Circadian variations in psychophysiological responses to heat exposure and exercise*

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Summary. Ten healthy men were tested at 0600, 1200, 1800 and 2400 hours on different days at rest in a laboratory at room temperature followed by 1 h of heat exposure in a climatic chamber at 42°C, 60% rh (50 min rest and 10 min exercise on a cycle ergometer at 50% \( V_O_{2max} \)). Heart rate, blood pressure, rectal temperature \( T_{re} \), metabolic rate, number connection test, visual and auditory reaction time, flicker test and catecholamine excretion were measured. Heat exposure and exercise caused lower heart rate acceleration at 2400 hours than at 0600 and 1200 hours, the smallest increase of \( T_{re} \) at 1800 hours, and an increase in metabolic rate greater at 1200 than at 1800 hours. In the afternoon, when, according to the circadian rhythm, the body temperature is highest, the additional heat load produced the smallest physiological effects. Performance efficiency, after heat exposure combined with physical exercise, improved slightly, but diurnal variations did not show significant circadian rhythm.

Key words: Circadian variations — Heat exposure — Metabolic rate — Performance tests

Introduction

Circadian rhythms have been established for many physiological variables. These variations can affect the metabolic cost and muscular efficiency of work and influence psychomotor and mental performance. This could be of significance for workers employed at different times of day, that is at different stages of the circadian rhythm. Shift work is often combined with warm or even hot climatic conditions at work (Rutenfranz et al. 1986).

The aim of the present study was to determine the influence of the combined effects of a hot environment and physical exercise on circadian variations of certain psychophysiological responses.

Methods

The study was carried out on ten healthy men aged between 23-34 years (mean 28.5 years). Their weight ranged from 59 to 83 kg (mean 69.6 kg), which was within the normal range (mean 104% of ideal body weight) according to the Metropolitan Insurance Tables (Statistical Bulletin 1966, 47:1-3). All persons were informed about the aim of the study before consenting to participate. Experiments were conducted in winter. During an initial laboratory visit each person was given a graded exercise test on a cycle ergometer to determine his \( V_O_{2max} \). Each subject was tested four times during a week on different days at 0600, 1200, 1800 and 2400 hours. The order of test time was randomized. No test was begun less than 24 h after the termination of the preceding test. Subjects were requested to avoid any strenuous activity or the drinking of coffee during the 24 h preceding the test. Clothing during the test consisted of shorts and shoes.

Each of the four experimental sessions consisted of a 30-min rest period in a laboratory at room temperature (1) followed by a 50-min heat exposure at rest in a climatic chamber at 42°C, 60% rh (2), and then by 10-min exercise on a cycle ergometer at 50% \( V_O_{2max} \). In these three situations heart rate, blood pressure, rectal temperature (\( T_{re} \)) and metabolic rate were measured. Metabolic rate was determined by indirect calorimetry. Gas was collected in a Douglas bag for a period of 5 min at rest and during the last 5 min of exercise. The gas volume was measured in a spirometer and the \( O_2 \) and \( C_2 \) fractions were determined in a Spirul-2 analyser. Sweat rate was estimated from weight loss assessed by weighing the subjects before and after the test. Before and immediately after every exercise period the following performance tests were conducted: number connection test, visual (vrt) and auditory reaction time (art), and flicker test, performed by a modified Alvar stroboscope (Spioch 1969). Urine samples for catecho-
lamine assay (Weil-Malwerbe and Bigelow 1968) were collected before and during the exercise period.

A paired t-test, and X² test were used for statistical analysis. The results were also analysed by both single and population mean cosinor methods (Cornelissen et al. 1980). The following parameters were calculated: mesor (M) — computer determined mean value of the rhythm defined by a cosine curve; acrophase (0) — timing of the highest point in the rhythm, hence the peak of the cosine curve expressed as time of the day; rhythm detection p value. Values are given as mean ± SEM.

**Results**

The Tre ($\bar{x} = 36.9 \pm 0.4 ^\circ C$) demonstrated circadian rhythm: $p < 0.02$; $M = 36.9 \pm 0.06 ^\circ C$: 0 = 248° ± 19°, i.e. 1631 hours (1515–1747 hours). The lowest Tre in the heat ($\bar{x} = 36.8 \pm 0.4 ^\circ C$) and during exercise ($\bar{x} = 37.2 \pm 0.2 ^\circ C$) was at 0600 hours ($p < 0.05$, Fig. 1). The smallest increase of Tre was at 1800 hours (0.4° C) when the highest Tre occurred.

