CARDIAC RHYTHM AND ADRENALINE EXCRETION AS PHYSIOLOGICAL PARAMETERS FOR MENTAL STRESS FOR THE STUDY OF WORK PHYSIOLOGY

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The influence of mental load upon the physiological functions was studied by measuring the urinary output of adrenaline and noradrenaline and by recording the heart rate continuously by cardiotachograph on 10 healthy adolescents (average 24 years) and 6 normal middle-aged men (average 52 years) during a continued arithmetical calculation test (Kraepelin-Uchida's test) lasting for 1 hour.

Adrenaline excretion significantly increased during the mental load in both the groups, but no significant increase of noradrenaline was recognized.

The heart rate also increased immediately after the beginning of the test, but it fell to some extent after a certain period of time. A marked physiological arrhythmia observed under the resting condition was interestingly suppressed by exposing to the mental stressor. From the change of the cardiac rhythm, it became apparent that the autonomic nervous function was more stable in the middle-aged than in the adolescent.

As there was an intimate relationship between the adrenaline excretion and the working capacity, the usefulness of the urinary output of adrenaline as a parameter for mental load is discussed.

As a result of the development of mechanical devices in recent years, mental works, rather than physical ones, tend to increase in industry. But a useful physiological parameter for the evaluation of some aspects of mental load, such as the energy consumption for muscular work, has never been proposed.

It is generally accepted that the hypothalamus-adrenocortical system takes part in the bodily adaptation to physical stressors and also to emotional stressors though not to such a extent. The adrenocortical hyperactivity under mental load was observed in the case such as very strong emotional stress or anxiety. Although the adrenomedullary secretion has been demonstrated to increase during several emotional stresses, the details in an intellectual work

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are not clear.

On the other hand, the heart rate is established by the rhythmic excitation of sino-atrial node and is continuously influenced by the autonomic nervous system. The impulse from cerebral cortex bombards on the cardioinhibitor and cardioaccelerator center in medulla oblongata, as indicated by many evidences. Excitement, anxiety, and fear influence upon the heart rate without increase of metabolic cost.

This report deals with the changes of cardiac rhythm and urinary catecholamine excretion during a brain work, with special regard to the age.

**EXPERIMENTALS**

*Diurnal Variation of Free Catecholamine Excretion*

Before setting the catecholamine excretion during 1 hour mental work against those during 1 hour control and recovery periods, the background variation of urinary catecholamine was studied on 5 healthy males for 2 days. The urine samples were collected at about 1.5 hour intervals from 6.00 to 21.00 and the subsequent samples to 6.00 next morning were combined.

*Mental Load Test*

Kraepelin-Uchida’s test (a continued arithmetical calculation) was chosen as a mental load, because of being able to know the individual performance. The subjects examined were 10 adolescents of 20—29 years, averaged 24 years, and 6 middle-aged male of 47—55 years, averaged 52 years. They kept sitting quietly from 9.00 to 10.30. At 9.30 the bladder was emptied and the ‘control’ urine sample was collected at 10.30. From this time the subject performed the arithmetical calculation test for 1 hour, and then was sitting at rest till 12.00 when the ‘test’ urine sample was collected. Thereafter he had his usual life without hard work and the ‘recovery’ urine was obtained at 13.30.

To each urine sample, hydrochloric acid was added as a preservative for catecholamine. Free adrenaline and noradrenaline were determined by the method of Euler and Lishajko. Creatinine was measured by the method of Folin. The catecholamine excretion was expressed as mg per creatinine 1 mg in order to correct the inaccurate urine collection occasionally occurred.

The heart rate was continuously recorded by cardiotachograph. The ECG was transmitted by the medical telemerning equipment of wireless system, 40.68 megacycles as the transmission frequency, and led to the cardiotachograph. To express the cardiac rhythm quantitatively, all cardiac periods in a given time (usually 3 minutes) were read in the cardiotachogram and the variation coefficient of cardiac periods was calculated. In this manner the existence of the physiological arrhythmia under certain conditions was quantitatively examined.

