

The effects of moderate heat stress on patients with ischemic heart disease

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ANDERSEN, I., JENSEN, P. L., JUNKER, P., THOMSEN, A. and WYON, D. P. The effects of moderate heat stress on patients with ischemic heart disease. *Scand. j. work environ. & health* 4 (1976) 256—272. With the use of a climate chamber, the effects of a 3-h exposure to moderate heat stress (23 to 29°C) on the physiology, comfort, and performance of 20 subjects, 10 with slight (group I) and 10 with moderate (group II) ischemic heart disease (IHD), were studied. Twenty matched control subjects were similarly exposed. All of the subjects performed sedentary, mental work throughout the exposure. Humidity was 9 mm Hg; air velocity, 10 ± 3 cm per second; and thermal resistance of the clothing, 0.7 clo. Under identical conditions no significant differences in rectal, skin, and finger temperatures or weight loss existed between the three groups, but during heat stress the temperatures and weight loss were always significantly higher than under the control conditions, except for rectal temperatures during the first 2 h. There was no difference between the groups or the two sets of conditions in respiration rate and diastolic blood pressure, but the patients had a significantly lower systolic blood pressure in the third hour of heat stress than under the control conditions. Heart rate and the rate-pressure-product during heat stress were significantly higher in the controls than in the patients. A few patients experienced a slight retrosternal oppression during heat stress, but only one had ECG changes, and none of these symptoms or signs were present under control conditions. Under both sets of temperature conditions the patients were uncomfortable during a longer period of time than the controls, and they were more sensitive to temperature changes, group II being more sensitive than group I. The comfort distribution curve was very narrow for group II. The performance tests were numerical addition, card punching, cue-utilization and creative association. In numerical addition no temperature effect could be shown on the speed of working, but for the patients in group II during heat stress the level of accuracy in the second hour was lower than under control conditions; the trend was the opposite for control subjects. No differences occurred in the first or third hour. In card punching the patients in group II worked significantly more slowly during heat stress than did the control subjects, who improved their performance in heat, as did the patients in group I. A similar effect was found on the accuracy with which this task was performed, the patients in group II making significantly more errors in the heat than patients in group I. Cue-utilization did not differ between groups or conditions. Patients performing the creative association test under heat stress supplied significantly fewer unique answers than did patients working under control conditions; no such effect of heat was observed for control subjects. We conclude that patients with IHD are more sensitive to moderate heat stress than healthy control subjects in terms of mental performance and comfort. There are some differences in cardiopulmonary function but no differences in thermoregulation.

Key words: heat stress, temperature variations, ischemic heart disease, heart patients, thermoregulation, cardiopulmonary function, comfort, mental performance, climate chamber.

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Heat stress and mortality have long been linked together. This connection applies to acute heat stress, e.g., urban heat waves (15, 30), and to seasonal variations in areas with comfortable winters and hot summers (8). In both cases the risk is substantially higher for persons with ischemic heart disease (IHD). The purpose of the present

investigation was to study the changes in physiology, comfort, and performance caused by short-time moderate heat stress imposed on nonacclimatized subjects with IHD. The study was designed to simulate the heat stress encountered in normal life situations with sedentary, mental work as in offices and schools.

MATERIALS AND METHODS

Subjects

The sample comprised 40 Danish male volunteers 45 to 59 years of age. Twenty were patients with IHD and 20 were healthy control subjects. The patients had been admitted to the coronary unit of the Aarhus County Hospital from 1967 to 1970 with a well-established acute myocardial infarction. None of them were suffering from arterial hypertension, cardiac rhythm disturbances, pulmonary disease, obesity, or other chronic disorders. Three patients had a slight cardiac enlargement in their chest X-ray, and all but one had ECG changes indicating a previous myocardial infarction. Digitalis and nitroglycerin were used by three and four patients, respectively, and were not discontinued. According to the criteria of the New York Heart Association for functional classification of heart disease (11) 10 patients belonged to class I (patient group I) and 10 to class II (patient group II).

By means of the national register in the town of Aarhus each patient was paired with five potential control subjects who

were of the same sex and age, had the same type of occupation, and who lived in a housing area of the same standard. With the use of a questionnaire the subject in each group of five who most resembled the patient as to weight and height was selected. Only clinically healthy subjects were included as controls. Neither patients nor controls were acclimatized to heat, and all were physically untrained.

The physical characteristics for the patients and the controls are given in table 1. No significant differences can be shown between each group of patients and their matched controls on these parameters. The three groups — controls, patients I and patients II — thus differed systematically only in that they presented, respectively, absence of, slight, and moderate IHD. At least two years had passed since the acute myocardial infarction of any patient.

Experimental conditions

The study took place in the climate chamber at the Institute of Hygiene, Aarhus, Denmark, (3) during 2 months when the weather was fairly constant, the average maximum and minimum outdoor temperatures being 9 and 2°C, respectively.

Two different sets of thermal conditions were used. The control conditions had a "saw tooth" temperature variation with a rise from 20 to 23°C during 50 minutes and a decrease to 20°C during 10 minutes. This variation was repeated twice during the next 2 h. The heat stress conditions had a base-line increase of 1°C per hour superimposed on the same saw tooth tem-

Table 1. Physical characteristics of the subjects. (Mean values $\pm$ one standard deviation; ranges in parentheses)

Group	Number	Age (years)	Height (cm)	Weight (kg)	Du Bois area (m ²)	Σ skinfold thickness ^a (mm)
Controls	20	51.4 $\pm$ 4.1 (45—59)	174.1 $\pm$ 6.6 (165—193)	74.4 $\pm$ 7.4 (59—87)	1.89 $\pm$ 0.11 (170—212)	78 $\pm$ 25 (29—117)
Patients, I	10	52.5 $\pm$ 4.6 (45—58)	175.9 $\pm$ 6.3 (165—187)	76.8 $\pm$ 6.4 (63—84)	1.93 $\pm$ 0.10 (170—208)	79 $\pm$ 26 (54—132)
Patients, II	10	53.3 $\pm$ 3.6 (46—58)	172.4 $\pm$ 5.7 (163—180)	73.7 $\pm$ 10.3 (64—98)	1.86 $\pm$ 0.11 (170—204)	79 $\pm$ 39 (36—172)

^a Σ skinfold thickness is the sum of measurements taken at the following five sites for each subject: midaxillary, supra-iliac, abdominal, triceps and thigh.

