Effects of Physiological Conditions upon the Heart Rate Response during Submaximal Work

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In order to examine the effects of physiological conditions on the heart rate response to work, seven healthy male students performed submaximal work on a bicycle ergometer under each of six physiological conditions, alcohol consumption (3 milliliters of shochu per 1 kilogram of body weight), food deprivation (24 hrs), food satiation (two portions of dinner), sleep deprivation (36 hrs), physical fatigue (after exhaustive running) and normal conditions.

The work load was individually determined so that a subject's heart rate under normal conditions showed $140 \pm 5$ beats/min and he performed these six kinds of work tests with the same work load. The mean heart rates during work under conditions of alcohol consumption and physical fatigue were significantly higher than that under normal conditions. The mean heart rate under conditions of sleep deprivation was $3.4$ beats/min lower than that under normal conditions though this change was not statistically significant. The changes of heart rate were greater at rest than at work, except for the case of sleep deprivation. Under the conditions of sleep and food deprivation, inter-individual differences were greater at work than at rest.

**Key words:** Heart Rate, Submaximal Work, Alcohol Consumption, Sleep Deprivation, Food Deprivation.

**INTRODUCTION**

Since the heart rate shows an appropriate linear function of both oxygen intake and work intensity (Åstrand and Ryhming, 1954), attempts have been made to estimate the energy expenditure during physical work and sport activities. The heart rate responses, therefore, provide information useful to understanding the phenomenon of physiological adaptation to physical activities. However, the obtained heart rate appears to be changed considerably by the work condition, even if the work was done with exactly the same intensity. The physical conditions such as temperature and barometric pressure in the room are some of the factors which affect the heart rate.

Another important factor may be the subject's physiological condition when he is working. There are some stresses which depress the work tolerance and affect the heart rate while working and resting.

For instance, alcohol ingestion elevates the heart rate during submaximal work due to the effect of vasodilatation (Blomqvist, Saltin and Mitchell, 1970), though some studies failed to show any effect of alcohol because of the small amount of alcohol ingested (Asmussen and Bøje, 1948; Miyashita, Kitagawa and Fumoto, 1977). Sleep deprivation decreased the heart rate at rest (Brodan and Kuhn, 1967; Holland, 1968; Pickett and Morris, 1975). The cause of this change has been discussed in terms of respiratory acidosis (Brozek, Tayler, 1954) or the specific activity of adenylic phosphate compounds in the blood (Luby, et al., 1960). Food deprivation (Henschel, Taylor and Keys, 1954, Tuttle, 1943) was found to increase the heart rate, the mechanism of this change is explained by acidosis, dehydration and low blood sugar (Henschel, Tayler and Keys, 1954).

Food ingestion (Dill, 1959) also decreased the heart rate...
rate both at rest and at work.

The condition of physical fatigue also may affect heart rate during work. Thus heart rate more or less changes under such conditions. However, the magnitude of the heart rate changes has been not accurately compared among the different types of physiological conditions on the basis of the data reported before, because the previous studies treated only one or two kinds of physiological conditions and because the subjects' sex and age, or test work load used were different.

The purpose of this study was to assess the effects of the six types of physiological conditions upon the heart rate at rest and at work. Physiological conditions treated were alcohol consumption, sleep deprivation, food deprivation, food satiation, physical fatigue and normal conditions. The work load was set at the submaximal level. It was also the purpose of this study to observe the inter-individual differences of heart rate changes in relation to these conditions.

**METHODS**

1) Subjects

Seven healthy young men listed in Table 1 volunteered for this experiment.

2) Measurement of heart rate

(1) Heart Rate at Rest

After 10 minutes rest in sitting position, the heart rate at rest was measured for one minute for the tests. Heart rate measurements were carried out by the telemeter method.

