

夏季，運動時における長距離選手の 耐暑性におよぼす2～3の因子

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FACTORS AFFECTING HEAT TOLERANCE IN DISTANCE RUNNERS DURING EXERCISE IN SUMMER METEOROLOGICAL CONDITIONS

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マラソンのように，長時間にわたるしかも激しい身体運動の成績は，低温環境下の場合と比較すると，高温環境下で著るしく低下することがよく知られている。しかしなかには，その酷暑環境に強く影響される者もいれば，影響力が比較的小さくてすむ者もいて個人差があることもよく知られている。すなわち後者は“暑さに強い選手”と呼ばれる者である。本研究は高暑負荷に対する生理的反應の個人差を検索し，耐暑性の支配的因子について検討しようとしたものである。

6名の長距離走者が本実験に参加した。それらの被検者に，個人の最大酸素摂取量の65～70%に相当する負荷による自転車労作テスト（60分）が外気温23℃と33℃，比湿60%の異なる環境温下で与えられた。その結果，低温環境下で

は全員がその60分労作テストを完了することができたのに対して，高温環境下では3名が，30分，40分，45分時にそれぞれ疲労困憊のために労作テストを中止した。そこで，これらの3名を2群とし，高温環境下で60分の労作テストを完了した残りの3名を1群として，両群の生理的諸反應を下記に比較した。

1. 酷暑環境下で労作テストを中止した時の2群の顕著な生理的反應は；1名が体温調節の臨界温度に近い高体中心部温（39.9℃）をまねき，次の1名は高体中心部温の他に過剰肺換気現象を呈し，そして残りの1名が高体温をまねく以前に頻脈（191/分）を伴う強度の生体負担度を示した。

2. 体中心部温に対する発汗開始の閾値温には，両群間に差を見ることができなかった。し

かし、体中心部温—発汗速度の関係においては、1群は2群よりも大きな勾配を呈した。このことは、同一高暑負荷に対して、耐暑性の大きい者の汗腺の感受性、あるいは興奮性が高いことを示すものである。この結果、1群の熱貯含量は2群よりも小さく、すぐれた奪熱(放熱)機転が考察された。

3. 耐暑性の大きい1群の皮膚熱貫流率は2群よりも大きく、放熱に対する末梢循環系の応答も効果的であったことが観察された。高暑負荷による2群の心拍応答が1群よりも大きいことから、2群の放熱の機転は全てにおいて1群より劣るものであった。

4. 2群の1名は過度の発汗量を高温下労作時に示した。その結果、発汗による水分および塩分の喪失は身体内部の平衡保持を乱すこととなり、過呼吸、めまいを伴う軽度の熱症状をまねくこととなった。このことは高温環境下での激しい運動では、有効汗量が重要な因子になることを示したものである。

5. 以上の結果、汗腺の興奮性や発汗の至適量を含めた発汗機能の良さが高温環境下における激しい運動の成績に及ぼす支配的因子と考えられ、そのようなすぐれた放熱機転をそなえた者が“暑さに強い選手”の特性であると考えられる。



Courtesy of Asahi Shinbun Newspaper Co.

SUMMARY

The present study was undertaken in order to investigate some factors limiting work performance in summer-meteorological conditions. Six distance runners performed on a bicycle ergometer at a constant work load which was set a 65-70% max $\dot{V}O_2$ measured at a comfortable temperature. The subject performed a full time 60-min work load with an identical work load both in cool (23.5°C) and hot (33.5°C) environments at 60% relative humidity. Three subjects were able to perform the standard test in the hot environment, whereas the remainders failed to complete it. The former was referred to as group 1 and the latter as group 2. The followings are some findings :

1. In the hot environment, $\dot{V}O_2$ cost for the work was raised to 75% (mean value) from 64% measured in the cool environment. The increase in submaximal $\dot{V}O_2$ might have been due to the additional O_2 requirements for peripheral circulation, sweating. A decrease in the efficiency of oxidative phosphorylation in the working muscle cells may have been due to hyperthermia because of the increased O_2 cost.

2. When the work was terminated at higher levels of ambient temperature, the physiological responses were somewhat different among the three men of group 2. One subject showed a typical symptom of hyperthermia indicating Tr 39.9°C, and HR 183 bpm. The hyperthermia of the subject was associated with lower sweat rate. The second man terminated the work with Tr 39.5°C. In addition, the subject exhibited pulmonary hyperventilation when he was forced to terminate the work. The third subject of group 2 stopped the work with the highest HR of 191 before the internal temperature approached a critical point. However, based on the observation that his blood lactate was elevated and that the subject was almost exhausted, his work load, which was about 60% in the cool environment, might have become highly intense at the hot environment.

3. The circulatory burden due to heat dissipation was obviously greater for those of group 2 than for those of group 1. Such a phenomenon reflected in the greater HR was associated with a rapid rise in Tr during the work.

4. A higher rate of body heat storage was exhibited by the subjects of group 2. This might have played a significant role in decreasing the work and producing hyperthermia.

5. With one exception hyperthermia, which was a main factor in limiting work performance was associated with lower sweat volume. In addition, sweating sensitivity reflected in the steeper slope of sweat rate-core temperature relation was greater for group 1 than for group 2, although there was no difference in sweating onset between two groups. This groups' sweat rate-core temperature relation may have served an important role in prolonging work in the hot environment.

6. The sweat rate of one subject in group 2 was 47% greater than the mean value of group 1. Loss of water and electrolytes due to excessive dehydration might have resulted in disturbing his internal homeostasis. This indicates that effective amounts of sweating are very important to perform strenuous exercises in heat.

