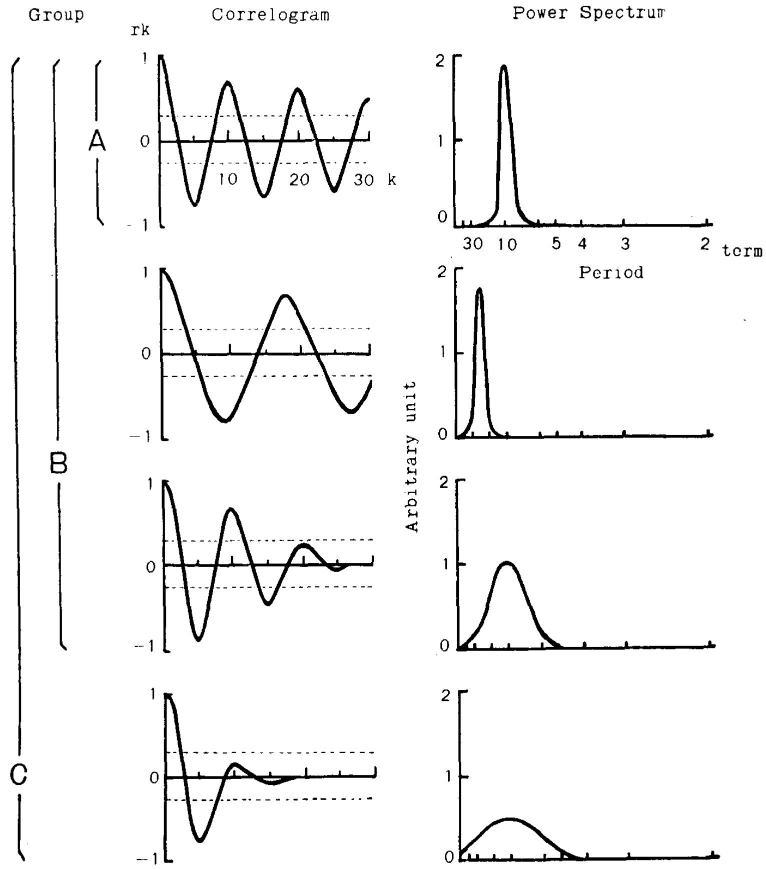
3 were obtained by this procedure. After the decomposition of the series by this analytical procedure, the serial correlation coefficients (r_k) of each series were calculated as follows.

$$r_k=\left(\frac{1}{N-k}\sum_{i=1}^{N-k}x_ix_{i+k}-\bar{x}^2\right)\Big/S^2$$

where $$0\leq k\leq 1/4\,N$$

Thus when the correlograms were recognized to be significant at 1% ratio of risk[8)], the series was judged to be periodical. Then, by taking into consideration the forms of the correlograms (Fig. 4), these periodical series were tentatively classified into 4 groups, A, B, C and D, as follows.

FIG. 4. *Schematic Illustration of Correlogram and Power Spectrum Corresponding to Groups A, B and C*



Note: Dotted lines indicate significant level.

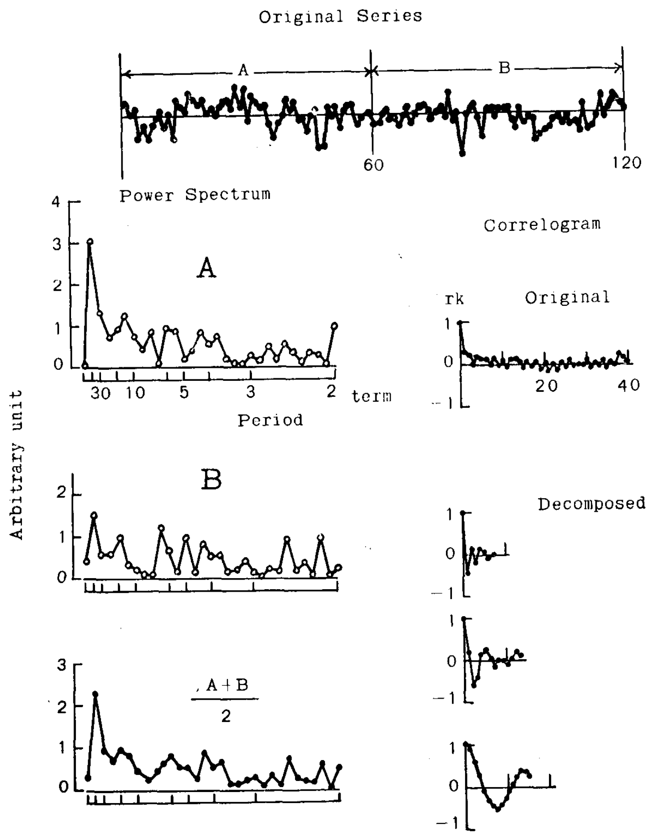
Group A: The set of series of which both the positive and negative tails of their correlograms were significant at least until the first 2 periods. The series belonging to group A was composed of nearly only one signficant frequency component and had full regularity of fluctuation. The power spectrum of each series showed one single very sharp peak.