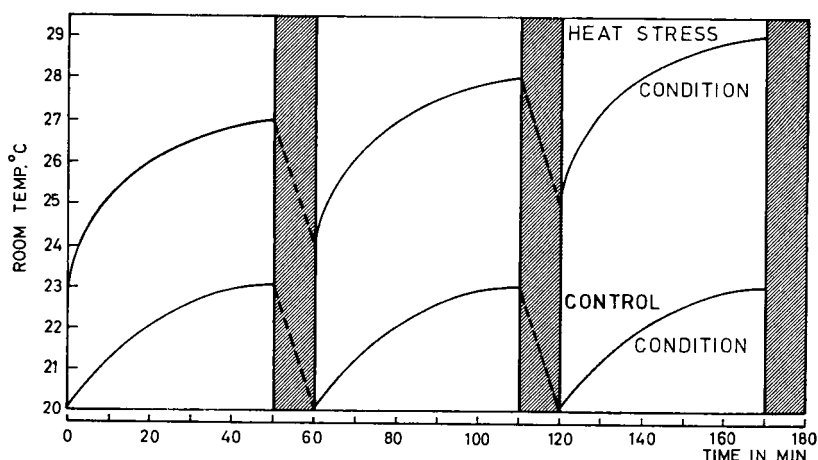


Fig. 1. The variation of room temperature with time (surface temperatures = air temperature) during heat stress and under control conditions. The hatched columns represent the rest periods.

perature variation starting at 23°C and ending at 29°C after 3 h (fig. 1). These temperature patterns are typical for occupied classrooms (2) and are also found in conventionally heated and ventilated offices. The temperature of the chamber walls and air was very similar ($\pm 0.5^\circ\text{C}$), the humidity was 9 mm Hg (50 % RH at 20°C), air velocity 10 ± 3 cm per second, and air supply rate 600 m³ per hour. The air was filtered by active charcoal filters and high performance filters; there was no recirculation. The measurements of the environment were taken according to the American Conference of Governmental Industrial Hygienists (1).

Experimental procedures

Pairs of subjects, two patients or two controls selected at random, were exposed at each session. The subjects attended to their normal work during the first 3 h of the day and were then brought to the laboratory by car, where they had a standard lunch and a general medical examination including a chest X-ray, a resting ECG (three standard leads and three precordial leads: V₁, 4, 6), and measurement of heart rate (HR) and systolic and diastolic blood pressure (BPS and D) in the supine position after 5 min of rest. Blood pressure was measured with the indirect auscultatory method (39). Electrodes for continuous ECG recordings were attached above the

sternum after careful skin preparation, and a thermal sensor at the nostril made it possible to record the respiratory rate (RR). An 11-point thermocouple harness for skin temperature measurements was attached, and a thermocouple in an indwelling catheter was inserted to a depth of 10 cm into the rectum. It was important to use procedures that would not disturb the performance tests, and due to its convenience rectal temperature was chosen instead of tympanic or esophageal temperature to indicate changes in the deep-body temperature. Finally, the subjects were dressed in a standard cotton uniform with a total thermal resistance of 0.7 clo.

In the climate chamber the two subjects were seated at individual desks facing a third desk used by the investigator (IA) who was present throughout the total exposure period. The subjects were then connected to the measuring equipment, and after a 20-min acclimatization period either the control or the heat stress conditions were commenced. During the periods of temperature increase (50 min — fig. 1) the subjects worked continuously at performance tests, but in the rest periods with decreasing temperature (10 min), they were allowed to relax and walk around in the chamber. During each session skin temperature at 10 points and finger and rectal temperatures were recorded continuously, ECG and RR were recorded at intervals of 15 min, and BPS and D were

measured at 5, 20 and 50 minutes. At the beginning and at the end of a session the subjects were weighed on a precision scale (± 3 g). The subjects were not allowed to smoke or drink alcohol for 12 h before the sessions, smoking and eating were not allowed during the sessions, but carbonated water was provided ad libitum. Each subject recorded his comfort sensations on a dial, on which the range of adjustment, covering a 270° angle, was divided into three equal zones, marked "cold," "comfortable" and "hot" clockwise. A pointer could be set to remain at any point on the scale, extremes of which were marked "much too cold" and "much too hot." No other graduation or wording appeared on the scale. Subjects were instructed at the beginning of each hour to ensure that the deviation of the pointer from the center of the scale always represented the magnitude of their sensation of thermal discomfort, and it was pointed out to them that this implied that they should alter the setting whenever they became aware of a change in their thermal sensation. No reminders were given during the periods of temperature increase. The subjects did not know the nature or size of the temperature fluctuations during the sessions, except that unbearable extremes (the end-points of the scale), at which they would be obliged to leave the climate chamber, would not occur in the experiment. This instruction was intended to discourage subjects from making settings at or close to the end-points, and thus scale compression would be avoided. The dial faces were recessed so that each subject could only see his own dial setting. As each pointer was connected to a potentiometer in a simple bridge circuit, the setting on each dial was remotely recorded every 72 s with an accuracy of 1 % of the full scale.

The performance tests were card punching, numerical addition, cue-utilization, and creative association. Card punching was performed for 15 min of each of the first 2 h by all subjects. Random number sequences of 40 digits were punched manually onto alternate columns of 80-column punch cards ("port-a-punch"),[®] each digit being entered by the removal of a perforated rectangle at the appropriate position. Though straightforward, the task demands considerable manual dex-

terity. The result was recorded as the number of columns punched and as accuracy. Under the heat stress conditions the temperature during this test rose from 23 to 26°C and from 24 to 27°C, respectively; and in the control conditions, from 20 to 22°C.

Numerical addition was performed for 20 min of each hour by all subjects. Random two-digit numbers printed in columns of five were to be added up, and the score was recorded as units added and the percentage correct. Under the heat stress conditions the temperature during this test rose from 26 to 27°C, from 27 to 28°C and from 28 to 29°C, and during the control conditions the temperature rose from 22 to 23°C. The ability to add is known to be impaired when the body temperature rises (40).