INTRODUCTION

When man exercise, his internal body temperature increases depending upon the intensity of the exercise (1,17,30). During exercise in environments between 5 and 30°C, less than 60% relative humidity, referred to as the prescriptive zone (15), the increase in the internal temperature due to the increased metabolism within the working muscles can be well regulated through the heat dissipation mechanism (18). It is common experience, however, that hot environments result in impaired ability to perform exercise that is easily done in cool environments. The degree of the deterioration by heat load depends largely upon the types of exercise. In fact, some investigators (5,13) have demonstrated significant decrements in maximal aerobic power in heat while others (19, 26,28) have reported no modification of the power which is represented by maximal oxygen consumption. In the former studies measurements were done in hot environments which induce hyperthermia, whereas in the latter studies the maximal oxygen consumption was assessed before thermal stress could cause hyperthermia.

Man's ability to adjust physiologically to high ambient temperatures above 40°C has been the subject of intensive study for the past decade. This phenomenon has been of particular interest to those in the athletic field insofar as it relates to the athletes' performance in hot weather. In most instances, temperature regulation is apparently a limiting factor in performing mild exercise in hot environmental conditions. However, exercise in heat places a double stress on the circulatory system which has to provide oxygen to the exercising muscles and at the same time increase peripheral circulation for heat dissipation. Since environmental conditions in summer, in general, go beyond the prescriptive zone, men participating in prolonged exercise face the aforementioned problems. Studies of the effect of high ambient temperatures on athletes' physical performance have been conducted by a few investigators in the past. Based on coaches' observations, it is well known that some distance and marathon runners are scarcely affected by heat load from summer weather while others are severely affected. The mechanism underlying this phenomenon are not yet well defined in terms of a scientific basis. In hot environments cardiorespiratory strain may serve as a limiting factor for some, while for others thermoregulating aspects may result in a major factor to limit work.

Purpose of the Study

The purpose of the present study was to investigate thermal and cardiorespiratory responses during moderate-heavy prolonged work in summer meteorological conditions. In conjunction with these responses in cool environments were also investigated.

Definition of Terms

Body core temperature. This term is defined, in this study, by rectal temperature measured at a depth to 10 cm from the external anal sphincter.

Body surface temperature. This term is defined as mean skin temperature computed as a weighted mean of 6 sites on skin.

MATERIALS AND PROCEDURES

Subjects

The subjects in this study consisted of six distance runners, aged 19-23 yr, at Chukyo University. Biometric data of the subjects are given in Table 1. None of the subjects was particularly heat acclimated. Due to technical problems, the maximal oxygen consumption of subject A was not assessed. However, former data on him showed that he had the highest value among the subjects. Several days before the experiments begun, maximal oxygen uptake was measured directly from the subjects on a motor-driven treadmill in room temperature of 22°C, employing the so called "Rikuren Method," the assessment technique for maximal oxygen uptake developed by the Japan Federation of Track and Field.

TABLE I
SELECTED SUBJECT DATA

Subject	Age (yr)	Hight (cm)	Weight (kg)	Body Surface (m ²)	$\dot{V}O_2$ max (l/min)	Work load (kpm/min)
A	23	172.0	64.4	1.76	—	1200
B	19	168.0	58.9	1.68	3.60	1200
C	20	172.5	66.0	1.78	4.16	1320
D	20	165.5	56.3	1.62	3.72	1200
E	19	170.0	50.8	1.58	3.81	1200
F	22	162.0	59.2	1.63	3.39	1080

Procedures

A standard exercise was performed on a friction bicycle ergometer (Monark) in cool (23.5°C, Ta; 60%, rh) and hot (33.5°C, Ta; 60%, rh) environments. Velocity of air movement was approximately 1 m/sec. The brake load on the bicycle was set at a different rate for each subject but at a rate which would yield an oxygen consumption between 60-and 70% of the individual's maximal oxygen uptake at an ambient temperature and then, one week later, in the hot environment. Because of the possibility of a circadian effect all assessment tests were performed at the same time of day.

On their arrival at the laboratory each morning in the post absorptive state, the subjects reclined on a nylon webbed cot for 1 hr after the preparations for the test including weighing were completed. On entering the climatic chamber the subjects sat on the bicycle while base-line measurements were printed out. The pedal frequency was kept at a constant rate of 80 rpm. The subjects wore short and tennis shoes only. No fluids were allowed the subjects during the exercise in either the cool or hot environments.

Physiological Parameters

Body temperatures were continuously monitored during the exercise. Rectal temperat-

ure (Tr) was measured at a depth to 10 cm from the external anal sphincter by a copper-constantan thermocouple. Skin temperatures were measured with copper-constantan thermocouples from 6 sites (forehead, 3 cm above the nipple, mid-point lateral surface of the forearm, middle finger, inner surface of the thigh, and mid-point of posterior surface of the calf). Mean skin temperature (\bar{T}_s) for each subject was computed as a weighted mean of the measurements as follows :

$$\bar{T}_s = 0.07\text{head} + 0.36\text{chest} + 0.14\text{arm} + 0.10\text{finger} + 0.20\text{thigh} + 0.13\text{calf}$$

Total evaporative sweat loss was determined from weight changes of the nude subject before and after the work with a scale sensitive to ± 5.0 g, with no correction for respiratory water loss. A 12.6 cm² capsule was used to obtain local sweat rates on the chest and back. Sweat was collected with filter paper discs at a collection interval of 10-min during the exercise and the sweat rate (SR) was measured by weighing the filter paper discs.

For the determination of oxygen consumption during the exercise, expired gas was collected with Douglas bags at the 10th, 30th, 60th minutes during the work period, air volume was determined with an electrically sucking gas meter, and gas analysis was performed using a O₂-CO₂ analyzer (Fukuda Respizizer). Heart rate (HR) was recorded with an ECG, every 5 minutes. Blood samples were drawn from the antecubital vein at the 0, 30th, and 60th minutes during the work for lactic acid (HLA) and for Hematocrit (Hct) determinations.

The rates of body heat storage (S) were determined by the equation $S = 0.83 Wt (0.9 Tr + 0.1 \bar{T}_s)$, where 0.92 is the specific heat of the body tissues in Kcal and Wt is body weight in kg which is then converted into Watt/m². Thermal conductance (K) was calculated from the following equation, $K = M / (Tr - \bar{T}_s)$, in which $K = \text{Watt} / (\text{m}^2\text{C})$, $M = \text{Watt} / \text{m}^2$ calculated from the measured O₂ consumption.

