Physiological Responses During a Light Muscular Exercise in Conditions of Air Temperature between 20°C and 28°C

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Abstract Eight male students, wearing only shorts, were exposed to 20, 22, 24, 26, and 28°C for 90 minutes on separate days. Relative humidity was 50% and air velocity was less than 20 cm/sec. Subjects kept rest in sitting posture for 60 minutes and then took a light fixed work (40W) for 30 minutes on a bicycle ergometer. Their exercise metabolic rate, heart rate, rectal temperature, and mean skin temperature were measured. Measurements between the 25th and 30th minute of exercise were used for statistical analyses.

Metabolic rate at 26°C was significantly lower than that at 20, 22, 24, and 28°C. Heart rate, rectal temperature, and mean skin temperature increased progressively in cooperate with rising of environmental temperature. Linear relationship was observed between air temperature and heart rate. This results means that under conditions of air temperature between 20°C and 28°C the metabolic rate during a light muscular exercise is influenced by the environmental temperature similar to the cases of heart rate and body temperature.

INTRODUCTION

The effects of hot environments on metabolic responses and physiological reactions to muscular exercise have been frequently studied (see WHYDHAM 1973, ROWELL 1974). Contradictory findings were, however, reported in literatures regarding metabolic responses during muscular exercise in hot environment. Under these conditions, some workers have re-

ported an increase in metabolic rate (CONSOLAZIO *et al.* 1963, KURODA *et al.* 1973, SATO *et al.* 1980), others a decrease (BROUHA *et al.* 1960, WILLIAMS *et al.* 1962, PETERSEN *et al.* 1973, GUPTA *et al.* 1977), still others no change (ROWELL *et al.* 1965, 1969, STRYDOM *et al.* 1966, KLAUSEN *et al.* 1967, SATO and IWAMOTO 1976). In these studies, metabolic rates during muscular exercise in hot environment were compared with those in "neutral" thermal environments (control values). However,

"neutral" thermal environment in which control values were obtained was different from each other in these studies. A careful attention has not been paid to these differences in "neutral" air temperature conditions. In our earlier study on resting metabolism in conditions of air temperature between 20°C and 28°C at intervals of 2°C, we observed that physiological functions such as metabolic rate, heart rate, sweat rate, and body temperature were influenced by changes in air temperature under these air temperature conditions (OHNAKA *et al.* 1981). On the other hand, studies on the effects of air temperature on metabolic response during muscular exercise under "neutral" air temperature range were limited in number. Hence, the present study was undertaken to compare the physiological reactions to muscular exercise in conditions of air temperature between 20°C and 28°C at intervals of 2°C.

METHOD

Subjects were eight healthy male students. Their physical characteristics with maximal oxygen intakes were given in Table 1. Maximal oxygen intake was calculated according to the formula of SATO *et al.* (1980). The subjects, wearing only shorts, were exposed to 20, 22, 24, 26 and 28°C ($\pm 0.5^\circ\text{C}$) in a climatic chamber for 90 minutes on separate days. Relative humidity was 50 % and air velocity was less than 20 cm/sec. They sat for 60 minutes before the onset of exercise: 50 minutes in a chair and 10 minutes on the bicycle ergometer to permit adjustment

Table 1. Physical characteristics of eight subjects with maximal oxygen intakes (VO_2max) and relative work loads (RWL).

Subject	Age (yrs)	Height (cm)	Weight (cm)	VO_2max (l/min)	RWL* (%)
A	19	172	56.1	2.34	29.4
B	19	172	75.4	3.37	24.4
C	19	177	54.8	2.37	29.9
D	22	170	54.4	2.52	28.1
E	19	165	63.1	2.66	26.9
F	19	166	53.2	2.88	25.7
G	20	170	62.7	2.70	27.0
H	18	171	61.1	2.51	30.4
mean	19.2	170.4	60.1	2.67	27.7
S D	1.2	3.7	7.3	0.33	2.1

*Relative work loads were presented in percent their maximal oxygen intakes.

to the environmental conditions. The exercise consisted of pedaling a magnetic brake bicycle ergometer at a rate of 60 rpm at a constant load of 40 Watt for 30 minutes. Expressed in percent of their maximal oxygen intakes of the exercise, subjects worked at a level of 27.7 % (24.4-30.4 %), and these values were also presented in Table 1. The expired volume and the fraction of O_2 and CO_2 in the expired air were measured continuously by a spirometer (Fukuda Sangyo CR-20) and a O_2 and CO_2 analyzer (Fukuda Irika Respirizer BM-10). For calculation of metabolic rate, the caloric equivalent of oxygen used was estimated from the value of R.Q. Rectal temperature was recorded by means of a thermister inserted to a depth of 10 cm into the subjects' rectum. Ten skin thermisters were attached to the subjects: 1, forehead; 2, shoulder; 3, chest; 4, epigastium; 5, abdomen; 6, forearm; 7, hand; 8, thigh; 9, leg; 10, foot. The

relative contribution of each area was weighted in calculation of mean skin temperature ($\bar{T}_s$) as follows (KURATA and FUNAZU 1953)

$$\begin{aligned}\bar{T}_s = & 0.098T_1 + 0.082T_2 + 0.166T_3 + 0.081T_4 \\ & + 0.081T_5 + 0.061T_6 + 0.053T_7 + 0.172T_8 \\ & + 0.134T_9 + 0.072T_{10} \text{ with } T_1-T_{10} \text{ as} \\ & \text{indicated above.}\end{aligned}$$

Heart rate was obtained from the electrocardiogram using chest leads. The order of exposure to five different air temperature conditions was randomized for each of the subject. Measurements between the 25th and 30th minute of exercise were used for the analyses. The results were

analyzed by calculating the analysis of variance and t -values. The analysis of variance was performed with respect to air-temperature and different individuals. Experiments were carried out during September.