A version of the Tsai-Partington test of cue-utilization capacity was performed by all subjects towards the end of the second hour of each exposure, i.e., at 28°C during heat stress and at 23°C under the control conditions. The task was to connect letters of the alphabet and numbers, placed seemingly at random on the page, by drawing a line between the symbols in the sequence 1-A-2-B-3-C- and so on. The score was taken as the total number of such links correctly completed in 20 s. The performance of this task is known to be decreased by arousal due to anxiety (14).

The creative association test was administered in the third hour of each exposure when the temperature rose from 27 to 28°C during the heat stress conditions and from 21 to 22°C under the control conditions. Subjects performed one of two versions for a period of 15 min. In version 1, performed always on the first occasion, subjects were asked to list as many different ways of using certain stimulus objects as possible. Their answers to this open-ended test were then compared and classified. Those considered insufficiently different from each other were classified as "repeats," while those answers supplied by, at most, two subjects were classified as "unique." These criteria of performance, together with the total number of answers (excluding repeats) supplied by each subject, were then examined separately. In version 2, performed always on the second occasion, subjects were

asked to list as many instances of certain types of objects as possible, and their answers were treated in the same way. However, version 2 cannot be regarded as of equal difficulty. The test was proposed by Wallach and Kogan (38) and its use in heat stress was described by Wyon (41).

The 20 patients were investigated twice on consecutive days, once during heat stress and once under control conditions, the sequence being kept random. The control subjects were only investigated once, under the conditions to which their matched-pair had been exposed on the first day.

RESULTS

For the 20 patients it was possible to compare the measurements on each individual patient during heat stress and under control conditions. Control subjects experienced only one of the two, so the

comparison of their measurements on the two different occasions was based on measurements from two different groups of 10 subjects each. The measurements of the 10 patients who experienced the control condition first could also be compared with those of the remaining 10 patients who experienced the heat stress condition first, an intergroup comparison identical to that used for the control subjects. A similar comparison is available between these groups of patients on their second attendance.

In the statistical analysis of skin, finger, and rectal temperatures, as well as comfort recordings, a detailed analysis showed that the variation with time was described by the following model:

$$\xi_{st} = \alpha_s + \beta_t$$

where ξ_{st} was the average of the measurements. Graphs drawn for each subject showed that different subjects had the same variation with time (β_t) but that this

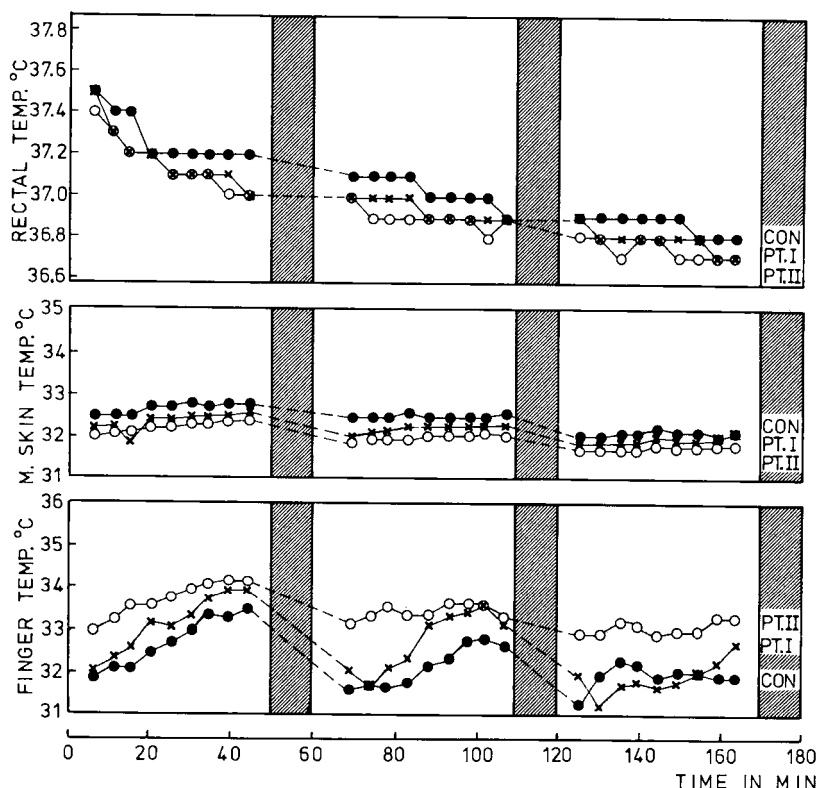


Fig. 2. The variation of rectal temperature, mean skin temperature and finger temperature with time for the two groups of patients and the control subjects under control conditions.

variation took place at a level (α_s) which varied from subject to subject. The conclusion of this investigation was that the average variation with time for the different groups and conditions could be used for analysis. Investigations of the structure of variance revealed that the statistical analysis of the averages should be based on differences within hours separately and that the change from the first to the second and from the second to the third measurement should be considered. An analysis of variance was carried out on these data (22).

For the analysis of weight loss, RR, BPS and D, HR, RPP, and performance test results the Wilcoxon matched-pairs signed-rank test was used for intraindividual comparison, and the Mann-Whitney U-test for the intergroup comparisons. Neither test assumes more than ordinal measurement, and both are nonparametric (31). The level of significance used was 95 %.

Physiological measurements

Rectal temperature. The variations of the rectal temperatures with time are given in the upper third of figs. 2 and 3. Under both sets of conditions the variation within hours and between hours was identical for the three groups of subjects. Patients tended to have lower rectal temperatures than control subjects, but no significant differences existed between any of the groups under the same conditions. In the third hour the rectal temperatures were significantly higher during heat stress than under control conditions.