Group B: The set of series of which both positive and negative tails of their correlograms were significant until the first period. This group B includes group A.

Group C: The set of the series of which at least the first negative tails were significant. All of the periodical series obtained in this experiment belonged to this group.

Group D: The set of series of which the correlograms of the original series showed (1) several peaks almost regularly and continuously or (2) a very high peak within the region of $k<1/4\,N$ on the correlograms of the original series. (This classification of group D was somewhat subjective).

FIG. 5. *Examination of Maintenance of Slow Rhythms found in Respiration Intervals in Prone Position Rabbit*



EXPERIMENTAL RESULTS

(1) Maintenance of Slow Rhythm

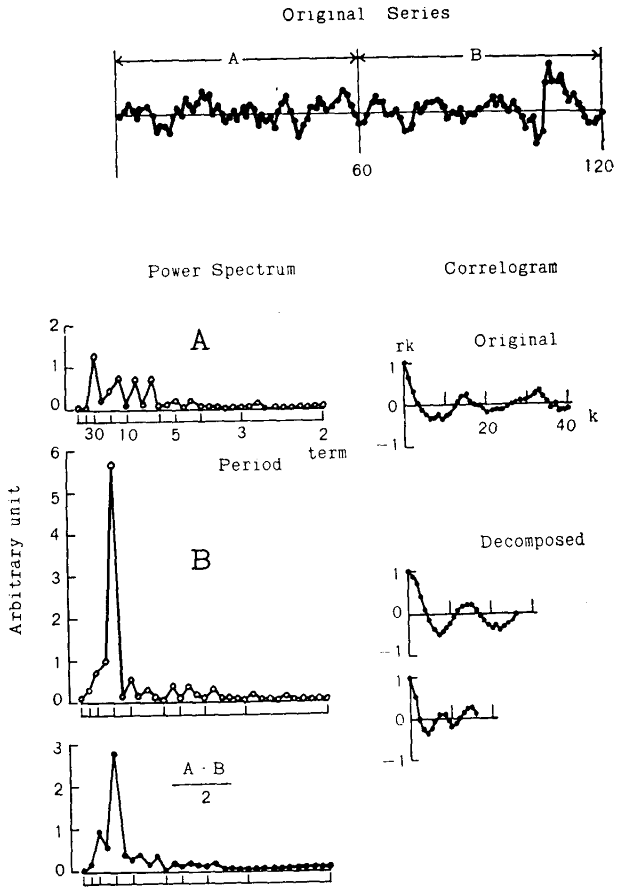
Two methods were applied for examination of the maintenance of slow rhythms.

a) First, the original series was divided into two partial series which had equal length, A and B, and then harmonic analysis was applied to these partial series respectively. Thus, the coefficients of harmonic fluctuations were obtained from (1) partial series A, (2) partial series B and (3) the average value of those of the two partial series.