RESULTS AND ANALYSIS OF DATA

Out of all the subjects three were able to perform the full 60-min work test at the higher ambient temperature while the other three subjects were unable to complete the work. The former are referred to in the text as group 1, whereas the latter, as group 2. The performance time of group 2 averaged 38.3 minutes. All the subjects were able to perform the full 60-min work in the cool environments. Mean $\dot{V}O_2$ and \dot{V}_E of each group under the two environmental conditions are graphically compared in Fig 1. Venous blood lactate concentrations, and rate of body heat storage and thermal conductance during the first 30-min of the work are also shown in the figure. Mean $\dot{V}O_2$ of group 1 in the cool and hot environments were 2662 (57.4 ml/kg) and 2797 (59.1) ml, respectively, while the corresponding values for group 2 were 2327 (61.1) and 2574 (65.3), respectively. There was no significant difference among any variables (group 1 vs 2, and Ta, 23.5 vs 33.5°C) except for the variable of group 2 between Ta, 23.5 and 33.5°C ($P < 0.05$). No significant differences were found in mean \dot{V}_E between either the two groups or the two different ambient temperatures.

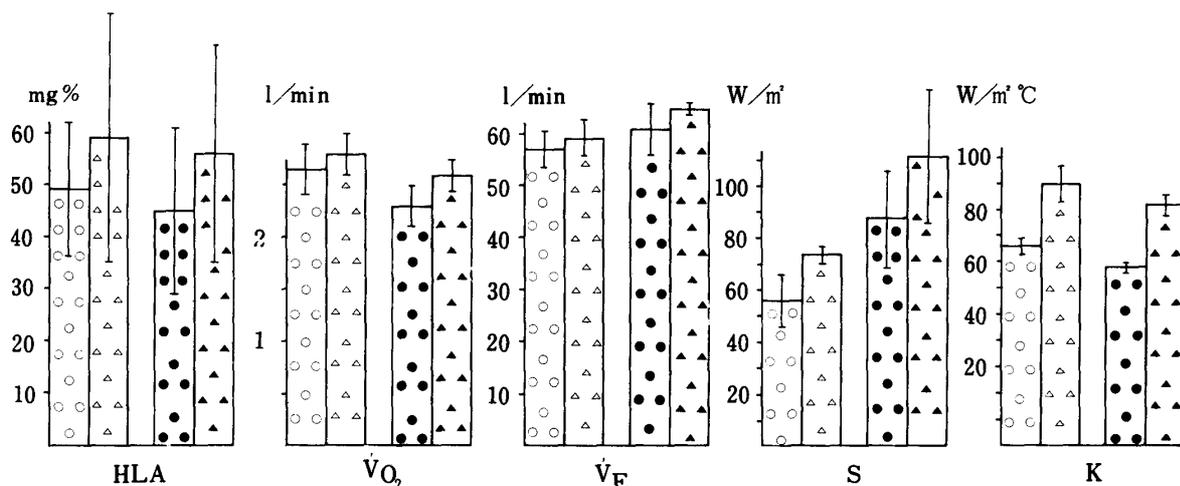


Figure 1. Mean Values for Blood Lactate, Oxygen Consumption, Pulmonary Ventilation, Rate of Body Heat Storage, and Thermal Conductance of Two Groups under Two Conditions

(The brackets (I) represent ± 1 standard deviation. Circular and triangular symbols denote cool and hot environments, respectively. Unfilled and filled symbols denote group 1 and group 2, respectively.)

Venous lactate patterns were similar during the work at both cool and hot environments, with greater mean lactate levels at the 30th and 60th min of work than at rest. Furthermore, blood lactate levels at the 30th min of work were significantly greater than at the 60th min ($P < 0.05$). Comparing the levels at corresponding times, however, no significant difference was seen either between the groups or the ambient temperatures. Surprisingly, body heat storage of group 2 in the cool environment was slightly greater than that of group 1 at the hot temperature. There were significant differences in the rates between the two groups at both environmental temperatures ($P < 0.05$). Group 1 showed greater thermal conductance in the cool ($P < 0.05$) and hot environments ($P < 0.01$) than their respective values in group 2. Such greater thermal conductance for group 1 may reflect greater blood flow to the skin. Conductance at the higher temperature for the two groups was higher than that of the lower ambient temperature ($P < 0.01$).

The time-course HR, Tr, and \bar{T}_s are presented in Fig 2. The mean values of all these parameters at any time during the work was lower in the cool than in the hot environments. It should be noted that after the beginning of the work, the \bar{T}_s at the higher level of T_a , rose rapidly and then tended to level off, whereas both HR and Tr showed no such a plateauing effect. The relationship between the HR and Tr is almost parallel. Furthermore, the HR and Tr of group 2 in both cool and hot environments tended to be higher than the respective values of group 1, while the \bar{T}_s of group 2 is lower than that of group 1. Comparing HR between the two groups at an identical T_a , no significant difference was found at the lower level of T_a , whereas at the higher level of T_a the HR of the group 2 was significantly higher than that of group 1 at the 5th, 10th, 15th, and 20th minute of the work ($P < 0.05$ or 0.01). In addition, the HR for group 2