Mean skin temperature. Below the rectal temperatures in figs. 2 and 3 the mean skin temperatures, the average of 10 measurements, are shown. Under both sets of conditions the variation within hours and between hours was identical for the three groups of subjects. Within each hour the

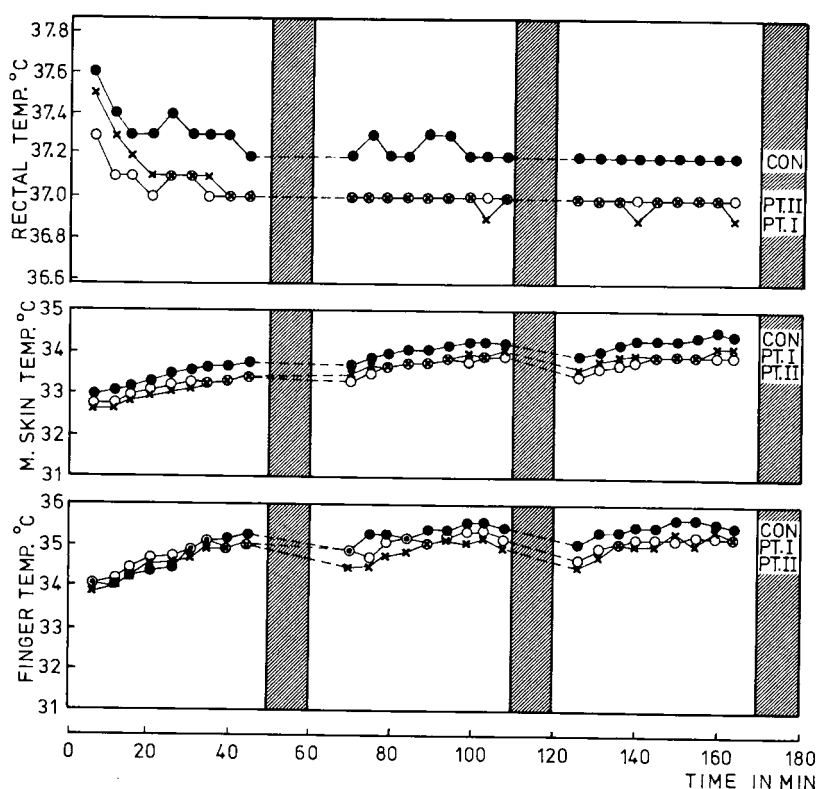


Fig. 3. Variation of rectal temperature, mean skin temperature and finger temperature with time for the two groups of patients and the control subjects during heat stress.

temperature increased significantly, i.e., 0.3, 0.2 and 0.1°C under control conditions and by 0.7, 0.5 and 0.3°C during heat stress in the first, second and third hour, respectively. From the end of the first hour to the end of the second hour and from that point to the end of the third hour the temperature decreased by 0.2 and 0.4°C, respectively, under control conditions and increased by 0.5 and 0.1°C, respectively, during heat stress. Under control conditions the mean skin temperature was between 31.6 and 32.7°C; and during the heat stress, between 32.6 and 34.6°C. There were no significant differences between any of the groups under the same set of conditions, but during heat stress the mean skin temperature was always significantly higher than under control conditions.

Finger temperature. The variation of the finger temperatures with time are given in the lower third of figs. 2 and 3. Under both sets of conditions the variation within hours and between hours was identical for the three groups of subjects under the same conditions. During each hour the temperature increased significantly, i.e., by 0.8, 0.8 and 0.2°C under control conditions and by 0.9, 0.6 and 0.3°C during heat stress in the first, second and third hour, respectively. From the end of the first hour to the end of the second hour and from that point to the end of the third hour the temperature decreased by 0.3 and 0.8°C, respectively, under control conditions and increased by 0.3 and 0.2°C, respectively, during heat stress. The temperatures ranged from 31.1 to 34.1°C under control conditions and from 33.7 to 35.6°C during heat stress. There were no significant differences between any of the three groups; for all groups the finger temperature during heat stress was significantly higher than under control conditions.

Weight loss. The average weight loss per hour under control conditions and during heat stress was 34 and 55 g per hour, respectively. Within both sets of conditions no differences existed between the three groups of subjects, but all groups had a significantly lower weight loss under control conditions than during heat stress, the ranges being from 21 to 48 and from 34 to 86 g per hour, respectively.

Cardiopulmonary measurements

During the study no attacks of angina pectoris or signs of overt cardiac failure were observed, but during heat stress a few patients experienced a slight retrosternal oppression. No significant differences were found between the resting values of RR, HR, and BPS and D in the three groups of subjects or in duplicate measurements on the same subjects. During the study RR was constant at 17 min⁻¹; there were no differences between the groups or between the two sets of experimental conditions.

The BPS was constant during the study with an average of 120, 112 and 118 mm Hg in patient group I, patient group II and the control group, respectively. During heat stress the patients had a slightly lower BPS than under control conditions, in groups I and II 4 mm and 2 mm, respectively. The difference was significant for the third hour of patient group I but only at the end of the third hour of patient group II. There was no difference between the conditions for the control subjects. Other inter- or intragroup differences did not occur during either set of conditions.

BPD was constant during the study with an average of 75, 70 and 70 mm Hg for patient group I, patient group II and the control group, respectively. No significant differences existed between the patients and the controls, and no changes were related to time or temperature.

The average HR under control conditions was 69, 69 and 70 min⁻¹ for the control group, patient group I and patient group II, respectively. Under heat stress the corresponding figures were 83, 73 and 74 min⁻¹ (fig. 4). In all groups HR was significantly higher during heat stress than under control conditions. A slow decrease in HR during the study was seen in all groups, the average rate of fall per hour being 3 min⁻¹. This decrease was statistically significant. Under control conditions there was no difference between the three groups, but during heat stress the control subjects had a significantly higher HR — about 10 min⁻¹ higher than that of the patients. The difference between patient groups I and II was not statistically significant.

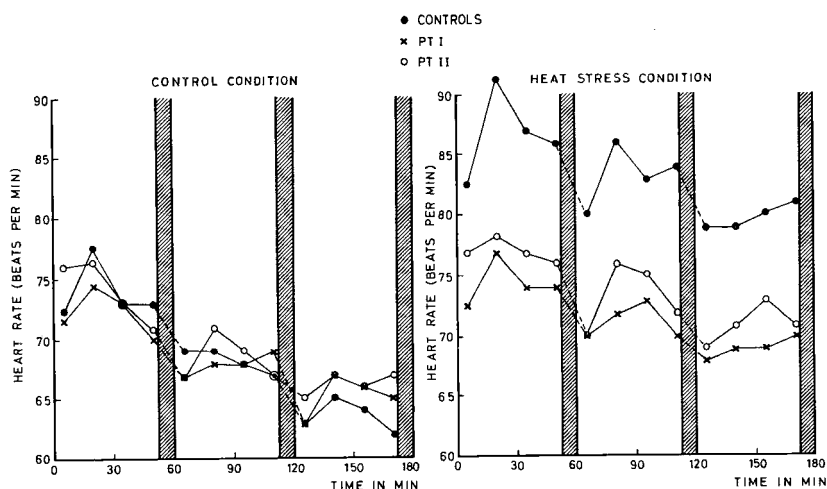


Fig. 4. The variation of heart rate with time in the three groups of subjects under control conditions and during heat stress. The shaded columns represent the rest periods.