In figs. 5 and 6, these power spectrums (left half in the figures) and the correlograms of original and decomposed series (right half) are shown. As is shown in these figures, the components which appeared in both partial series A and B, were recognized to form the dominant part of the power spectrums. At the same time, it was also recognized that the dominant periods found from the averaged value of the spectrums were equal to those that appeared in the correlograms of original series. Furthermore, these periods appeared to be in good agreement with those of the component series which were included in groups A and B.

b) Second, an examination was performed to see whether the slow rhythm could continue

FIG. 6. *Examination of Maintenance of Slow Rhythms found in Pulse Intervals in Prone Position Rabbit*



during comparatively long periods of time (30 minutes). The results obtained from the records which between 1 and 2 in the figure had 30 minutes interval under identical experimental conditions, are shown in fig. 7. This figure shows the change of periods which was estimated from the correlograms obtained after the analyzing procedures described above have been carried out. Thus, both of the slow rhythms found in pulse and respiration intervals, at least within 30 minutes, had some fluctuations in their periods but did not change in number of their dominant frequency components.

(2) Number of Components Included in a Series

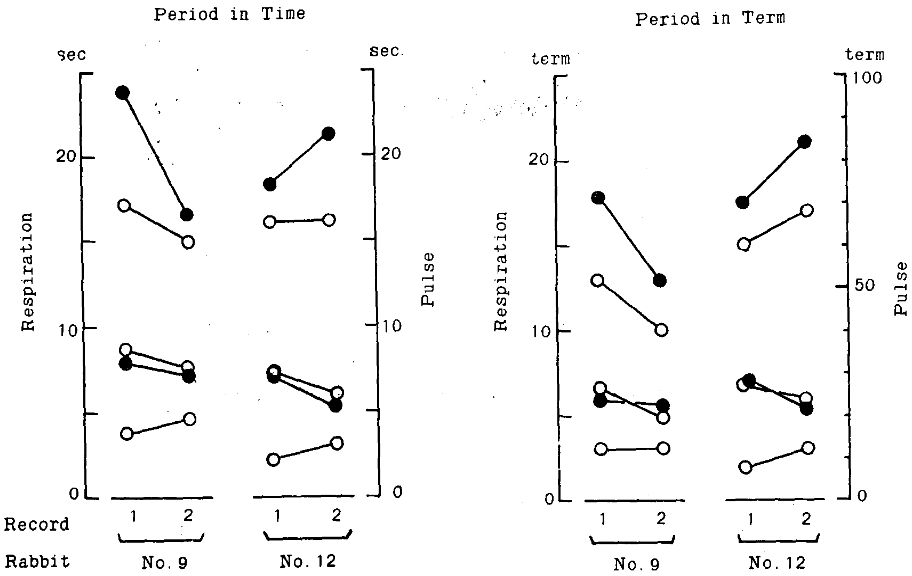
In the series of respiration intervals, significant 2 term components were observed in groups A, B and C with the frequencies, 0, 11 and 54% respectively in the 35 determined cases.

The occurrence of slow rhythms having periods longer than 2 terms is shown in table 1.

(3) Frequency Distribution of the Periods of Slow Rhythms

Frequency distribution of the periods of slow rhythms is shown in fig. 8. As for the periods of respiratory slow rhythms, the following distributions were obtained. In group A,

FIG. 7. *Examination of Maintenance of Slow Rhythms by Means of Continuous Record in Prone Position Rabbits*



Notes: ●: Pulse
○: Respiration

TABLE 1. *Occurrence of Slow Rhythms*

	GROUP			
	A	B	C	D
Respiration	0.2	1.4	2.5	49
Pulse	0.4	1.1	1.9	71

Notes: Groups A, B & C: number of components included in a series (average of 35 cases)
Group D : percentage of occurrence in 35 cases

