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LIMITS OF ENDURANCE FOR HEAT STRESS ARISING FROM WORK WHILE TOTALLY INSULATED

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Herman P. Roth and W. Vincent Blockley

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SUMMARY

Ten healthy, physically-fit male subjects, ranging in age from 23 to 39 years, walked on a treadmill in an environmental chamber, at four incremental levels of energy expenditure, in a clothing/environment combination which assured near-zero heat exchange and compelled storage in the body of all metabolically-produced heat. Each test was carried to the limit of the subject's endurance, at which time he was rapidly cooled. Heart rate and temperatures of the ear canal, rectum and 9 skin surface locations were continuously recorded, and oxygen uptake was continuously monitored.

Great differences in tolerance time at each metabolic level were found, which were not correlated with physical fitness as measured by a standard work tolerance test given each subject three times during the program. Five older, more mature subjects had markedly better endurance than the five younger ones. Overall group mean endurance times for the four levels (1000, 1500, 2000 and 2500 Btu/hr) were respectively 46.8, 38.2, 30.1 and 24.5 minutes. Individual times ranged from 70 down to 15 minutes. The best subject endured the most severe condition (2500 Btu/hr) longer than the poorest subject tolerated the mildest load (1000 Btu/hr).

Rate of rise of ear canal temperature proved to be the best predictor of average tolerance time. Judged by increase in mean body temperature, heat storage of about 1000 Btu in the high-tolerance group of 5 men, and about 800 in the low-tolerance group of 5, brought subjects near to the collapse point, though some tolerated as much as 1400 Btu increase in body heat content. These storage tolerance values for exercising subjects are from about 50 to 100% higher than an average of 584 Btu determined in a previous study of seated subjects in very hot environments. It appears that the difference may represent the change in heat content which is normally associated with the change to a new thermal equilibrium during the first hour of work in a moderate to warm climate.

LIMITS OF ENDURANCE FOR HEAT STRESS

ARISING FROM WORK WHILE TOTALLY INSULATED

INTRODUCTION

Physical work by the human organism is always accompanied by an increase in its heat production, above that at rest, which is closely proportional to the level of energy expenditure. In ordinary living situations, this increased heat production initiates physiological adjustments whose effect is to increase the rate at which the heat is conveyed to the environment and thus to minimize the rise in temperature of the body core.

If transfer of heat to the environment is impeded, body temperature will rise by somewhat more than the small amounts which occur in optimal conditions, and can ultimately reach levels which are associated with impaired performance of both intellectual and motor tasks.

Pressure suits are employed by astronauts to provide an environmental pressure over the surface of their bodies, consistent with normal functioning. In the current state of the art of design of such impervious pressurized garments, provision is made for transfer of metabolic heat to the external environment by a circulating fluid system, which receives heat from the body's surface and conducts it out of the suit to some point where it can be rejected to the external environment.

Partial or total failure of this heat transfer system can result in undesirable or dangerous accumulation of heat within the body. This is because pressure suits have an inherently low rate of heat conduction through their walls, and there is essentially no opportunity for body cooling through normal convection or evaporation; further, the radiant environment may present a heat gain to the suit surface, further complicating the problem. It was the central purpose of the work reported here to investigate the physiological consequences of such a failure of the heat delivery system.

While there is a body of information of predictive value in assessing non-compensable heat stress in the sedentary male (1, 2, 3), the prediction of limits to heat stress tolerance in <u>working</u> men has never been systematically explored except in very general statistical terms. The concept of non-compensable heat stress, as distinct from compensable but time-limited stress, is not easily applied to the working situation because of the fact that body temperature typically rises during work, even when there is no significant heat stress present at all. It is therefore not possible to state with any certainty at the start of a period of work in a warm environment whether a compensatory adjustment of body temperatures will be able to produce a gradient from core to surface sufficient to deliver the full metabolic heat production to the external environment.

By definition, an environment-metabolism combination is non-compensable if the full metabolic heat production cannot be transferred from the body surface to the environment. In a compensable heat stress situation, the body is able to achieve displacements of physiological parameters ("strain") sufficient to attain a balance between heat production and heat loss. In such situations, the endurance limits are very much a function of the individual characteristics, being determined by the ability to tolerate the levels of strain elicited by the stress.

The present work is concerned with the truly non-compensable type of heat stress, where the achievement of equilibrium is impossible. The special case chosen for initial study was the totally-insulated working man, whose heat loss to the external environment is held at zero from the time he starts to work until he reaches the stage of incipient collapse. The endpoint definition chosen reflects in part the experimental condition (or assumption) that body cooling would be started abruptly within seconds after the termination of the heat stress.

EXPERIMENTAL PLAN

The basic experimental plan for this study was to have 10 male subjects walk on a treadmill at four metabolic levels (from about 3 to 7-1/2 times resting rate), wearing an impervious garment, in an environment permitting no appreciable loss of body heat, with observation of body core and skin temperatures and other relevant physiological parameters including oxygen consumption, and with incipient collapse as the end-point.