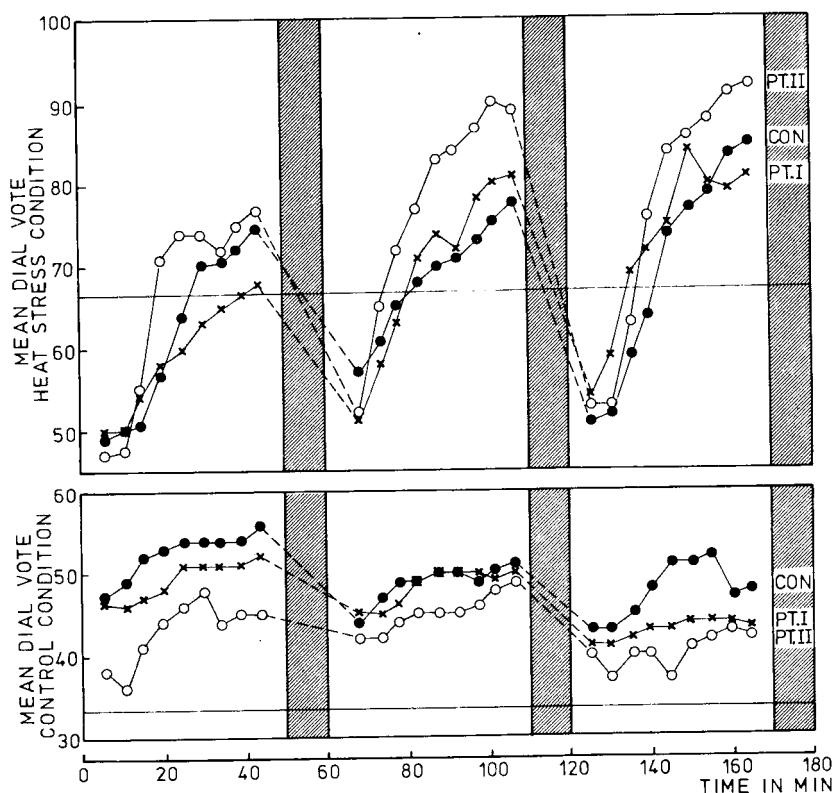


Fig. 5. The variation, with time, of the mean dial vote showing the comfort of the three groups of subjects under control conditions and during heat stress. The boundaries between the cold and the comfortable zone and between the comfortable and the hot zone are shown as horizontal lines at 33 and 67, respectively.

The rate-pressure-product (RPP), which is calculated by multiplying the systolic BP with HR, provides a fairly good estimate of myocardial oxygen consumption and work (9, 10). No differences existed between patients in groups I and II. In both the patients and the controls there was a slight decrement in the RPP with time. Under control conditions there was no difference between the patients and the control subjects. For patients there were no significant differences between the control conditions and heat stress, but the control subjects had a significantly higher RPP during the latter and it exceeded the RPP of the patients by about 20 %.

During the study only small ECG changes occurred, the most marked being a group II patient who exhibited sporadic ventricular ectopic beats towards the end of heat stress. Under control conditions he had no changes. All subjects completed the program.

Comfort

The mean dial voting showing the comfort of the subjects under control conditions and during heat stress is shown in fig. 5. Under both sets of conditions all groups,

through each hour, had an increase in the voting which followed the variation of the temperature with time. There were no differences between the three groups at the beginning of each hour except for the first hour of control conditions, during which patient group II had a significantly lower mean dial vote than the other subjects. Paired comparison revealed no statistically significant differences during the study except that all groups showed a higher rate of increase during heat stress than under control conditions. The average increase from the beginning to the end of each hour for the controls and the patients of groups I and II was 7, 6 and 4 % of the full scale, respectively, during heat stress.

Under control conditions throughout the experimental sessions there was a slight general decrease in the mean dial vote of all three groups. The dial votes of the control subjects were very near 50, which was the middle of the comfort scale, whereas patient groups I and II voted to the colder side, patients in group II feeling colder than patients in group I. During heat stress the general change in the mean dial vote reflected the base-line increase in temperature during the session. There was no marked difference between control subjects and patients in group I, whereas

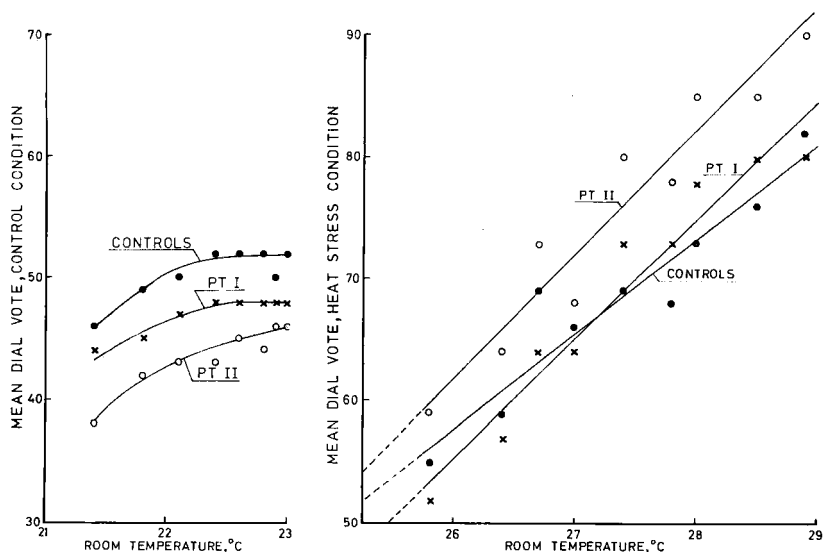


Fig. 6. Relation between room temperature and mean dial vote for the three groups of subjects under control conditions and during heat stress.