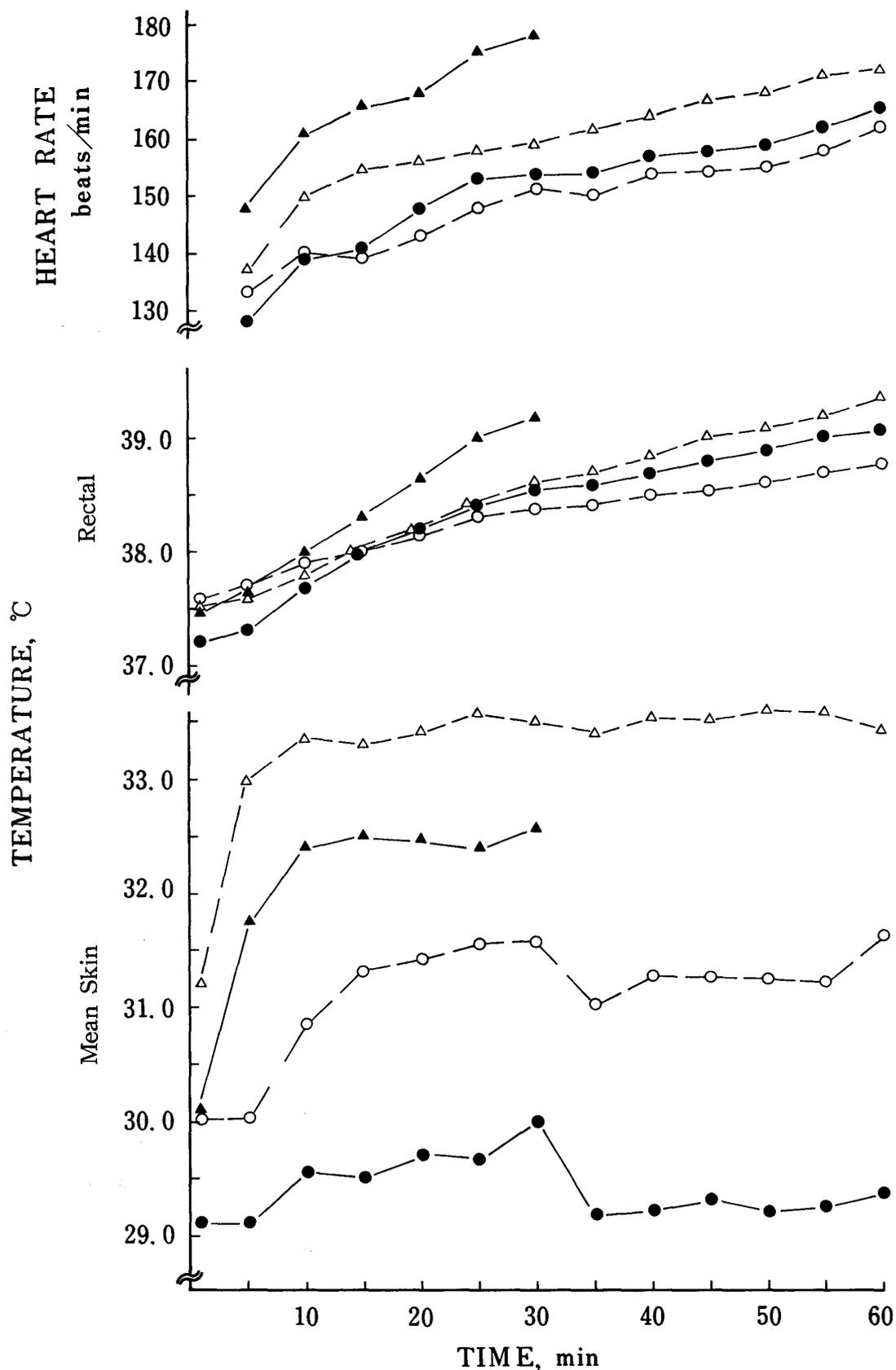


Figure 2. Average Heart Rate, Rectal Temperature, and Mean Skin Temperature of Two Groups during Work under Two Environments (Symbols as Figure 1.)

at the higher level of T_a was significantly higher than that at the lower level of T_a , whereas no significant difference was seen for group 1 except during the last 10 minutes between the two environments. Fig 3 shows T_r as a function of HR. The lower ambient temperature results in lower HR for both groups; thus the slope of the T_r on HR is shifted to the right at the higher ambient temperature. According to the figure, one can draw the conclusion that environmental conditions obviously affect the HR for group 2 more than for group 1. It is noteworthy to observe from the figure that the slopes of the T_r /HR for both groups are parallel but that the slope for group 2 has shifted to the right.