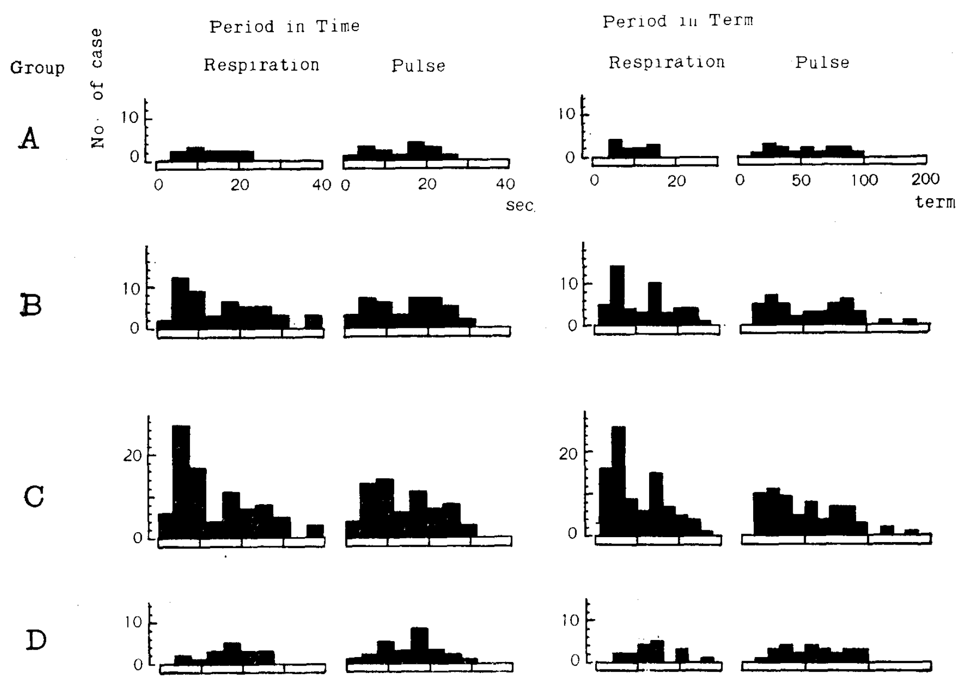
peakless uniform distribution having wide width was observed. In groups B and C, bimodal distribution was observed in which the two peaks were within the ranges of 4 to 8 and 18 to 20 seconds respectively. The peak in the lower ranges was higher than the peak in the higher ranges. In group D, unimodal distribution with a peak between 18 to 20 seconds was observed.

On the pulse slow rhythms, the following distributions were obtained. In groups A, B and C, bimodal distribution with two peaks of almost equal height was observed. In group D, uniform distribution which had wide width was observed.

DISCUSSION

Several studies have been performed to clarify the functional conditions of the central nervous system by means of analysis of the peripheral phenomena of the

FIG. 8. *Frequeucy Distribution of Period of Slow Rhythm*



animal body, applying the time series analyzing method. Such method has also been applied to the pulse and respiration intervals. However, all these reports admittedly describe only small experimental cases, only preliminary ones, so there are many more points required for perfection of the analytical methods and gathering of other basic information. With such considerations in mind the writer made the present approach mainly to obtain basic information and to perfect analytical methods of study of slow rhythms using rabbits under the condition of untreated prone position.

(1) On the Maintenance of Slow Rhythm

It is essential to assure that a slow rhythm continues during the experimental periods under a certain given experimental conditions.

At first, it was recognized that frequency components appeared in both of the two continuous partial series into which halves the original series was divided. This component was the dominant one among the several components of the original series. This fact provides an expectation that the component could also appear in a series having a few times the length of the original series. Furthermore, this dominant component occupied an almost equal period with those which had relatively high regularity among the components which appeared in the divided series and which were detected from the correlogram of the original series. Thus, it is advisable for one to make examinations using the periods detected from the original series in order to ascertain the relations between the periods of slow rhythm and other experimental and environmental conditions.

On the basis of the results, it is reasonable to belive that the frequency components detected from the correlogram of the original series and the components that had full regularity, were the dominant components among the determined time series, and then, these components may continue even in the extrapolated series.

This idea was extended to a period of 30 minutes by another method. By this latter experiment, it was demonstrated that there took place no essential change in each frequency component at least within this period, in spite of there being some changes in the periods of time.

Therefore, the slow rhythm can be used itself for an experiment aimed to follow a time course, since no appearance or disappearance of its periodic component was recognized within 30 minutes.

(2) On the Procedure of Analysis

In this experiment, slow rhythms were classified into 4 groups, A, B, C and D, according to their regularity. As schematically illustrated in fig. 4, a time series composed of the frequency component which formed a sharp peak on its power spectrum, develops with a relatively regular fluctuation.