RESULTS AND DISCUSSION

Rectal temperature (T_r), mean skin temperature ($\bar{T}_s$), metabolic rate ($\dot{M}$), and heart rate (HR) were presented in Table 2. According to analyses of variance for individual factor on these measurements, the significant differences among individuals were found in all meas-

Table 2. Rectal temperature, mean skin temperature, metabolic rate and heart rate of eight subjects during exercise in five air temperature conditions.

Air temp. (°C)	Rectal Temperature (°C)					Metabolic Rate (kcal/m ² •hr)				
	20	22	24	26	28	20	22	24	26	28
Subject										
A	36.7	36.5	36.4	36.9	36.8	131.00	129.72	128.04	124.14	128.72
B	37.1	36.9	37.3	37.4	37.1	141.83	136.68	137.08	132.11	129.38
C	37.3	37.1	37.3	37.7	37.7	141.18	130.21	129.37	127.99	128.26
D	37.2	37.3	37.1	37.1	37.6	141.80	136.21	136.99	129.42	136.63
E	37.1	37.3	37.3	37.4	37.4	142.53	139.83	148.64	142.88	148.61
F	37.1	37.1	37.5	37.3	37.5	152.72	146.04	142.64	140.45	141.78
G	37.3	37.1	37.2	37.2	37.2	140.49	129.75	127.04	127.88	129.73
H	37.2	37.4	37.4	37.3	37.4	140.63	137.25	133.29	132.88	143.63
mean	37.1	37.1	37.2	37.3	37.3	141.52	135.71	135.39	132.22	135.84
S D	0.19	0.29	0.34	0.23	0.29	5.85	5.72	7.54	6.46	7.99
	Mean Skin Temperature (°C)					Heart Rate (beats/min)				
A	28.8	30.3	31.2	32.2	33.4	93	94	99	97	101
B	28.8	30.6	32.0	31.7	32.5	99	93	99	102	94
C	29.2	30.7	31.8	31.8	33.0	103	108	109	107	121
D	29.0	31.0	32.0	32.4	33.6	100	101	104	103	111
E	29.8	30.6	31.9	32.1	32.7	101	102	104	104	106
F	29.3	30.8	32.1	32.7	34.3	99	102	104	108	115
G	29.3	30.8	31.1	33.3	33.7	96	95	92	111	108
H	29.2	31.4	31.8	33.1	33.7	100	112	123	111	110
mean	29.2	30.8	31.7	32.4	33.4	98.9	100.9	104.3	105.4	108.3
S D	0.32	0.33	0.38	0.58	0.60	3.1	6.8	9.1	4.8	8.3

Air temp. (°C)	Tr	$\bar{T}_s$	$\dot{M}$	HR
20				
22				
24				
26				
28				

x p<0.05 xx p<0.01

Fig 1. Significant differences of rectal temperature (Tr), mean skin temperature ($\bar{T}_s$), metabolic rate ($\dot{M}$) and heart rate (HR) in five air temperature conditions.

urements (Tr: $F=10.24$, $P<0.01$, T_s : $F=4.00$, $P<0.01$, M : $F=15.85$, $P<0.01$, HR: $F=5.98$, $P<0.01$). Statistical comparisons of these measurements between air temperatures were, therefore, performed using a paired t -test, and the significant differences between the values under five air temperature conditions are shown in Fig. 1.

At pre-exercise rest, rectal temperature was not significantly different in five air temperature conditions, that is, rectal temperature (mean $\pm$ SD) at 20°C Ta were 37.13 $\pm$ 0.25°C, 37.14 $\pm$ 0.25°C at 22°C Ta, 37.26 $\pm$ 0.14°C at 24°C Ta, 37.21 $\pm$ 0.17°C at 26°C Ta, and 37.26 $\pm$ 0.27°C at 28°C Ta, respectively. Rectal temperature fell gradually during the initial 10 minute of exercise, then increased during the period from 10th to 20th minute of exercise. After 20th minute of exercise, rectal temperature remained at each relatively steady level in five air temperature conditions. At the end of exercise, rectal temperatures at 26°C Ta and 28°C Ta were significantly higher than that at 20°C Ta, and at 28°C

Ta was higher than that at 22°C Ta. It is well known that body temperature typically stabilizes at an elevated level during exercise. NIELSEN (1938) showed that exercising man exhibits a stable elevated rectal temperature throughout long periods of exercise. NIELSEN also showed that this elevated temperature was rather independent of environmental changes; over a wide range of conditions, only small deviations of rectal temperature above normal were observed. KITZING *et al.* (1968) observed that esophageal temperature which respond much more rapidly than rectal temperature, maintained during exercise was influenced by environmental temperatures ranged from -4°C to 32°C Ta. In the present study, rectal temperatures during exercise at 26°C and 28°C were higher than those at 20°C or 22°C. It was confirmed that the temperature maintained during exercise was influenced by environmental temperature (BRENGELMANN 1977) under air temperature conditions ranged from 20°C to 28°C.