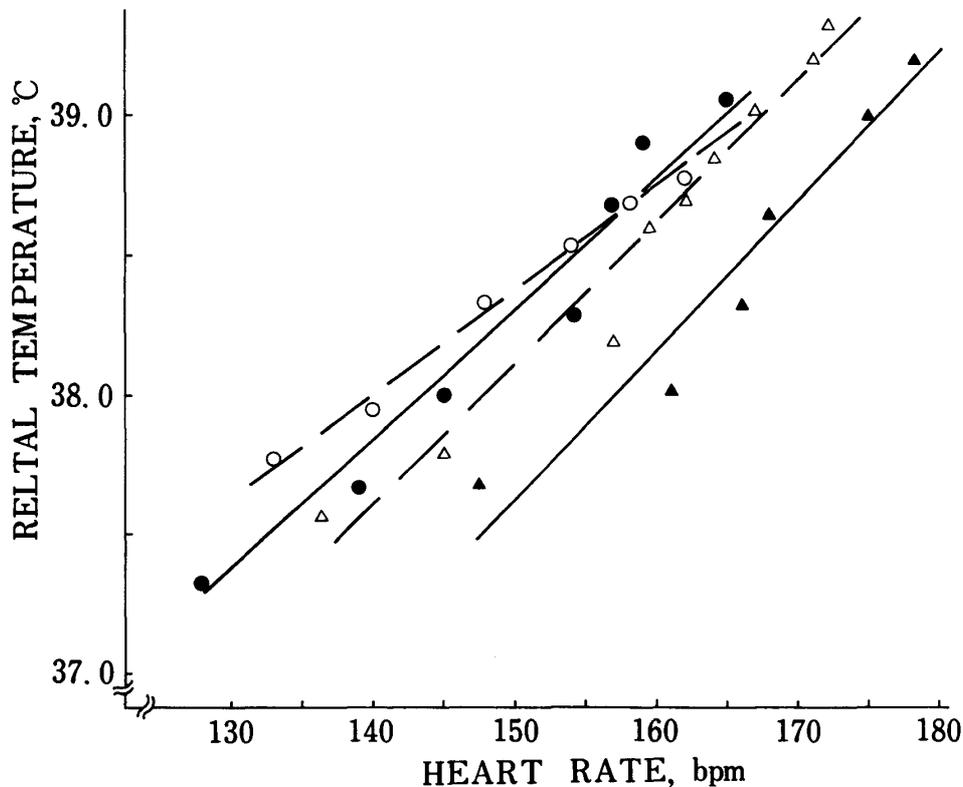


Figure 3. Core Temperature as a Function of Heart Rate
(Broken lines and solid lines denote group 1 and group 2 respectively.
Symbols as Figure 1.)

Although there was no significant difference in the T_r in general between the two groups at the lower levels of ambient temperature, it should be pointed out that the terminal T_r for group 2 reached above 39°C . No obvious equilibration of changes in the T_r was found in either group 1 or group 2 at either lower or higher level of T_a . The T_r of group 2 rose sharply to a terminal value of 39.2°C under heat conditions by 0.66°C higher than the corresponding value in the cool room ($P < 0.05$). The terminal value at the 60th minute of work in a hot environment for group 1 was also raised by 0.57°C ($P < 0.05$). It should be noted in particular that the T_r of group 1 obtained at any time during the first half period of work was not significantly raised by heat. Thereafter T_r at the higher level of T_a was significantly higher than that at the lower

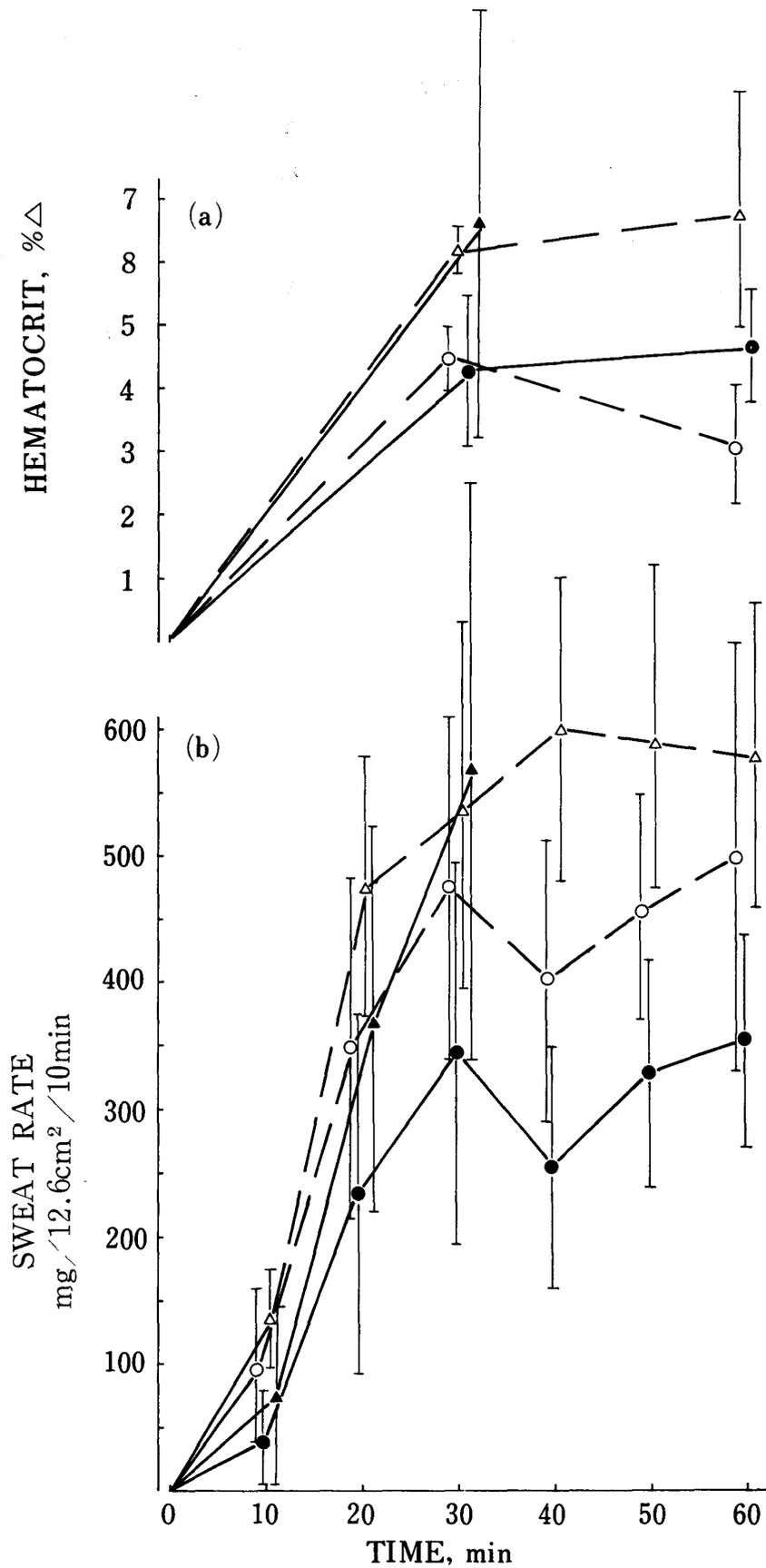


Figure 4. a and b. The Time Courses of Hematocrit (a) and Sweat Rate (b) of Two Group during Work under Two Conditions (Symbols as Figure 1)

level of T_a .

Mean skin temperature was obviously influenced by environmental conditions. In contrast to the T_r and HR described above, \bar{T}_s for group 2 was lower than that for group 1 at both ambient temperature. Furthermore, \bar{T}_s approached equilibrium following its initial rise.

