STATISTICAL STUDY ON THE FLUCTUATION OF R-R INTERVALS IN ELECTROCARDIOGRAM

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When R-R intervals of electrocardiogram are measured, considerable fluctuations are found in them. So the writer undertook to study the fluctuation with the method relying on autocorrelation coefficient which IMAHORI and SUHARA (1947, 1949) applied to analyze brain wave. The terms of R-R intervals which are measured sequently are interdependent respectively. Therefore it is presumed that the series is a Markoff sequence. The Markoff sequence is prescribed by the transition probability. In physics, to investigate phenomena of intermittence and of diffusion, the transition probability or the statistics derived from it has been applied. In the present report, however, on the assumption that the series of R-R interval is a stationary time series, the method depending on autocorrelation coefficient was used. Significant results were obtained.

After having carried out this experiment, the writer found that DOHI had made a research on the period of heart beat with the very same method and indicated that the large periodic time coincided with half of the large period in respiration. In this paper, however, the cause of the large period of heart beat was investigated under several conditions.

MATERIAL AND METHOD

When stationary time series is $x_1, x_2, \cdots, x_N$, serial mean $\bar{x}$, serial variance s^2 and serial correlation coefficient γ_k are defined by the following equation.

$$\bar{x} = \frac{1}{N} \sum_{i=1}^{N} x_i \qquad (1)$$

$$s^2 = \frac{1}{N} \sum_{i=1}^{N} (x_i - \bar{x})^2 = \frac{1}{N} \sum_{i=1}^{N} x_i^2 - \bar{x}^2 \qquad (2)$$

$$r_k = \frac{1}{N-k}\sum_{i=1}^{N-k}(x_i-\bar{x}_1)(x_{i+k}-\bar{x}_2)/s_1 s_2$$
$$= \left(\frac{1}{N-k}\sum_{i=1}^{N-k}x_i x_{i+k}-\bar{x}_1\bar{x}_2\right)/s_1 s_2, \quad (3)$$

where

$$\bar{x}_1 = \sum_{i=1}^{N-k} x_i/(N-k), \qquad \bar{x}_2 = \sum_{i=k+1}^{N} x_i/(N-k),$$
$$s_1^2 = \sum_{i=1}^{N-k}(x_i-\bar{x}_1)^2/(N-k), \qquad s_2^2 = \sum_{i=k+1}^{N}(x_i-\bar{x}_2)^2/(N-k).$$

If N is enough larger than k, then formula (3) may further show that

$$r_k = \left(\frac{1}{N-k}\sum_{i=1}^{N-k}x_i x_{i+k}-\bar{x}^2\right)/s^2. \quad (4)$$

The electrocardiograms were examined with limb lead under several conditions and the 30∼80 R-R intervals were measured sequently. In this paper the serial correlation coefficient was calculated by formula (4) where k was half of N. Five normal healthy human adults, a rabbit and a dog were examined. In adults, the time beyond 1/20 second was accurately measured but the time below 1/20 second was estimated. In rabbit and dog, the time beyond 1/100 second was exactly measured but the time below 1/100 second was approximate.

The electrocardiograms were examined under the following conditions. 1) Adult: The electrocardiograms were examined while breathing and with suspended respiration. 2) Rabbit: Being fixed in a supine position without any treatment, a healthy female rabbit weighing 2 kg was examined. 3) Dog: A healthy male dog weighing 10 kg was anesthetized by intravenous application of 10 ml of one per cent molchium hydrochloride solution and fixed in a supine position. After the electrocardiogram was taken in this state and the vagi of both sides were cut at neck, the electrocardiogram was again examined 10 minutes after the treatment was done and respiration became stationary.