As shown in Table 1, heart rate ($\bar{x} = 74.2 \pm 8.1$ beats·min⁻¹) increased in the heat ($\bar{x} = 84.7 \pm 1$ beats·min⁻¹) and during exercise ($\bar{x} = 154.1 \pm 13$ beats·min⁻¹). A smaller increase in heart rate was observed at 2400 hours than at 0600 and 1200 hours ($p < 0.01$). The decrease of the systolic blood pressure during heat exposure (from 16.4 ± 0.5 to 15.4 ± 1.7 kPa) and the increase during exercise (to 22.5 ± 2.9 kPa) did not show any circadian variation. The decrease in diastolic blood pressure was greater during exercise (from 11.0 ± 1.1 to 8.0 ± 2.4 kPa) than during heat exposure alone (9.6 ± 1.2 kPa) and also showed no circadian variation.

Metabolic rate ($\bar{x} = 122.8 \pm 23.7$ W) was lowest at 0600 hours (106.7 W) ($p < 0.05$). The increase of the metabolic rate during physical exercise in the

<table>
<thead>
<tr>
<th>Hours</th>
<th>Rest</th>
<th>H</th>
<th>HE</th>
</tr>
</thead>
<tbody>
<tr>
<td>0600</td>
<td>72.0 ± 11.2</td>
<td>84.6 ± 8.8</td>
<td>160.0 ± 16.2</td>
</tr>
<tr>
<td>1200</td>
<td>75.3 ± 6.4</td>
<td>86.6 ± 8.7</td>
<td>157.0 ± 12.3</td>
</tr>
<tr>
<td>1800</td>
<td>75.8 ± 5.5</td>
<td>86.6 ± 7.4</td>
<td>153.6 ± 11.7</td>
</tr>
<tr>
<td>2400</td>
<td>73.8 ± 9.4</td>
<td>81.0 ± 8.2</td>
<td>145.8 ± 13.8</td>
</tr>
</tbody>
</table>

$x = 74.2 ± 8.1$  
$84.7 ± 8.3$  
$154.1 ± 13.5$

**Table 2.** Diurnal variations in metabolic responses to heat exposure (H) and heat + exercise (HE) (mean ± SD)

<table>
<thead>
<tr>
<th>Hours</th>
<th>Metabolic rate (W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rest</td>
<td>H=heat</td>
</tr>
<tr>
<td>0600</td>
<td>106.7 ± 18.1</td>
</tr>
<tr>
<td>1200</td>
<td>131.9 ± 31.4</td>
</tr>
<tr>
<td>1800</td>
<td>120.7 ± 26.5</td>
</tr>
<tr>
<td>2400</td>
<td>131.2 ± 18.1</td>
</tr>
</tbody>
</table>

$x = 122.8 ± 23.7$  
$131.2 ± 16.0$  
$586.0 ± 62.8$

heat was greater at 1200 hours than at 1800 hours ($p < 0.02$) (Table 2). Sweat loss ($\bar{x} = 449 ± 170$ g) did not demonstrate a circadian rhythm.

The results of the number connection test did not change over 24 h (Table 3). After the heat load, out of 10 subjects examined the test results were shorter in 6, 6, 9, and 7 subjects at successive test times, respectively.

The vrt and art were slightly longer at 2400 hours than at other times. After heat exposure vrt was shorter in 9, 8, 7, and 8 of the 10 subjects examined at successive test times; the shortest test results were at 1200 hours ($p < 0.05$).

Flicker test results did not show any significant circadian variation after heat load.

Noradrenaline excretion (47.5 ± 28.9 ng·min⁻¹) after heat load increased at 0600 and 1200 hours in 7 subjects, at 2400 hours in 8 subjects, but only in 4 subjects at 1800 hours, when the mean noradrenaline excretion after heat load was the lowest (Fig. 2).

**Discussion**

It has been known for about 100 years that the circadian rhythm of body temperature reaches its