Fig 4 and 5 depict the time-course changes in local sweat rate and changes in rate as a function of core temperature, respectively. It is of interest to observe the following : 1) the slope of the sweat rate/rectal temperature relation at both lower and higher environments was greater for group 1 than for group 2 ; 2) the slope obtained from the two different environmental conditions was almost identical for each group ; 3) the threshold for sweating at the higher temperature was identical for both groups ; 4) the threshold for group 1 shifted slightly to the left at the higher temperature, whereas that for group 2 was identical at both temperatures.

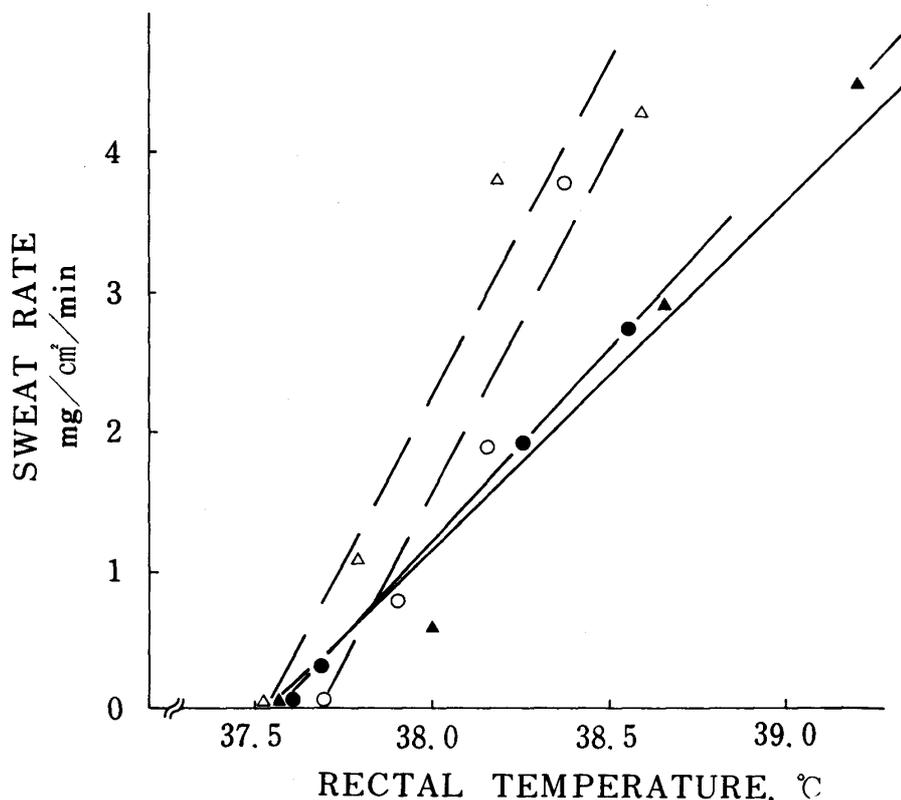


Figure 5. Sweat Rate in Relation to Core Temperature
(Symbols as Figures 1 and 3)

Table 2 shows the individual values of HR, \dot{V}_E , T_r , and the sweat rate (local) in group 2 when the work was terminated. The corresponding mean values of group 1 are also presented in order to make clear which factor influenced the work performance in heat for the individuals in group 2. Subject D terminated his work in heat with a T_r and the sweat rate of 39.90°C and 1.29 mg/min/cm², respectively. These values are higher by 2.3% and lower by 37.4% than the respective mean values of group 1. The T_r of 39.90°C was the highest among all the subjects. Subject E finished the work with

\dot{V}_E , Tr, and the sweat rate of 85.9 l/min, 39.57°C, 5.12 mg/min/cm², respectively. The \dot{V}_E was greater by 55.4% than that of group 1 indicating hyperventilation in heat. Furthermore, the value obtained in heat was raised by 40% from that in the cool environment, whereas no obvious influence was seen on the \dot{V}_E of the other subjects. It should be noted that sweat produced by subject E was 47.1% greater than that of group 1 while the other two who could not tolerate the full 60-minute of work produced a smaller volume of sweat. Subject F terminated the work in heat with HR and Tr of 191 beats/min and 38.80°C, respectively, indicating that the HR was higher by 20% while the Tr was higher by only 0.5% more than the corresponding mean values of group 1. It must be pointed out that the Tr of 38.80°C is generally not high enough to force the subject to terminate work.

TABLE 2
INDIVIDUAL VALUES OF HEART RATE, PULMONARY VENTILATION, RECTAL TEMPERATURE, AND SWEAT RATE AT THE 30TH MIN DURING WORK IN GROUP 2 AND AVERAGE VALUES OF THE SAME PARAMETERS IN GROUP 1 IN TWO ENVIRONMENTS

Subject	HR, bpm		\dot{V}_E , L/min		TR, °C		SR, mg/cm ² /min	
	Individual Value	Mean Group 1	Individual Value	Mean Group 1	Individual Value	Mean Group 1	Individual Value	Mean Group 1
Group 2	(±△%)		(±△%)		(±△%)		(±△%)	
Ta=23.5°C								
D	160	162	60.9	60.0	39.35	38.77	1.29	3.03
	(-1.2)		(1.5)		(1.5)		(-57.4)	
E	161	162	60.4	60.0	38.84	38.77	3.13	3.03
	(-0.6)		(0.7)		(0.2)		(3.3)	
F	176	162	66.7	60.0	39.00	38.77	1.76	3.03
	(8.6)		(11.2)		(0.6)		(-41.9)	
Ta=33.5°C								
D	182	167	55.7	61.9	39.90	39.02	2.18	3.48
	(9.0)		(-11.1)		(2.3)		(-37.4)	
E	173	164	96.2	61.9	39.53	38.86	5.12	3.48
	(5.5)		(55.4)		(1.7)		(47.1)	
F	191	159	62.2	59.1	38.80	38.60	2.06	3.05
	(20.1)		(4.9)		(0.5)		(-32.5)	

In summary, as compared to group 1 performed the full 60-min work in heat, subject D terminated his work in heat with a higher internal temperature and with a lower sweat rate; subject E, with hyperventilation and hyperthermia; and subject F, with a higher HR and a low sweat rate.