EXPERIMENTAL RESULTS

1. Adults

The distributions of R-R intervals follow normal types (Fig. 1). When respiration is suspended, they frequently indicate transition to the long time and distortion in the short time. The correlograms are shown in figs. 2∼7. Fig. 2 A indicates a remarkable respiratory uniform periodic undulation which shows the period of 5 terms. It is, moreover, evident that the period of 16 terms consists in the series of R-R intervals, when 16th term and the 32nd term are noticed. As the serial mean is 0.92 second, it may be denoted by the periodic time of 4.60 seconds and of 14.72 seconds. The 4.60 second time accords with the period of respiration, but it is an interesting problem what causes the period of 14.72 seconds. Fig. 2B shows the correlogram of the same case with suspended respiration. In this case, the undulation caused by respiration vanishes completely, but the long period of 9.57 seconds remains. The same phenomena are shown in figs. 3 and 4. But the fluctuation which derives from respiration is not conspicuous in comparison with that of fig. 2A. As an example, the respiratory undulation shows beat (Fig 3A). In fig. 5A both the respiratory fluctuation and the large period of 9.57 seconds are recognized ; then in order to diminish the respiratory fluctuation, the series being treated by the arithmetic moving average of 3 terms, the large periodic time

FIG. 1. *Distribution of R-R Intervals in Adults*

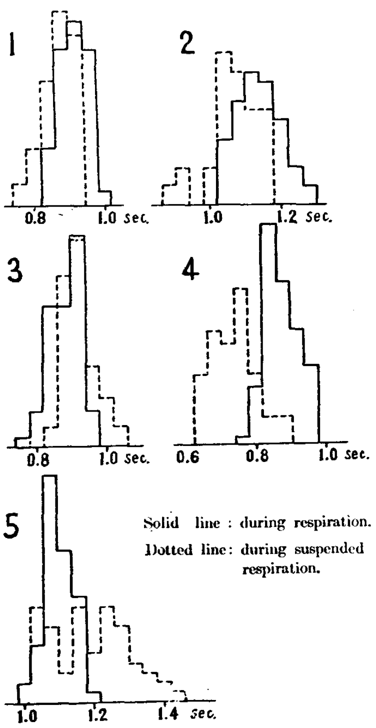


FIG. 2. *Correlogram of R-R Intervals (Adult 1)*

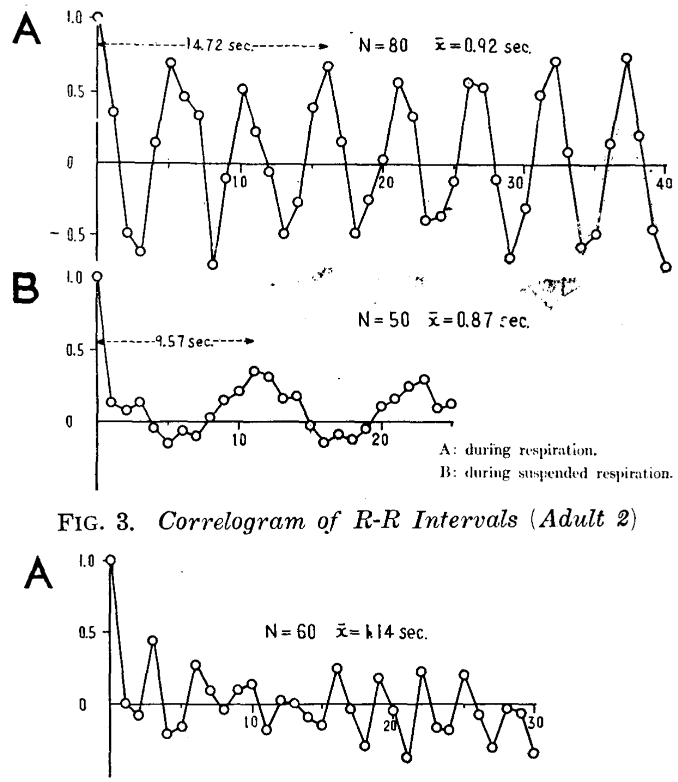
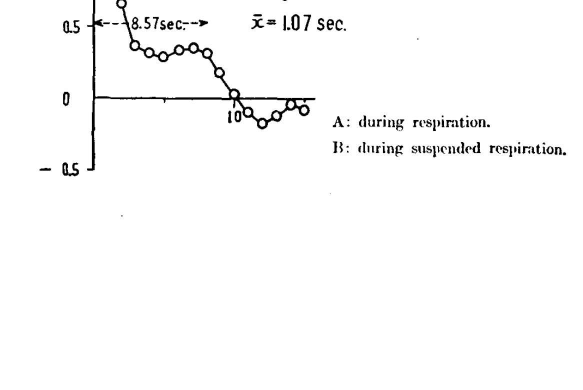


FIG. 3. *Correlogram of R-R Intervals (Adult 2)*



is made clear as fig. 6 shows. In this example, the correlogram with suspended respiration indicates the very large period of about 20.70 seconds (Fig. 5B). In the other example, the fluctuation which derives from respiration shows damped oscillation (Fig. 7A). When respiration is suspended, the correlogram illustrates aperiodic process (Fig. 7B).