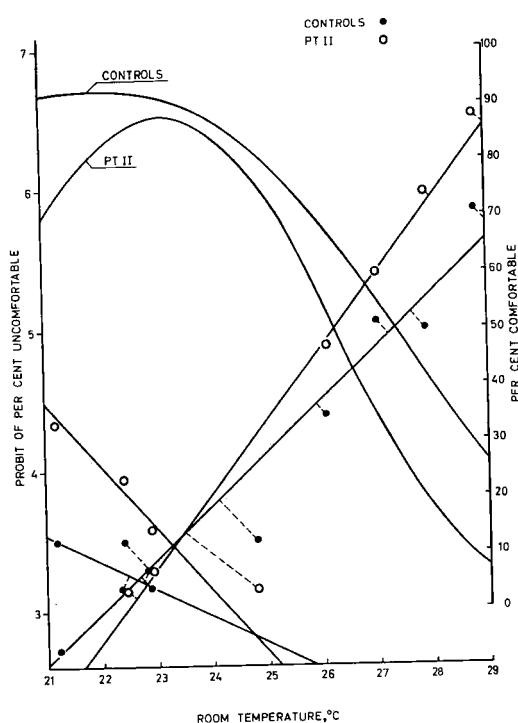


Fig. 7. Proportion of control subjects and patients in group II who were comfortable, uncomfortably cold and uncomfortably hot at various room temperatures. The two truncated distribution curves show the percentage comfortable. The four lines show the probit of the percentage uncomfortably cold or hot.

patients in group II felt warmer than the former two groups.

The mean dial vote for the three groups of subjects at 5-min intervals from the start of each experimental period is shown as a function of room temperature in fig. 6. It appears that the patients in group II (left part of fig. 6) preferred a higher environmental temperature under control conditions than the control subjects. The latter were at maximum thermal comfort. In the right half of fig. 6 the corresponding values for the heat stress conditions are shown. The scatter diagrams indicate a linear relationship for each group of subjects, and the coefficients of correlation for the control group, patient group I and patient group II are 0.79, 0.94 and 0.79, respectively. In the comparison

of the regression lines (22) of the controls and the patients in group I no statistical difference was found. A comparison of the regression lines of the controls and the patients in group II showed no significant difference between the slopes, whereas the positions of the two lines were significantly different. Also patients in group II were more uncomfortable than the controls and the patients in group I when the ambient temperature exceeded thermal neutrality.

In fig. 7 the proportion of control subjects and patients in group II who voted "too cold," "comfortable," and "too hot" is shown calculated on the basis of 5-min periods and related to the room temperature at the time of the voting. A probit analysis was performed, regression lines were calculated, and the distribution of the proportion "comfortable" was obtained. It appears that the slopes of the two regression lines ("too cold" and "too hot") for patients in group II were steeper than the corresponding lines of the control group; these patients thus were less tolerant to changes in temperature than the control subjects. The comfort distribution curve shows that these patients had the narrowest distribution; they were comfortable only in a very limited temperature range. Where the probit regression lines intersect, the proportion "too cold" is equal to the proportion "too hot." Any deviation from this point results in an overall increase in the total proportion "uncomfortable." For controls the lines intersect at 22.6°C; and for patients in group II, at 23.3°C.

When scaling is avoided and only the period of time each group of subjects returned votes in the uncomfortable region is used, it appears from table 2 that under both sets of temperature conditions the patients were uncomfortable during a

Table 2. Mean percentage of the time the votes remained in the "uncomfortable" region.

Period	Control group	Patient group I	Patient group II
Control conditions	8	13	20
Heat stress	48	53	67

Table 3. Mean number of minutes voted "too cold" before a vote of "comfortable" was recorded. (10 subjects encountered each condition; each period was 45 min)

Period	Control group			Patient group I			Patient group II		
	1	2	3	1	2	3	1	2	3
Control conditions	0	0	5	0	6	7	9	4	10
Heat stress	0	0	0	0	0	0	0	0	0

Table 4. Mean number of minutes tolerated before vote of "too hot" was recorded. (10 subjects encountered each condition; each period was 45 min)

Period	Control group			Patient group I			Patient group II		
	1	2	3	1	2	3	1	2	3
Control conditions	42	45	42	45	41	45	42	44	45
Heat stress	29	20	22	32	17	14	19	10	16

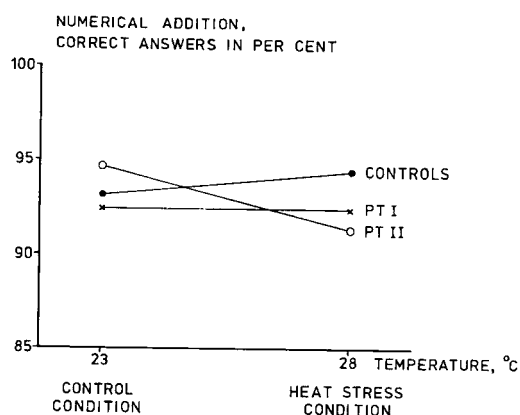


Fig. 8. The accuracy of numerical addition in the second hour of the control and heat stress conditions.

longer period of time than the controls, and the difference was more pronounced in group II than group I.

As the temperature rose throughout each experimental 50-min period, it was possible to calculate the mean number of minutes voted "too cold" before the

vote "comfortable" was recorded, as well as the mean number of minutes tolerated before the vote "too hot" was recorded. The results are shown in tables 3 and 4. It can be seen that the patients felt "too cold" during a longer period of time than the controls, this effect being clearer for the patients in group II than for those in group I. During heat stress the vote "too cold" was never recorded. The vote "too hot" was only recorded for a few minutes by each group of subjects under control conditions. During heat stress there was no difference between the controls and the patients in group I during the first 2 h, but in the third hour the patients of group I voted "too hot" earlier than the controls. Patient group II voted "too hot" at a much earlier time than the two other groups during heat stress.