Fig 4, a demonstrates the hemoconcentrations during work at the cool and hot environments. Both groups show similar patterns of time-course changes in Hct. The Hct for group 1 tends to approach the pre-exercise value after it attained its maximal value in the lower level of Ta, whereas the Hct in the higher level of Ta increased by 8.2%

followed by a small increase at the 60th min of work.

DISCUSSION

With respect to the energy requirement for exercising in hot environments, it is a matter of some debate whether the exercise $\dot{V}O_2$ increases, decreases or remains comparable to that in comfortable environments. The results obtained in the present study showed a trend in which submaximal $\dot{V}O_2$ was increased by 13 and 12 percents in a hot environment for group 2 and 1, respectively. This finding was in agreement with other reports (3, 8, 16, 20). Possible factors accounting for this phenomenon are the increased energy requirements for peripheral circulation, heat dissipation, sweating activity, hyperventilation, and high internal temperature. Because of the relatively heavy work load in the present study, a trend of progressive increase in $\dot{V}O_2$ over time has been seen in the hot environment. From this observation it is obvious that the increased $\dot{V}O_2$ in heat was due to fatigue. It is of interest to note, however, that Kuno (14) estimated maximal metabolic costs of sweating to be relatively negligible.

In contrast to these findings, there are some controversial reports in which the $\dot{V}O_2$ during work in hot environments decreased below normal values. The reasoning is based upon a failure to observe greater than normal increments in cardiac output in response to work in heat (23, 28). However, such an interpretation is not applicable to the results observed in the present study because O_2 cost for the work in heat did not approach near maximal value except for subject F. Brooks *et al.* (2) in a well-designed study have attributed the decrease in efficiency of oxidative phosphorylation in skeletal muscle to elevated temperature which results from exercise-induced hyperthermia. This finding could account for the increase in submaximal $\dot{V}O_2$ under conditions of hyperthermia. The authors of this study would speculate that the increased submaximal $\dot{V}O_2$ in heat was due at least to the reduced phosphorylative efficiency in addition to the extra demands placed on the cardiovascular system.

Subject E of group 2 was forced to terminate the work in heat with marked hyperventilation accompanied by a critical temperature of 39.53°C. Ventilation in the heat condition reached about 1.8 times as high as that in the cool environment. It has previously been reported that tolerance time in hot environments was reduced due to hyperventilation (7, 9, 16). Since we have made no attempt to analyze blood pH nor P_{CO_2} , it is difficult to attribute the hyperventilation to respiratory alkalosis. Because of the fact that the lactic acid level of the subject in heat was elevated about 2 times as high as the corresponding value in the cool environment, it is probable that the source of hyperventilation is due, at least, to respiratory alkalosis. Hackabee (12) demonstrated that HLA elevation during hyperventilation was related to respiratory alkalosis.

Blood HLA concentration for a given work tended to be raised by heat stress although no statistical significance existed. Such an elevation of HLA in heat has been also reported in previous studies (21, 22, 28). The principal reasoning for this phenomenon is that O_2 transport to the working muscles has been compromised by increased levels of cuta-

neous blood flow for heat dissipation. Since a tendency for increased submaximal $\dot{V}O_2$ in heat was observed in the present study, the above-mentioned interpretation is not applicable to the results obtained in this study. Based on the theory of decreased efficiency of oxidative phosphorylation, this tendency should be interpreted as the O_2 demand in the muscles exceeding the O_2 supply so that the work could be done more anaerobically. As stated in the preceding section, work in heat places a double stress on the circulatory system which must provide O_2 to the working muscles and at the same time increase cutaneous circulation for heat dissipation. Thus an elevation of HR in heat is clearly demonstrated in Fig 2. The double stress caused a greater increase in heart rate with higher Tr in group 2 leading to early termination. Consolazio *et al.* (4) have described similar results. Fig 3 shows clearly that the men of group 2 were affected more by work-heat stress in terms of the cardiovascular system reflected in HR. In the figure the slope of the Tr/HR relation for group 2 was shifted more to the right indicating a greater increase in HR per degree rise of core temperature. Thus it is obvious that the cardiovascular burden during standard work in a hot environment was greater for group 2 than for group 1. Especially subject F of group 2 terminated the work with the highest value of 191 bpm but without approaching critical internal temperature. Also, an augmented decline in stroke volume during exercise in heat has been widely noted (16, 24, 27). The most common explanation for this would appear to be a reduced ventricular filling pressure resulting in a pooling of the blood in the cutaneous venules. Such an impaired cardiac function as a result of heat might have played a main role in limiting the working ability of subject F whose core temperature did not reach the critical temperature. The least effect of heat on HR was seen in those whose aerobic power is superior to others. This finding may suggest that a higher level of aerobic fitness is essential in order to tolerate a prolonged work in hot environments.

Subject D of group 2 showed typical responses to work-heat stress. His terminal values of HR and Tr were 182 bpm and 39.90°C , respectively, resulting in the highest rate of S, 140 w/m^2 . Clearly, his thermal load is outside Lind's prescriptive zone (15) in these conditions, i. e., T_a is 33.5°C , rh 60%, and work load 70% max $\dot{V}O_2$. Since the subject showed a higher internal temperature of 39.35°C even in the cool environment, the temperature regulating function of the subject was obviously lower than the others. Tolerance time is a well known function of body heat storage of which rectal temperature is the major contributor. In general, the Tr of group 2 failed to reach an equilibrium level indicating that in hot-wet environments with a moderate-heavy work thermal equilibrium is not achieved. Fig 1 illustrates a trend in which group 1 had a lower rate of S with a higher K while group 2 had a higher rate of S with a lower K during work in the hot room. The implication of this is that the circulatory role for the transfer of heat to the periphery is more effective for group 1 than for group 2. Fig 6 further illustrates this relationship. In the figure the K at the 30th min of work in both environmental conditions was individually plotted as a function of core temperature. The degree of increment of K along with an increase in Tr is more sensitive for group 1 than for group 2. This higher sensitivity exhibited by group 1 suggests that effective heat dissip-

ation is the result of cutaneous blood flow and might have played as an important role as dissipating function.