The relation of the serial means and the periods is shown in table 1. In view of the results so far achieved, it may be evident that the undulation caused by respiration is qualitatively classified and that the large period has no connection with motion of respiration directly. It is, furthermore, considered that the large period during breathing is about 3.5 times the periodic time in respiration.

FIG. 4. *Correlogram of R-R Intervals (Adult 3)*

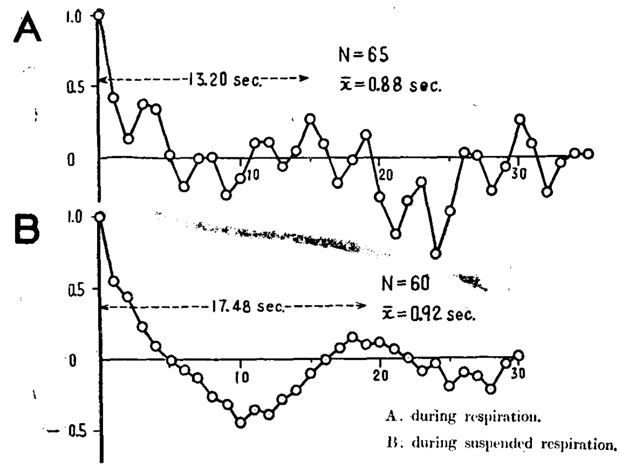


FIG. 5. *Correlogram of R-R Intervals (Adult 4)*

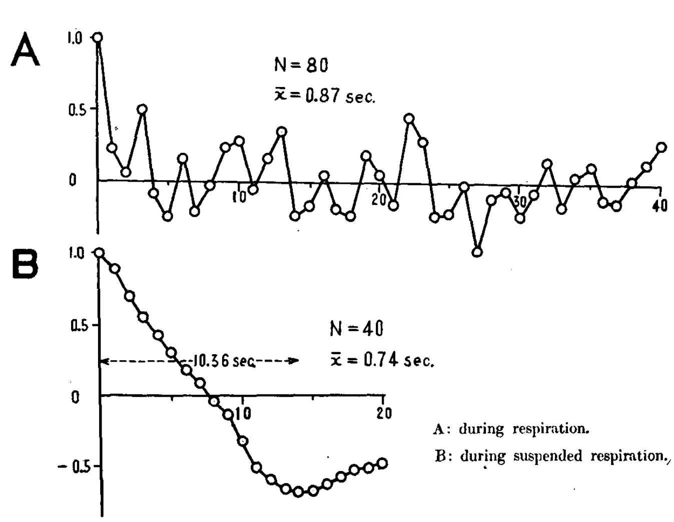


FIG. 6. *Correlogram of R-R Intervals after Arithmetic Moving Average of Three Terms while Respiration (Adult 4)*