(2) Heart Rate during Submaximal Work

The subjects exercised on a bicycle ergometer under the given conditions. They wore athletic shorts only. Their work loads were predetermined individually and kept constant among these six work tests. Each work load was determined so that the subject's heart rate under normal conditions reached the level of 140±5 beats/min. It was extrapolated utilizing the linear relationship between heart rate and work level (Åstrand, and

<table>
<thead>
<tr>
<th>Subject</th>
<th>Age (yrs)</th>
<th>Height (cm)</th>
<th>Weight (kg)</th>
<th>Work Load (kp) 50rpm</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>21</td>
<td>165.0</td>
<td>59.0</td>
<td>2.0</td>
</tr>
<tr>
<td>2</td>
<td>21</td>
<td>165.0</td>
<td>67.0</td>
<td>2.0</td>
</tr>
<tr>
<td>3</td>
<td>21</td>
<td>168.0</td>
<td>67.0</td>
<td>1.5</td>
</tr>
<tr>
<td>4</td>
<td>21</td>
<td>176.0</td>
<td>62.0</td>
<td>3.5</td>
</tr>
<tr>
<td>5</td>
<td>27</td>
<td>167.2</td>
<td>69.5</td>
<td>3.0</td>
</tr>
<tr>
<td>6</td>
<td>21</td>
<td>165.0</td>
<td>68.5</td>
<td>3.0</td>
</tr>
<tr>
<td>7</td>
<td>21</td>
<td>167.5</td>
<td>48.0</td>
<td>1.5</td>
</tr>
<tr>
<td>Mean</td>
<td>21.9</td>
<td>167.6</td>
<td>63.0</td>
<td>2.3</td>
</tr>
<tr>
<td>S D</td>
<td>2.1</td>
<td>3.6</td>
<td>7.0</td>
<td>0.7</td>
</tr>
</tbody>
</table>

Ryhming, 1954).

Pedaling frequency was maintained at 50 rpm by a metronome. The heart rate was continuously recorded for 6 minutes. Table 1 shows the physical characteristics and the test work loads of the seven subjects. All tests began at 7:00 p.m.. Room temperature was kept constant at 20±2°C.

3) Treatment of Physiological Conditions

(1) Normal condition

This was the usual condition and the subjects were free from the requirements of the physiological conditions mentioned below.

(2) Alcohol consumption

The subjects drank 3 milliliters of shochu per 1 kilogram of body weight (Japanese liquor, 25%) 45 minutes before the submaximal work test.

(3) Food deprivation

The subjects were not allowed to take any food for a period of 24 hours. They were allowed to drink water, but were told not to drink too much.

(4) Food satiation

The subjects were told to have breakfast and lunch as usual. Prior to the work test, each of them was required to eat two portions of dinner (approximately 1700 Kcal) 10 minutes before the submaximal work test.

(5) Sleep deprivation

After 36 hours of sleep deprivation, the submaximal work test began.

(6) Physical fatigue
The subjects were required to run on a treadmill. The initial work load was 140 m/min, 5% grade, this was increased by 20 m/min every two minutes during first 6 minutes, then this was increased every minute by 20 m/min. The work was continued until the subject reached exhaustion. The submaximal work test began after 60 minutes.

The order of the submaximal work tests was randomized.

RESULTS

1. Heart Rate at Rest

Mean heart rate at rest for each of the five conditions is shown in Table 2.

The heart rates under alcohol consumption and physical fatigue conditions were significantly higher than that under normal conditions (t-test, p<0.05). In contrast, significant decrease was observed in the condition of sleep deprivation (t-test, p<0.05). Individual values of heart rate difference between the normal and each of the physiological conditions are presented in Fig. 2.

2. Heart Rate at Work

Fig. 1 shows the mean heart rate changes at the work. The steady state phenomenon could not be obtained on this work load and work duration. The means, standard deviations (SDs) and coefficients of variation (CVs) of heart rate during work from 5 to 6 minutes are shown in Table 2. Individual values of heart rate difference between normal conditions and each of the five conditions are presented in Fig. 2.