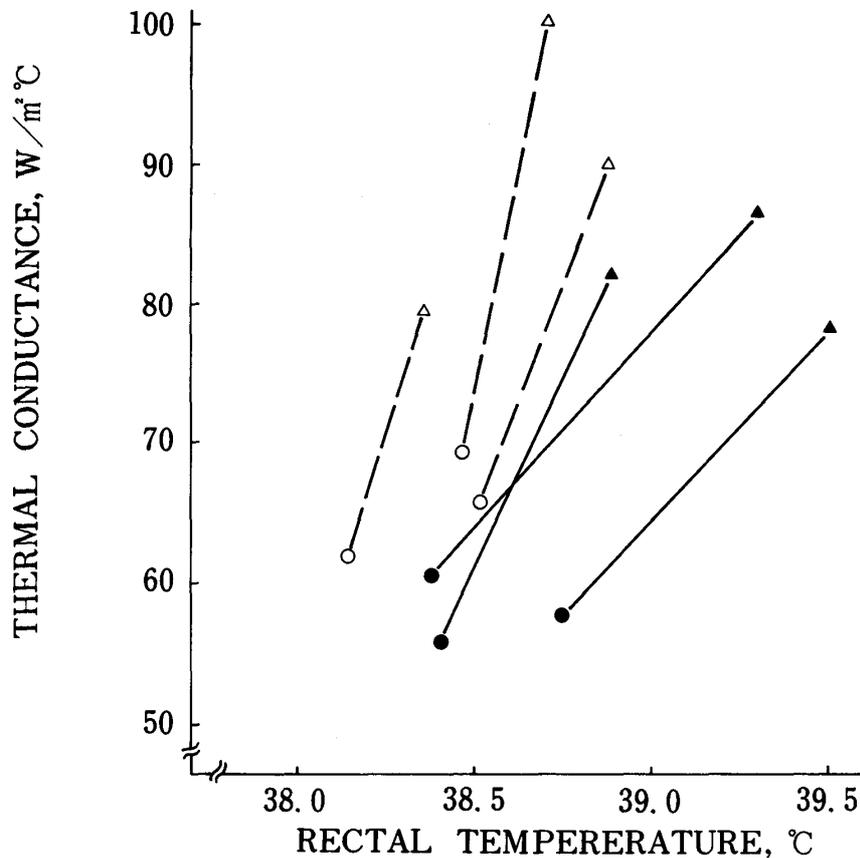


Figure 6. Thermal Conductance at the 30th Min of Work under Two Conditions for Two Groups (Symbols as Figures 1 and 3)

The failure of heat dissipation to occur in group 2 in the hot environment is not only the result of reduction in heat transport as stated above, but also as a result of less power in evaporative cooling. The latter is the major function to regulate body temperature under work-heat stress. Since the amount of total heat produced is a function of the absolute metabolic rate, it must be said that group 1 could have dissipated more of the metabolic heat produced during the work although it was greater than that of group 2 according to the observed absolute value of $\dot{V}O_2$. With the exception of subject E, greater heat storage was associated with the lower sweat rate represented as a local rate (see Table 2) in group 2. It is of interest to note that, even in the cool environment, the \dot{S} of two subjects in group 2 was larger than the mean value of group 1 in the hot room. This finding clearly indicates that the thermoregulating system of these subjects is not powerful enough to control the exercise-induced hyperthermia even in cool environments. Fig 5 offers us a clear-cut information to understand the aforementioned phenomenon from the view of sweating. At the higher level of T_a , the mean T_r threshold for sweating was identical for both groups. However, the slope of the sweat rate-

core temperature relation was steeper for the group 1 than for group 2, indicating a greater sensitivity of the sweat gland activity to a given thermal stimuli in group 1. Thus the heat dissipating thermal balance resulting in prolong work capacity in hot environments. The improved sweating capacity reflected in the greater gain of SR/Tr has also been reported as an improved temperature regulation (29). Further it has been reported that the lower Tr and HR during exercise in heat was associated with enhanced sweating at a given level of central thermal drive (10).

From the preceding section, one can draw the conclusion that sweating serves as an important role to tolerate work when exercising in heat. However, subject E was forced to terminate the work in high ambient conditions with hyperventilation and elevated Tr showed a greater sweat volume indicating 3.2% of body weight loss per hour. His local sweat volume was greater by 50% than the mean value of group 1. Since the internal temperature of the subject attained a critical point, it is obvious that the greater amount of sweating was ineffective in terms of heat dissipating power. It is probable to infer that such an over-dehydration might rather have contributed to the disturbance of his internal homeostasis resulting in the shortening of performance time in the hot environment.

CONCLUSIONS

Based on the findings of this investigation, the following conclusions appear to be warranted.

1. man's ability to prolong work in hot environments depend largely upon his thermoregulating function which dissipates heat from core to surface. In this regard, the greater sensitivity of sweat gland activity is the main factor in maintaining thermal balance.

2. Peripheral circulation has also a large role in heat conductance from core to surface. Consequently the level of aerobic fitness may serve to tolerate work under hyperthermia conditions.

3. Excessive sweating, in turn, deteriorates work tolerance in heat due to the disturbance of the internal homeostasis. This suggests the importance of the effective sweating system.

4. Efficiency of cardiovascular and cell functions is also essential in order to prevent an increase in metabolic burden, so that man can minimize and delay his fatigue due to heat stress.

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