**RESULTS**

*Background Diurnal Variation of Catecholamine Excretion*
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On carrying out the experiment lasting for 3 to 4 hours to investigate the influence of mental load upon the catecholamine excretion, it is necessary to clarify the background excretion of these amines. Fig. 1 shows the normal diurnal variation of catecholamine on 5 healthy male subjects in ordinary lives. Though the individual difference was relatively large, there was no remarkable variation in the mean values between 9.00 and 16.00 with regard to catecholamine excretion, while the specific diurnal rhythm of 17-hydroxycorticosteroid excretion is generally accepted. As the mental work experiment was performed under resting condition, the background variation of catecholamine excretion is expected to have been less than that seen in the ordinary life. Therefore one may evaluate accurately the effect of stressor on the catecholamine excretion taking no account of its diurnal variation, if the experiment is performed in daytime.

**Mental Load Test**

1. Catecholamine excretion. Excretory rates of adrenaline and noradrenaline for each individual are given in Table 1. A remarkable increase of adrenaline excretion during the mental load was recognized in all subjects. Adrenaline excretion averaged 6.6 μg/mg crea. for the control period, regardless of age, and significantly increased to 16.1 μg/mg crea. in the adolescent (p<0.01) and 10.7 μg/mg crea. in the old (p<0.05) during the mental load. Fig. 2 shows the relative change of adrenaline excretion to the control value. The per cent increase tended to be more remarkable in the adolescent group (average 130%).

![Graph showing diurnal variation of catecholamine excretion](image_url)
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Table 1. Catecholamine excretion before, during and after the mental work.

<table>
<thead>
<tr>
<th>Subjects</th>
<th>Number of figures calculated</th>
<th>Noradrenaline (mg/mg creatinine)</th>
<th>Adrenaline (mg/mg creatinine)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>before</td>
<td>during</td>
<td>after</td>
</tr>
<tr>
<td>T</td>
<td>58</td>
<td>18.5</td>
<td>21.2</td>
</tr>
<tr>
<td>O</td>
<td>51</td>
<td>15.8</td>
<td>23.4</td>
</tr>
<tr>
<td>Adolescent A</td>
<td>55</td>
<td>22.4</td>
<td>27.5</td>
</tr>
<tr>
<td>Y</td>
<td>61</td>
<td>15.8</td>
<td>13.3</td>
</tr>
<tr>
<td>I</td>
<td>52</td>
<td>17.8</td>
<td>21.9</td>
</tr>
<tr>
<td>S</td>
<td>52</td>
<td>9.7</td>
<td>11.1</td>
</tr>
<tr>
<td>K</td>
<td>43</td>
<td>14.7</td>
<td>12.3</td>
</tr>
<tr>
<td>O</td>
<td>38</td>
<td>21.8</td>
<td>16.5</td>
</tr>
<tr>
<td>H</td>
<td>57</td>
<td>13.2</td>
<td>13.5</td>
</tr>
<tr>
<td>K</td>
<td>101</td>
<td>21.8</td>
<td>21.6</td>
</tr>
<tr>
<td>Average</td>
<td>57</td>
<td>17.2</td>
<td>18.2</td>
</tr>
</tbody>
</table>

| M        | 42     | 24.2   | 25.1  | 24.5   | 6.34   | 10.9  | 12.5 |
| F        | 33     | 6.34   | 9.6   | 8.4    | 5.67   | 6.74  | 2.84 |
| Middle-aged T | 53 | 23.0   | 22.7  | 20.3   | 3.36   | 10.5  | 7.36 |
| group    | T      | 51     | 33.3  | 32.0   | 27.4   | 7.41  | 9.85  | 6.12 |
| M        | 36     | 13.9   | 20.3  | 18.0   | 5.67   | 8.06  | 8.13 |
| T        | 37     | 16.8   | 24.8  | 16.3   | 11.0   | 17.8  | 10.5 |
| Average  | 42     | 19.6   | 22.4  | 19.2   | 6.58   | 10.7  | 7.92 |

