RELATIONSHIP BETWEEN SLEEP EEG AND CIRCULATORY ACTIVITIES

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It has generally been believed that the circulatory activities are depressed during sleep.\(^1,2\) However, the grade of the depression has not been well known in relation to the depth of sleep. Several reports have been published lately on various physiological functions during sleep, including the circulatory activities, by means of the polygraphic recording. In those studies, EEG was used as an indicator of the depth of sleep.\(^3,4,5,6\)

The present paper is concerned with the correlation between EEG patterns and some circulatory activities, e.g. heart rate, blood pressure, pulse interval, amplitude and velocity of pulse wave during sleep.

METHODS

Among 58 healthy male students whose EEG were taken during natural all night sleep, twenty were subjected to the recording of circulatory functions. The pulse wave was taken from the radial artery. Blood pressure was measured at the interval of thirty minutes as a rule, but at a shorter interval when necessary. In some cases the pulse interval was recorded by an electrocardiotachograph. The velocity of pulse wave propagation was indicated by the time distance between R in ECG and the rising point of the pulse wave, measured by the fast running records.

The records of GSR, respiration curve, eye and body movement are shown in the figures here presented, though there is no mention or only some passing mention of them in this report.

GSR was taken from the palm with the indifferent electrode placed on the internal distal part of the arm. For the record of eye movement, the electrodes were placed on both sides of one eye so that the records might indicate mainly the horizontal eye movements. The body movements were recorded by a strain gage connected with the bed.

From these records, the relationships of the heart rate, pulse interval, the velocity of pulse wave and blood pressure to the electroencephalographic sleep stages were investigated.

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RESULT

The depth of sleep is not fixed but alters during sleep. Therefore, each electroencephalographic sleep stage appears many times repeatedly in the whole course of all night natural sleep. The changes with the sleep stage of pulse rate, blood pressure and velocity of pulse wave are shown in Fig. 1. Each value is the average of a large number of samples taken from all night continuous records of twenty subjects.

The pulse rate decreased with the deepening of sleep level, though it showed a tendency of slight increase in the deep sleep stages (3-1, 3-2). Both the maximal and minimal blood pressure showed a significant drop in the light and moderately deep sleep stages, with a manifest drop of the minimal pressure in 1-5 stage. In the deep sleep stages (3-1, 3-2), however, they were not much lowered and the maximal pressure was about the same as in the awake state. (FIG. 1)

In general the pulse wave propagates slowly during sleep, but in this experiment an exceptionally fast propagation is recognized in 1-5 and 3-1 stages. In most cases (17 of 20) the amplitude of the pulse wave varies in different rhythmical manners during sleep. In general, it fluctuates rhythmically synchronizing with the respiratory rhythm in the lighter sleep stages, where the spontaneous GSR appears very weak. This rhythmical fluctuation could be seen in 17 cases among 20. (Fig. 2A) In the deeper sleep stages, on the other hand, the fluctuation of the pulse wave amplitude is slower and indifferent to the respiration, where the spontaneous GSR appears very vividly. This was recognized only in five cases among 17. (Fig. 2B)

The average pulse interval changes in close parallelism with its standard variation as shown in Tab. 1, where $\bar{I}$ and $S$ stand for the average interval and standard variation respectively. The average pulse interval as well as the variation shows two distinct levels during sleep, changing in the drowsy or very light sleep stage (1-5); at the onset period of sleep, the pulse interval is short and almost equal, while in the sleep stages deeper than 1-5 stage, it is longer
Fig. 2. Examples of rhythmical fluctuation of pulse wave amplitude during sleep.

A. synchronized with respiration, weak GSR.
B. unsynchronized with respiration, strong GSR.

Fig. 3. An example of the rhythmical fluctuation of pulse interval, synchronized with respiration. (represented by tachogram)
TABLE 1.
Average pulse interval (sec.) and its standard variation in each sleep stage.