Groups A and D and a part of Group B correspond to this type of series, and therefore there remains no trouble concerned with analytical procedure for them. But, on the other hand, the series characterized by relatively low regularity which are included in groups B and C, included several components simultaneously which corresponded to the part of the summit of their power spectra. Thus, this means that there exists some possibility that one may select an 'incorrect' (not so dominant in the series) periodic component which does not exactly correspond to the summit point of the power spectrum by repeating moving averages with use of the same terms. Therefore, in order to avoid this uncertainty, the moving average which aimed to extract a periodic component, was used only one time with the term numbers estimated from the correlogram of the original series, for separating each periodic component.

(3) On the Periods of Slow Rhythms

Expecting the following interpretation of the physiological significance of slow rhythms, the present author classified them into 4 groups.

The slow rhythms which have full regularity such as those belonged to groups A and D, might be originated from a mechanism similar to a 'hunting' which is seen in the case of a machine. And then, the slow rhythms might reflect the unstabilized and disturbed condition of the regulating function controlling the pulse and respiration intervals.

On the other hand, the slow rhythms falling into groups B and C, which contain mainly the frequency components of lower regularity, might reflect a better controlled regulating function for pulse and respiration intervals. Thus, the present author could suggest that the slow rhythms might reflect the condition of regulating function of living body and that the periods of the slow rhythms might show the time during which the regulation would be performed.

In the present experiment, the distribution of the periods of slow rhythms belonging to groups B and C were designated bimodal distributions, in both pulse and respiration. This may suggest that the slow rhythms belonging to groups B and C might include slow rhythms which originated from 2 or 3 different mechanisms by which the regulation of the intervals would be performed in the time corresponding to the periods of slow rhythms.

SUMMARY

Periodic fluctuations (slow rhythms) were detected from the time series of respiration and pulse intervals of untreated prone position rabbits, by means of moving average and serial correlation coefficient. The examination on maintenance, occurrence and periods of slow rhythms were described.

1. No changes of slow rhythms of respiration and pulse intervals were recognized in respect to number of components within 30 minutes; therefore, one can plan to perform an experiment under control at least within this length of time.

2. The slow rhythms, which were detected directly from the correlograms of the original series, were of highly regular and were the most dominant component among the frequency components composed of the original series.

3. Frequency distribution figures were drawn with the periods of slow rhythms found in respiration and pulse intervals. The figure showed a distribution which is unimodal in the group having comparatively higher regularity and is bimodal in the groups including almost all of the slow rhythms.

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REFERENCES

1) CERLETTI, A. (1946): *Helv. physiol. Acta*, **4**, 589
2) FLEISCH, A.& R. BECKMANN (1936): *Z. ges. exp. Med.*, **80**, 487
3) KATO, M. (1956): *J. physiol. Soc. Japan*, **18**, 867 (in Japanese with English Summary)
4) KUSACHI, R. (1954): *Jap. J. vet. Res.*, **2**, 169
5) MATSUDA, K. (1948): *Tohoku J. exp. Med.*, **49**, 246
6) MIYAKAWA, K. (1955): *J. physiol. Soc. Japan.*, **17**, 383 (in Japanese with English Summary)
7) NAKATA, Y. (1943): *J. met. Soc. Japan*, **21**, 1 (in Japanese)
8) OGAWARA, M. (1956): *Applied Statistics*, Tokyo, Kanehara Publications (in Japanese)
9) OKABE, T. & H. SAWAZAKI (1953): *J. Jap. vet. Sci.*, **15**, 327 (in Japanese with English Summary)
10) SAGAWA, K. (1955): *J. physiol. Soc. Japan*, **17**, 402 (in Japanese with English Summary)
11) SATO, H. (1951): *Tohoku J. exp. Mea.*, **53**, 325
12) TOHI, I. (1951): *Med. & Biol.*, **20**. 67 (in Japanese)
13) TOMINAGA, S. (1956): *Jap. J. vet. Sci.*, **8**, 37 (in Japanese with English Summary)