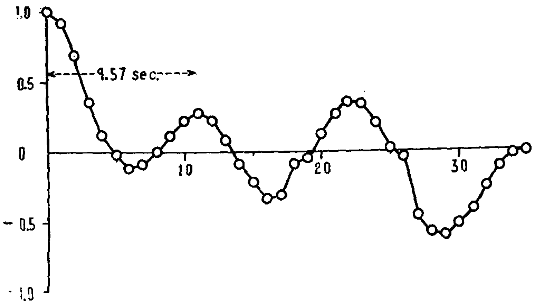


FIG. 7. *Correlogram of R-R Intervals (Adult 5)*

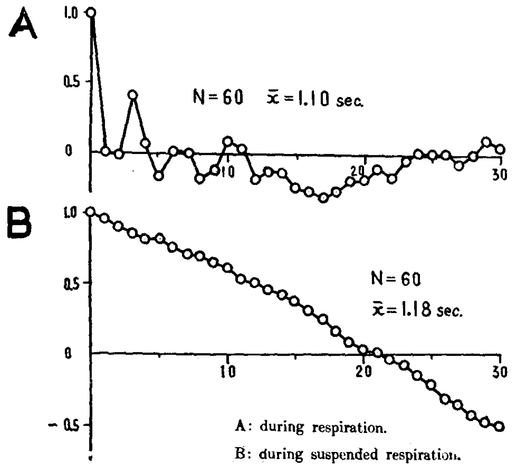


FIG. 8. *Distribution of R-R Intervals in Rabbit*

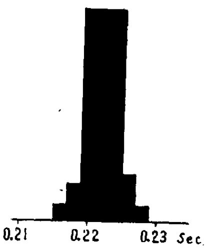
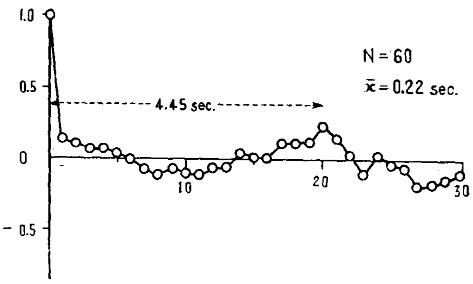


FIG. 9. *Correlogram of R-R Intervals in Rabbit*



2. Rabbit

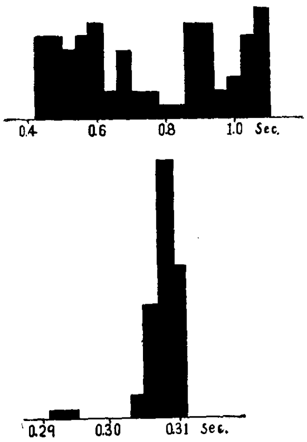
The distribution of R-R intervals is of normal type (Fig. 8). Respiratory fluctuation is not observed at all (Fig. 9). But the large period of 4.45 seconds can be considered as hidden periodicity.

3. Dog

The distribution of R-R intervals after anesthetizing shows combination of 3 normal types (Fig. 10) and the range of distribution is very large. The correlogram after anesthetizing illustrates the remarkable respiratory fluctuation, whose period is 3.75 seconds. It is additionally evident that the period of 14.25 seconds exists (Fig. 11A).

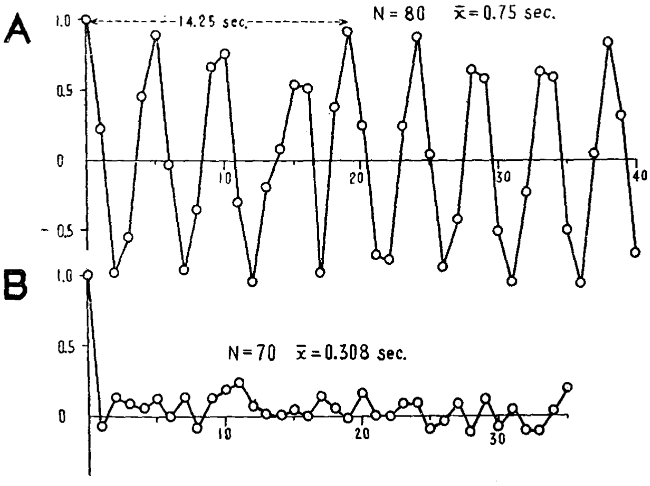
After the vagi are cut, the distribution is of normal type (Fig. 10). Neither the undulation derived from respiration nor the large period can be observed (Fig. 11B).

FIG. 10.
Distribution of R-R Intervals in Dog



Above: after anesthetizing.
Below: after vagi are cut.

FIG. 11. *Correlogram of R-R Intervals in Dog*



Above: after anesthetizing.
Below: after vagi are cut.