Mean skin temperature at pre-exercise rest at 20°C Ta was $29.19 \pm 0.29^\circ\text{C}$, and it increased to $33.24 \pm 0.40^\circ\text{C}$ at 28°C Ta. The time course of mean skin temperature during exercise was similar to that of rectal temperature. The correlation coefficient between mean skin temperature and air temperature was highly significant ($r=0.938$; $P<0.001$).

Metabolic rate during exercise at 26°C Ta was significantly lower than at 20, 22, 24, and 28°C Ta. When man was exposed to cold, his heat production increased in order to maintain heat balance. It seems that in the 20, 22 and 24°C environments where no shivering occurred, there is a tensing of the muscles (WINSLOW and HERRINGTON 1949). We also observed an increase in metabolic rate at 28°C Ta. Although some workers observed the increase in metabolic rate during exercise in hot environment as compared with a control value, the air temperature at which they observed the increase in metabolic rate was considerably high. CONSOLAZIO *et al.* (1963) showed that there was a significantly higher metabolic rate during exercise at 37.7°C Ta than at 29.4°C Ta or 21.1°C Ta. KURODA *et al.* (1973) found that metabolic rate at 40°C Ta was somewhat higher than at 20°C Ta or 30°C Ta. SATO *et al.* (1980) found an increase in metabolic rate at 35°C Ta as compared with at 15°C Ta.

Others showed no change in metabolic rate during exercise in hot environment as compared with control value. KLUSEN *et al.* (1967) showed that metabolic rate during exercise was approximately the

same in heat (32.1°C Ta) as in the control (24.8°C Ta). MIURA *et al.* (1972) tested the effects of air temperature under conditions of air temperature under conditions of air temperature between 5°C and 40°C at intervals of 5°C, and found an increase of metabolic rate during exercise in only the coldest condition. STRYDOM *et al.* (1966) revealed no change of metabolic rate under conditions of air temperature between 29.4°C and 36.1°C.

In contrast with these findings, WILLAMS *et al.* (1962) found a lower metabolic rate during exercise at 36.1°C Ta than that at 21.1°C effective temperature. BROUHA *et al.* (1960) found that metabolic rate at 37.2°C Ta was significantly lower than that at 25°C Ta.

Since a metabolic rate in hot environment was compared with a control value which was obtained in different air temperature conditions an increase in metabolic rate which was observed at 28°C Ta in this study might have been failed to be noticed.

Heart rate at 26°C and 28°C were higher than that at 20°C, and at 28°C also higher than that at 22°C. A linear relationship was observed between heart rate and air temperature ($r=0.431$, $P<0.01$), which agrees with DILL (1942) who showed that heart rate during exercise increased with elevating air temperature above 20°C environment.

In our earlier study on resting metabolism in conditions of air temperature between 20°C and 28°C, metabolic rate at rest in the 24 and 26°C environments were significant lower than that at 20, 22

and 28°C. (OHNAKA *et al.* 1981). Under these experimental conditions, physiological functions such as metabolic rate, body temperature and heart rate were influenced by changes in air temperature under conditions of air temperature between 20°C and 28°C. In the studies on effects of high or low air temperature conditions on physiological functions, conditions air temperature between 20°C and 28°C were adopted as control thermal conditions frequently. It means that differences in physiological functions among these thermal conditions have to be taken into consideration in evaluating effects of high or low air temperature on physiological functions at least at rest or during a light exercise.

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気温20～28°Cにおける軽作業時生理反応

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8名の男子大学生を被検者とし、人工気候室において気温20, 22, 24, 26及び28°Cの環境下で60分間の安静坐位ののち、40Wの自転車エルゴメータ作業を30分間行わせた。相対湿度は50%、気流は20 cm/sec以下に保った。被検者の衣服は短パンのみとし、作業中の直腸温、平均皮膚温、代謝量及び心拍数を測定した。各測定値は作業終了前5分間について検討された。

直腸温は気温26及び28°Cにおいて、気温20°Cより有意に高い値を示した。また気温28°Cにおける直腸温は気温22°Cにおける直腸温より有意に高かった。平均皮膚温及び心拍数は気温が高い程、高い値を示し、平均皮膚温及び心拍数と気温との間には正の相関が存在した。代謝量は気温26°Cにおいて最低値を示した。

従来の作業時生理機能に及ぼす低温及び高温の影響に関する研究において、対照として採用されることの多い気温条件の範囲内(20～28°C)においても、作業時の生理機能が気温の影響を受けることが示された。特にそれらの条件下において、体温や心拍数のみならず代謝量においても気温の影響が存在することが示された。