Fig. 2. Relative increase of adrenaline excretion during the work to the control value.
(Control value = the value before the work)
○ middle-aged group
■ adolescent group
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than in the middle-aged group (average 70%), but did not differ between the two groups. After ceasing the test, the values returned to the slightly higher level than that of the control period in both the groups. Considerable change of noradrenaline excretion was recognized in neither of the groups.

2. Cardiac rate. The changes of cardiac rate in the two groups are shown in Fig. 3. The pulse rate per minute at rest averaged 75 in the adolescent group and 72 in the middle-aged group. Immediately after starting the test, the heart rate rapidly increased to about 90 in both the groups (overshoot phenomenon), subsequently decreased in some degree, and then kept the steady level which was 85 in young and 80 in old (stabilization phenomenon). The duration of the initial tachycardia was longer in young (20—25 min) than in old (10—15 min). After releasing the load, the heart rate rapidly returned to about the same level as in pre-test period.

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![Fig. 3](image-url) Change of cardiac rate during the mental work in two age groups. ---middle-aged group, -----adolescent group.

![Fig. 4](image-url) Cardiac rhythm during the mental work in two age groups. ○---middle-aged group, ●---adolescent group.
3. Cardiac rhythm. As above-mentioned, the cardiac rhythm or the degree of physiological arrhythmia was quantitatively expressed as the variation coefficient of cardiac interval in a given time period. The changes of the coefficient are illustrated in Fig. 4. At rest, the cardiac intervals in both the groups were irregular, as indicated by the large variation coefficient, mainly due to the existence of respiratory arrhythmia. During the load period, there was a considerable difference in cardiac rhythm between the adolescent and the old; in the young group the rhythm became smaller at the beginning and again larger in the later period of load, while in the old group the rhythm also diminished, though not so markedly as in the adolescent, and did not change throughout the load period. After releasing the load the remarkable arrhythmia again appeared in both the groups.

**DISCUSSION**

Several investigators have demonstrated that the increase of adrenaline secretion and excretion is caused by exposing to the various stressors such as cold, hypoxia, hypoglycemia, exhaustive physical exercise, vibration and centrifugation and also in mental stresses such as fear, anxiety and other emotional excitements. However, the change of adrenaline excretion in an intellectual work has been still unknown. In the present study, the subjects were not exposed to any physical stressor to induce the increased adrenaline secretion, hence the significant increase of adrenaline excretion may be attributed to the mental load and its attendant psychological tension.

It is generally accepted that a major proportion of endogenous adrenaline originates in the adrenal medulla which is innervated by the autonomic nerves and that the increase of adrenaline secretion is brought about by excitation of hypothalamus, particularly by stimulation of the posterior paraventricular area. This autonomic center is controlled by higher centers such as the cerebral cortex and the limbic system. In fact, adrenaline secretion increases by emotional excitation, the center of which is located in the cerebral limbic system.

![Graph](image_url)

Fig. 5. Correlation between relative increase of adrenaline excretion and working capacity.

○: middle-aged subjects, ●: adolescent subjects.
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In the case of intellectual work, it is expected that the cerebral cortex excites and the resulting impulse is transmitted to the adrenal medulla via the hypothalamus and followed by the increased adrenaline secretion.

To examine the reason for the different adrenaline excretion during the mental load between the two age groups, the relative increase of adrenaline excretion is plotted to the number of figures calculated, i.e. working capacity and there was found a close correlation between them (r=0.65, p<0.01). Therefore the difference in adrenaline excretion between the two groups should be attributed to the distinct working capacity, not to the function of adrenal medulla itself. As it is well known that the dexterous activity declined with the increase of age, less working capacity of the old subjects in arithmetical calculation, even the best of their ability, was conceivable and it was perhaps reflected in the adrenaline excretion.