TABLE 1. *Relation of the Serial Means and the Periods*

ANIMAL	SMB (sec.)	SMS (sec.)	PR (sec.)	PB (sec.)	PS (sec.)	PB/PR	PS/PR	PR/PB
Adult 1.	0.92	0.87	4.60 (5)	14.72 (16)	9.75 (11)	3.20	2.20	0.69
" 2.	1.14	1.07	3.42 (3)	not clear	8.57 (8)	—	2.66	—
" 3.	0.88	0.92	3.52 (4)	13.20 (15)	16.56 (18)	3.75	4.50	1.20
" 4.	0.87	0.74	2.61 (3)	9.57 (11)	20.72 (28)	3.66	9.33	2.55
" 5.	1.10	1.18	3.30 (3)	not clear	aperiodic	—	—	—
Rabbit	0.222	—	—	4.45 (20)	—	—	—	—
Dog	0.75	—	3.75 (5)	14.25 (19)	—	3.80	—	—
Dog*	0.308							

SMB: serial mean while breathing. SMS: serial mean with suspended respiration. PR: period of respiratory undulation. PB: large period while breathing. PS: period with suspended respiration. Dog: after anesthetizing. Dog*: after vagi are cut. The number in brackets is of term.

DISCUSSION

The hypothesis that the series of sequential R-R intervals is stationary has not yet been tested. In the examples, except adults with suspended respiration, it may be evident that the hypothesis is truthful under ideal conditions. On the contrary, it is not expected that the series in adult with suspended respiration is stationary. Strictly speaking, therefore, it is necessary that trend of the sequence is calculated and the series is made stationary. But such management was not tried, because approximation was required. Even during suspended respiration, the sequence is actually stationary in approximate quantity as the examples in figs. 2B and 4B.

It is well known that respiratory arrhythmia is frequently observed. So far as the writer knows, no report of a qualitative research on it has yet been published. Depending on the writer's method the arrhythmia is qualitatively classified in type of damped motion, of beat and uniformed type etc. and this method may be applied in clinical investigation.

It is a significant problem from what the large period during breathing and with suspended respiration derives. As compared with TRAUBE-HERING's wave in the fluctuation of blood pressure, the character of the large period is analogous to the wave. So it may be considered that the long period is produced by central regulation, but it must be also deliberated whether it derives from heart.

NAKABAYASHI investigated the change of cardial rhythm, after a certain point of the brainstem was destroyed in cat. It was indicated that the center regulating cardial rhythm is located in the neighbourhood of the third ventricle. TSUYA reported that a large periodic fluctuation of cardial rhythm occurred after applying the X-Ray to the diencephalon in rabbit and concluded that the high center adjusting the rhythm of the heart was in the diencephalon.

From results of the writer's experiment it may be decided that the long period of cardiac rhythm has no connection with motion of respiration directly, that the vagus from the experiment in dog has an important role in regulating the long period, and that the long periods during breathing and with suspended respiration are due to the same and identical cause. If the large period is generated by the heart, it must be present after the vagi are cut. So it may be concluded that some parts of diencephalon adjust the large period by the help of the vagus. Furthermore, it may be, on the other hand, possible that the state of some parts in diencephalon is tested by the large periodic time in cardial rhythm.

DOHI found that the large period of cardial rhythm coincided with one half of the large period in respiration. In writer's experiment, the constant relation is shown between the large period of cardial rhythm during respiration and the periodic time of respiration (Table 1).

Therefore, while breathing, the center adjusting cardial rhythm is regulated by the respiratory center, or by the impulse caused by motion of respiration which vagi conduct.

SUMMARY

To study on the fluctuation of R-R intervals measured sequently in electorocardiogram, the method depending on autocorrelation coefficient was applied. The following results were obtained.

1. The fluctuation of R-R intervals caused by respiration can be qualitatively investigated by this method and classified in type of damped motion, of beat and uniform type whose period can be decided in adult.

2. In the fluctuation of R-R intervals, it is found that the large period which is 8.56～20.72 seconds in adult during breathing and during suspending respiration, 4.45 seconds in rabbit and 14.25 seconds in dog anesthetized with molphine is present.

3. The large period disappears after the vagi are cut at neck in dog.

4. It may be concluded that the large period is governed by agency of vagus, generated by some parts of diencephalon, probably in the neighbourhood of the third ventricle.

5. It may be also decided that some parts of diencephalon adjusting cardial rhythm are regulated by the respiratory center or by the peripheral impulse which is caused by motion of respiration in normal state.

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