<table>
<thead>
<tr>
<th>Treatment Condition</th>
<th>Heart Rate at Rest</th>
<th>Heart Rate at Work</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean, S, D, C, V</td>
<td>Mean, S, D, C, V</td>
</tr>
<tr>
<td>Normal</td>
<td>79.4, 7.7, 9.75</td>
<td>141.3, 10.8, 7.64</td>
</tr>
<tr>
<td>Alcohol Consumption</td>
<td>99.9, 25.3, 25.32</td>
<td>154.3, 10.3, 6.68</td>
</tr>
<tr>
<td>Food Deprivation</td>
<td>73.6, 13.2, 17.98</td>
<td>141.4, 10.8, 7.64</td>
</tr>
<tr>
<td>Food Satiation</td>
<td>84.3, 10.8, 12.75</td>
<td>141.1, 7.4, 5.24</td>
</tr>
<tr>
<td>Sleep Deprivation</td>
<td>77.3, 8.1, 10.59</td>
<td>137.9, 8.8, 6.38</td>
</tr>
<tr>
<td>Physical Fatigue</td>
<td>102.6, 5.5, 5.33</td>
<td>153.4, 6.7, 4.37</td>
</tr>
</tbody>
</table>

The heart rates under alcohol consumption and physical fatigue conditions were significantly higher than that under normal conditions (t-test, p<0.05). The mean heart rate of the sleep deprivation condition was 3.4 beats/min lower than that of the normal conditions, but this difference was not statistically significant. No significant difference was found in either the food deprivation or the food satiation conditions. As can be seen in Fig. 2, the changes of heart rate were greater at rest than at work except for the case of the food deprivation.
alcohol consumption both at rest and at work, the smallest CV at rest was in the sleep deprivation condition, and at work was in the food satiation condition. In the alcohol consumption and in the physical fatigue conditions, CV was greater at rest than at work. On the contrary, in the food deprivation and sleep deprivation conditions, greater CV appeared at work than at rest.

**DISCUSSION**

No physiological condition (except for the case of sleep deprivation) was found in which heart rate response was more sensitive during submaximal work than at rest. This tendency coincides with the findings of Blomqvist *et al.* on alcohol-exercise (1970). They observed that heart rate increase was of lesser magnitude as the work intensity increased and there was scarcely any difference at the maximum level of work. The data of heart rate relating to the physiological conditions seems to provide more useful information in the condition of resting than working.

Previous studies concerning the work performance in conditions of sleep deprivation (Brodan and Kuhn, 1967; Copes and Rosentwieg, 1972: Holland, 1968) and food deprivation (Brozek and Taylor, 1954; Henschel, Taylor and Keys, 1954; Taylor *et al.*, 1954) have found a serious deterioration in maximum work performance.

And it is also well understood through everyday experiences that alcohol consumption, physical fatigue and food satiation depress man’s maximum work performance. Therefore, it may be expected that these conditions also act as a stress during submaximal work as well as maximal work. It may cause the heart rate to change.

The work efforts of alcohol consumption and physical fatigue obviously increased the heart rate in this study, but in the other conditions such as sleep deprivation, food satiation and food deprivation, heart rates did not show any significant change. However, the results do not necessarily
mean that these conditions had no effect on the 
work tolerance. Changes of the working heart rate 
seem to be so complicated that they can not be 
interpreted in a simple manner.

Martin (1981), and Martin and Gaddis (1981) 
investigated the psychological effects of sleep loss. 
They found that ratings of perceived exertion were 
significantly elevated during submaximal work, 
even though the working heart rate was unchanged. 
They suggested that such psychological effects as 
feelings of fatigue, discomfort and pain may 
contribute to work tolerance.

Pickett and Morris's study (1975) was undertaken 
in a mixed stress conditions, where the subjects 
were exposed to both food and sleep deprivation. 
They showed significant decrements in the maxi-
mum working time, but the heart rate level during 
submaximum work changed slightly. Since sleep 
derprivation tended to decrease and food deprivation 
tended to increase working heart rate, they speculated 
that the subjects exposed to both food and 
sleep deprivation showed little change because of 
the countereffect of the two kinds of stresses. Thus, 
the same level of heart rate does not always 
represent the same physiological condition. Much 
attention should be paid to the subjects' physi-
ological condition when the work test used involves 
heart rate assessment.

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