As regards the change of cardiac rate during the mental load, the overshoot period lasting for 15 to 20 min was followed by the stabilization period. The energy consumption increases only slightly during the mental load, according to some earlier investigation6), hence the tachycardia observed in the present study should be ascribed to other factor than the increase of oxygen consumption. This inference is suggested by the well-known fact that the overshoot phenomenon is not observed in physical exercise causing the increased oxygen consumption. The heart rate in the overshoot period was about 90 irrespective of age. Therefore the initial tachycardia seems to be attributed to a direct effect of the higher center on the heart such as some psychological tension accompanied by the test, not affected by the working capacity. As seen in Fig. 3. the overshoot phenomenon disappeared after a certain period of time, which suggests that such a direct effect was eliminated after the subjects had acclimated to the experiment.

The correlation between the working capacity and the increase of heart rate was not significant, but the correlation coefficient between the increase of heart rate and of adrenaline excretion during the load was significant (r=0.61, p<0.05). Accordingly, the promotion of heart rate was probably due to the increase of circulating adrenaline.

The earlier investigators7) showed that the 17-OHCS excretion might be a parameter for the response to the mental work. But there was no significant change in 17-KGS excretion during the same mental work, as seen in Table 2. From the above result it seems conceivable that the cardiac rate and the adrenaline excretion may be useful indices for the mental work. Discussing the comparative evaluation of the cardiac response and the adrenaline

Table 2. 17-Ketogenic steroid excretion before, during and after the mental work in 4 adolescent subjects.

<table>
<thead>
<tr>
<th>Subjects</th>
<th>17-Ketogenic steroids (µg / mg creatinine)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>before</td>
</tr>
<tr>
<td>W</td>
<td>9.5</td>
</tr>
<tr>
<td>K</td>
<td>8.0</td>
</tr>
<tr>
<td>Y</td>
<td>9.3</td>
</tr>
<tr>
<td>K</td>
<td>7.5</td>
</tr>
<tr>
<td>Average</td>
<td>8.6</td>
</tr>
</tbody>
</table>
excretion as a parameter for the mental load, the increase of the heart rate was not directly related to the working capacity and was not so large. Furthermore, many factors as well as mental stress influence on the heart beat. On the other hand, the adrenaline excretion seems to reflect directly the degree of the mental load, so it is presumably more useful than the cardiac rate.

As Fig. 4 shows, the cardiac intervals under the resting condition were relatively variable. The variability is mainly due to the respiratory arrhythmia. On exposing to the mental stressor the arrhythmia was abruptly suppressed. The suppression was more remarkable in young than in old at the initial stage of load. Thereafter, in young the physiological arrhythmia gradually reappeared, while in old the degree of its suppression was maintained constantly throughout the test. As the pulse rate is regulated by the autonomic nervous system, this finding may indicate that the vegetative nervous system, particularly the parasympathetic, is more stable in old than in young.

Bartenwerfer and Kalsbeek have suggested that the suppression of physiological arrhythmia may be a more useful parameter for mental load than the changes of the respiratory frequency and of the blood pressure, since the above arrhythmia was suppressed during the mental load such as car-driving, binary choice work and continued arithmetical calculation. But they referred neither to the degree of the suppression of arrhythmia quantitatively nor to the age difference nor to the duration of the suppression. In the present study the cardiac rhythm was investigated correcting the above defects. It appears that the cardiac rhythm, especially the degree of the suppression of physiological arrhythmia, is a useful parameter for mental load, in spite of some disadvantages such as its age difference and the dependence on the duration of test. When the experiment is carried out in a short-term period not enough to collect a urine sample, the observation of cardiac rhythm will be useful. The relative usefulness of the three parameters, adrenaline excretion, heart rate and cardiac rhythm, is under investigation concerning with the exposure to various mental and physical stressors.

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References