<table>
<thead>
<tr>
<th>sleep stage</th>
<th>number of samples</th>
<th>( \bar{x} )</th>
<th>S</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-1</td>
<td>17</td>
<td>.928</td>
<td>.038</td>
</tr>
<tr>
<td>1-2</td>
<td>44</td>
<td>.993</td>
<td>.042</td>
</tr>
<tr>
<td>1-3</td>
<td>48</td>
<td>.958</td>
<td>.038</td>
</tr>
<tr>
<td>1-4</td>
<td>28</td>
<td>.958</td>
<td>.038</td>
</tr>
<tr>
<td>1-5</td>
<td>45</td>
<td>1.050</td>
<td>.048</td>
</tr>
<tr>
<td>2-1</td>
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<td>.048</td>
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<tr>
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<tr>
<td>3-2</td>
<td>12</td>
<td>1.084</td>
<td>.048</td>
</tr>
</tbody>
</table>

Samples are taken at random from the EEG records of twenty subjects and each sample is composed of about 100 measurements of pulse interval. \( \bar{x} \) represents the pooled average.

and unequal. An example of the rhythmical fluctuation of the pulse interval is shown in the tachographic record, which is synchronized with the respiration. (FIG. 3)

DISCUSSION

Principally it is reasonable to account the depression in various circulatory activities during sleep, i.e. the slowing of pulse frequency, lowering of blood pressure, decrease in stroke volume for the depression of the metabolic rate. However, it is another problem to notice some relationships between circulatory depression and the sleep depth.

As many authors have reported, various circulatory functions were depressed with the onset of sleep in this experiment also. But the degree of depression was not always proportional to the electroencephalographic sleep level: The pulse wave propagation was somewhat accelerated in 1-5 and 3-1 stages. In the deep sleep stages the blood pressure as well as the heart rate was not much depressed. The maximal and minimal blood pressure were the lowest in 1-5 stage. The average pulse interval and its variation were quite different in the lighter and the deeper sleep stages, showing a significant step in the 1-5 stage.

It is a general tendency that the pulse wave amplitude and the average pulse interval show the regular rhythmical fluctuation, well synchronizing with respiration in the light sleep stage, while they show irregular and slow fluctuation, not corresponding to respiration, in the deeper sleep stages. Such an independence of circulatory and respiratory rhythms in the deeper sleep stages should be regarded as the manifestation of the proper autonomic activity during
sleep, being released from the influence of respiratory mechanism.

These changes in circulation are generally accompanied with the high incidence of spontaneous GSR, various depressive signs in circulation, respiration, body temperature, metabolic rate, and other physiological activities, which are termed as parasympathetic dominance.

Most of these characteristic changes in various functions, including circulatory activities, during sleep begin to appear definitely in the sleep stages deeper than 1-5 stage. This 1-5 stage corresponds to so-called very light sleep stage and many physiological functions appear to be quite labile. After and before this transient labile stage, most physiological activities are quite stable and they show the characteristic features for sleep in the stages deeper than 1-5 stage. That is to say, the 1-5 stage of sleep may play the specific role in sleep-awake mechanism to turn conscious to unconscious, awake to sleep, sympathicotonia to parasympathicotonia, ergotrophic to trophotrophic, dynamogenic to hypnogenic and so on. Thus, the further study of this particular stage is needed.

**SUMMARY**

The correlations between electroencephalographic sleep level and some circulatory activities, i.e. the heart rate, blood pressure, pulse interval, velocity and amplitude of pulse wave during sleep were investigated on twenty healthy male students. The respiration, GSR, eye and body movement were recorded polygraphically. Most of these functions showed the distinct patterns in the lighter and deeper sleep stages, but there could not always be found a close parallelism with the depth of sleep; especially in 1-5 stage, various functions showed particular patterns.

**REFERENCES**

1) **McWilliams, J. A. Brit. Med. J. 2**: 1196, 1923.