Performance

Numerical addition. The numerical addition test was performed for 20 min of each hour by all subjects. As could be expected for such a well-practiced skill as numerical addition, no improvement in performance with time could be observed. Subjects attempted an average of 80 to 95 units in the time available, each unit being the addition of five two-digit numbers. No significant effects of temperature on this aspect of performance could be shown, and the patients attempted as many units as the controls. In the first and third hours subjects maintained an accuracy of 91 to 94 % on the average, with no significant differences between the groups or between the two sets of conditions. However, in the second hour, in which temperatures during heat stress rose from 24 to 28°C, there were differences between the groups and between the two sets of conditions, as shown in fig. 8. The 10 control subjects who experienced the heat stress tended, on the average, to maintain a higher level of accuracy than the 10 controls under the control conditions, but this difference was not significant. In contrast group II of the patients maintained a significantly lower level of accuracy during heat stress. Only 2 out of 20 patients maintained a higher level of accuracy under the heat stress conditions, both being from group I.

Card punching. The card punching test was performed for 20 minutes of each of the first 2 h by all subjects, and they improved their performance from the first to the second hour. The results from the first and the second hour are shown in fig. 9. Control subjects tended to punch a greater number of columns when exposed to heat stress. This tendency was not significant in the first hour but approached significance in the second hour. The performance of the patients in group II during heat stress was, in both hours, significantly worse than that of the controls, although in neither hour were there significant differences between the groups under control conditions. In the first hour of heat stress (23–27°C), patients of group II punched significantly fewer columns than did the control subjects, and significantly fewer than did the patients in group I. In the second hour of heat stress (24–28°C), patients in group II punched significantly fewer columns than did the control subjects and again tended to punch fewer columns than did the patients in group I, although this difference was not significant. It can be seen in fig. 9 that the scores of the patients in group I in the second hour were similar to those of the control subjects.

Accuracy in punching was similar

in the first and second hours, and the average accuracy was therefore computed for each subject. The scores obtained by the control subjects could not be shown to differ between the two sets of conditions, nor could they be shown to be different from those obtained from either group of patients. Patients in group I, like the controls, tended to maintain a higher level of accuracy during heat stress, whereas patients in group II tended to maintain a reduced level of accuracy during heat stress. Although neither tendency could be shown to be significant per se, it was possible to show that the accuracy scores obtained by patient group I were significantly higher than those obtained by patient group II during heat stress, there being no significant difference between the scores obtained by these groups under control conditions.

Cue-utilization. The total number of links completed in the cue-utilization test ranged from 3 to 15. The performance of the 10 control subjects meeting the task at 28°C tended to be better than that of the 10 control subjects meeting the task at 23°C, but this difference was not significant. Patients taken as a single group showed reduced performance in heat, and the scores of patient group II were lower than those of patient group I. However,

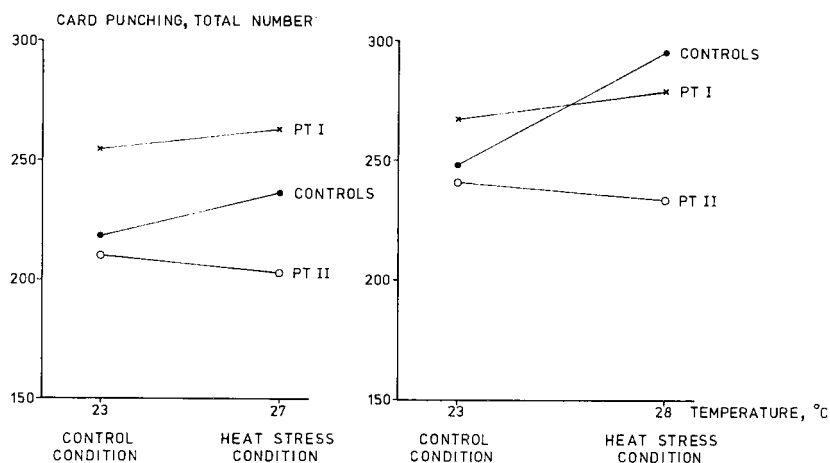


Fig. 9. Mean rate of card punching in the first (left-hand set of curves) and in the second hour (right-hand set of curves) of the control and heat stress conditions.

of a hot, dry environment (37°C , 66 % RH), patients with arteriosclerotic heart disease were increasingly uncomfortable during prolonged heat stress, but owing to a lesser increase in HR than in control subjects (6 and 12 min^{-1} , respectively) no greater stress was put on the diseased cardiovascular system than on that of the control subjects (21). In the literature no data are available on the effect of a moderate heat stress such as could be encountered in daily life in offices, schools, etc., on IHD patients.

We studied IHD patients without clinical evidence of congestive heart failure. Patients with other disorders, especially cardiovascular and pulmonary abnormalities, were not included.

We found changes in HR and BPS and consequently in RPP. A formula predicting the HR response to work, environment, and clothing has been presented by Givoni and Goldman (20). It is based on a formula derived from rectal temperature responses (19). At environmental temperatures of 20 , 23 and 29°C the formula gives an equilibrium HR of 68, 70 and 74 min^{-1} , respectively. In cold environments the formula assumes a constant HR at 65 min^{-1} . It appears from fig. 4 that under control conditions our data are in accordance with the prediction of HR between 68 and 70 min^{-1} except for the first hour. During heat stress the prediction of a HR between 70 and 74 held good for the patients but not for the healthy subjects, who had a significantly higher HR — the average increase being about threefold that of the patients. The model has shown good agreement between measurement and prediction in tests on data from heat acclimatized healthy subjects, but it obviously underestimates the HR response in these older nonacclimatized subjects exposed to heat. It should be noted that in the rest period before the study there was no difference in the HR of the control subjects and the patients; therefore we assume that the marked HR increase of the control subjects in the heat was heat induced.

From previous investigations it appears that an increase in HR is accompanied by a rising cardiac output (7, 8, 9, 10, 12, 25). The slight, but insignificant, drop of the systemic arterial pressure in the heart patients, together with the relatively lower

augmentation of HR during heat stress, resulted in an approximate status quo of left ventricular work as indicated by the RPP — in marked contrast to the 24 % increase seen in normals. Thus, judged by the RPP, moderate heat stress seems to place a smaller burden on the diseased heart than on that of healthy control subjects. Alternatively, the hypokinetic circulation may be attributed to failure of the diseased myocardium to increase its mechanical efficiency in the hot environment. However, the heat dissipative demands for increasing skin blood flow elicited by the temperature range utilized in the present study are, no doubt, considerably less than the estimated maximal increase of $1.8\text{ l/m}^2\text{ min}$ (25) and should easily be achieved by the patients in groups I and II. Accordingly, no significant differences in mean skin temperature, which reflects cutaneous blood flow (8, 35), were observed under either set of conditions. The investigation by Sancetta et al. on the regional distribution of cardiac output in healthy subjects and in patients with left ventricular heart disease when they were exposed to dry heat have shown reduced splanchnic, renal, and cerebral resistance and no change in blood flow. There was a fall in coronary blood flow, left ventricular oxygen consumption, and work which positively correlated with a fall in the systemic arterial pressure (28, 29, 32, 33, 34). They concluded that exposure to moderate dry heat stress may be beneficial for the disabled cardiovascular system. However, the basic mechanisms by which left ventricular performance is kept constant during moderate heat stress are not fully understood, and it appears that factors other than solely myocardial insufficiency are involved.

The comfort votes in this study were obtained by dial voting, which gave results not systematically different from Bedford scale votings (43). Using the same technique as in the present experiment, these authors investigated 36 male 17-year-old students and found a comfort maximum at 23°C . The patients in group II of the present study had a comfort maximum which was very near (23.3°C) that of the young subjects and which had a similar distribution curve, whereas the healthy control subjects and the patients in group I had a comfort maximum at a

lower temperature (22.6°C) and a wider distribution curve (i.e., a lower sensitivity to temperature changes). The patients in group I only reacted like the patients in group II under the hottest conditions. Thermal comfort has been studied extensively by Fanger. In an investigation (16) of 64 college-age and 64 elderly subjects (mean age 68 years) under almost the same conditions as in the present investigation he found comfort maximums at 26.1 and 26.5°C, respectively. The regression equations for the estimated mean thermal sensation vote as a function of ambient temperature were similar, but the elderly had the lowest correlation coefficient, especially due to variation in the observations below maximum comfort. The difference in comfort maximums between the present investigation and Fanger's study is probably due to the fact that our subjects performed mental work throughout the study, whereas Fanger's subjects were sitting still without performing mental work. Subjects performing mental work thus preferred a 3°C lower ambient temperature than predicted by Fanger's comfort equation (26). Fox et al. (18) found a large number of old people with low deep-body temperatures and a lack of awareness of cold. This phenomenon, in conjunction with the results of the present experiment, indicates that the sensibility to temperature deviation from comfort conditions is lower in older than in younger males, the difference, however, being so small that it may be of no practical consequence, whereas the IHD patients in our group II with a relative insufficiency of the heart during normal daily physical activities are more sensitive and in this respect resemble young subjects.

Extreme heat has been studied extensively and is known to decrease mental performance (27). The effects of the moderate heat stress met so commonly in daily life has been studied in relatively few experiments, and to our knowledge no experiments on cardiac patients have yet been carried out. To simulate the daily life situation, we used well-defined mental performance tests resembling work in schools and offices. In the numerical addition test heat affected the performance of patients in the second hour only. This occurrence could be due to the particular temperature levels reached in that hour

(24–28°C). An alternative explanation is that their level of motivation decreased in the middle period of the experiment, but this reason is rendered less plausible by the absence of any such effect on the total number of units attempted, a criterion even more likely to be affected by a change in motivation. It seems likely that patients were distracted by the apprehension produced by the rising temperature, being anxious about the effect of high temperature on their cardiac condition. By the third hour the pattern of gently rising and falling temperature would have become clear, but in the second hour the temperature approached uncomfortable levels with no certainty that it would decrease again. The intermediate position of the less severely ill patients strongly supports the reality of the temperature effect.

Card punching is a real task, which has not been used before as a performance test. In this mainly manual skill the control subjects evidently were aided by heat-induced relaxation. The more severely ill patients, possibly anxious about the effect of the heat on their cardiac condition, did not relax and therefore did not improve either their speed or accuracy of punching under the heat stress conditions. Again, the intermediate position of the less severely ill patients strongly supports the reality of the temperature effect.

The results of the cue-utilization test, though not statistically significant, do support the interpretation made for the numerical addition and card punching tests, namely, that the patients became anxious about the effect of heat on their cardiac condition and therefore maintained a raised level of arousal during the heat exposure, in marked contrast with the reduced level of arousal expected for normal subjects and observed in the control group.

In the creative association test the results obtained with version 2 showed that on the second occasion patients exposed to heat supplied significantly fewer unique answers than did patients under control conditions. This result lends support to the interpretation that patients exposed to heat did maintain a higher level of arousal due to anxiety, the resulting decrease in cue-utilization capacity being

detrimental to their performance of the open-ended creative association task.

Our results are in good agreement with the few earlier studies on moderate heat stress. In an experiment (41) on 11-year-old school boys at 20, 23.5 and 27°C, an increase of temperature impaired performance or increased the mental effort to maintain performance in tasks demanding concentration. In tasks demanding relaxation the performance improved at 27°C. In an investigation of 8- to 12-year-old children performing a variety of tests at 20, 27 and 30°C under school conditions significant decrements in performance due to heat were also shown (24).

The effects of thermal stress, i.e., the combined effect of the physical parameters of temperature, vapor pressure and air movement, may be expressed as a strain on the human body at three levels. The lowest level is a subsystem of the body — the internal thermoregulatory system — the next level is thermal comfort representing the conscious interaction of an individual with the environment. The highest level in this hierarchy is the efficient functioning of the total system (a school, an office or a factory) of which the individual forms only a part. The relevant strain measures at this level are performance measures (42). In the moderate heat stress situation there was no difference between control subjects and patients in the subsystem thermoregulation, and some differences in cardiopulmonary function, but the narrow thermal comfort range of the patients showed that they were more sensitive to deviation from maximum comfort than the control subjects. The most pronounced effect of the moderate heat stress on patients occurred for mental performance. Effects were always more distinct on patients in group II, whereas patients in group I often behaved like control subjects. It may be concluded that, in a thermally controlled environment at maximum comfort, the IHD patients perform just as well as healthy subjects. Deviations from this temperature cause discomfort and a decrement in mental performance and should, therefore, be avoided. It is worth noting that behavioral criteria were more sensitive indicators of heat strain than were any of the physiological criteria used, par-

ticularly for subjects with known cardiac insufficiency.

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