Each subject was required to meet a standard level of physical fitness in a preliminary test on a bicycle ergometer. This fitness test was repeated after a series of at least five 1-1/2-hour training sessions, during which the men walked in a comfortable environment wearing light clothing at a metabolic level of about 2000 Btu/hr. The subjects took the fitness test again at the end of the program. After the training walks, each subject was given a "calibration" treadmill test, to determine the walking speed and grade combinations which elicited metabolic levels of 1000, 1500, 2000 and 2500 Btu/hr precisely. These individual speed-grade combinations were then used for the subsequent heat-stress experiments. For convenience in subsequent discussion, the four respective heat-stress levels will be referred to as HST-1, -2, -3 and -4.

In order to avoid heat acclimatization as a complicating factor, all training sessions prior to the heat stress tests proper were conducted in environments within the normal comfort range. The heat stress environments were presented in ascending order of severity for the same reason.

LABORATORY FACILITIES AND INSTRUMENTATION

The chamber in which the experiments were conducted has a floor area of 13 x 9 feet and a ceiling height of 8.5 feet. Air is exhausted through perforations in one end wall which occupy the total area except for an observation window and the door. The air is re-circulated by a large variable-speed blower mounted in the roof, which discharges into a plenum above the false ceiling of the chamber; the air enters the room through the full area of the perforated end wall.

The resultant air flow pattern is unusually laminar and free of "drafts" or eddies. For these experiments the velocity was approximately 100 feet per minute in the horizontal plane. Air temperature is controlled to close tolerance by heating and refrigeration units mounted in the inlet plenum.

The chamber provides ample space for the treadmill, bicycle ergometer, precision beam scale for subject weighing, and for the saturated air breathing system, as well as for other minor operating supplies and instrumentation.

Instrumentation Area

Outside the environment chamber, monitoring instrumentation is grouped around or near the observation window. Ample space is available for subject preparation prior to a test, and for restorative treatment and observation following a run.

Treadmill

A Quinton Instrument Company treadmill was used for imposing selected metabolic work loads on the subjects, by variation of walking speed, grade, or both. Its range of speed is 1.8 to 15 mph, and grade 0-35 per cent. Speeds used in this project were about 2-3 mph, and grades 0-16%.

Thermal Instrumentation

Both physiological and environmental temperatures were measured primarily by thermistors (YSI), checked by precision liquid-in-glass thermometers. Disc-type thermistors were used for sensing skin temperatures (YSI Nos. 409 or 425), and spot-type probes for other body-temperature sensing, including rectal and oral (YSI No. 401) and tympanic temperatures (YSI No. 402). Immediate visual readout was by YSI Tele-Thermometer and by a Digitec digital thermometer with a range from 75°-115°F reading to .01°F.

Automatic sequential recording of nine skin temperatures and two internal temperatures was provided by a special Thermistor Computer/Logger developed by Webb Associates California. This instrument provides automatic switching to one servo-recorder of the 9 individual thermistor sensors of skin temperature, plus automatically-computed values for mean skin temperatures and weighted mean body temperature. Simultaneously, the instrument switches to another servo-recorder alternately the output from the rectal and ear canal thermistor probes.

A YSI Tele-Thermometer was also used to periodically check temperatures of the chamber walls and ceiling, also dry-bulb and wet-bulb temperatures in the air stream entering the breathing facepiece.

Individually-Molded Ear Plugs. An ear plug of foamed silicone plastic was custom-molded to the left ear canal of each subject, to assure proper positioning and retention of the thermistor used to sense temperature deep in the ear canal, adjacent to the tympanum. The procedure used was that described by Gibbons(4).

Cardiac Instrumentation

Pre-cordial electrodes were attached to the subject by means of double-sided adhesive discs, and connected to a Biocom telemetry transmitter. The signals received on a Sherwood FM receiver were recorded continuously on a Sanborn 4-channel recorder, along with the average heart rate computed from the FM signal by means of a Physiometrics Tachometer-Totalizer.

Bicycle Ergometer

The bicycle ergometer used for the work tolerance tests was the standard Monark unit manufactured by Mark-Crescent AB of Varberg, Sweden, widely-used in this country. It is of a Prony-brake type, in which the force-differential between the ends of the friction band is both applied and measured by a pendulum-type loading weight, with a handwheel for adjustment of its value. Position of the pendulum is indicated on a sector bearing calibration markings for reading the applied load in kiloponds (kilograms force` The scale reads from 0 to 7 kp, with markings at 1/2 intervals.

One complete turn of the pedals causes a point on the rim of the friction wheel to move exactly 6 meters. The loading pendulum measures the difference in force between the two ends of the friction belt running around the rim of the wheel. The product of the force (measured in kp) and the distance the rim moves in a given period of time provides a measure of the work done. A constant rate of work requires a constant pedaling rate. The manufacturer recommends a pedaling rate of 50 rpm, in order to simplify load calculations; i.e., with that rate a load of 1 kp gives a work rate of 300 kp-m/min (kilopond-meters per minute). Other work-rates are directly proportional to rpm and to load. Since 1 watt = 6.118 kp-m/min, pedaling at 50 rpm with 1 kp load provides a load of 343.4 watts.

The protocol specified for the work tolerance test in this program called for applying an initial load of 50 watts for 3 minutes, followed by load increments of 15 watts per minute, up to the man's tolerance. The Monark scale sector was therefore provided with an overlay scale to indicate each of the desired work-rate levels in watts, both for convenience in performing the tests and to assure maximum accuracy and replicability of setting.

Considerable prior experience in using the Monark ergometer with American subjects indicated that a 60 rpm pedaling rate would probably minimize

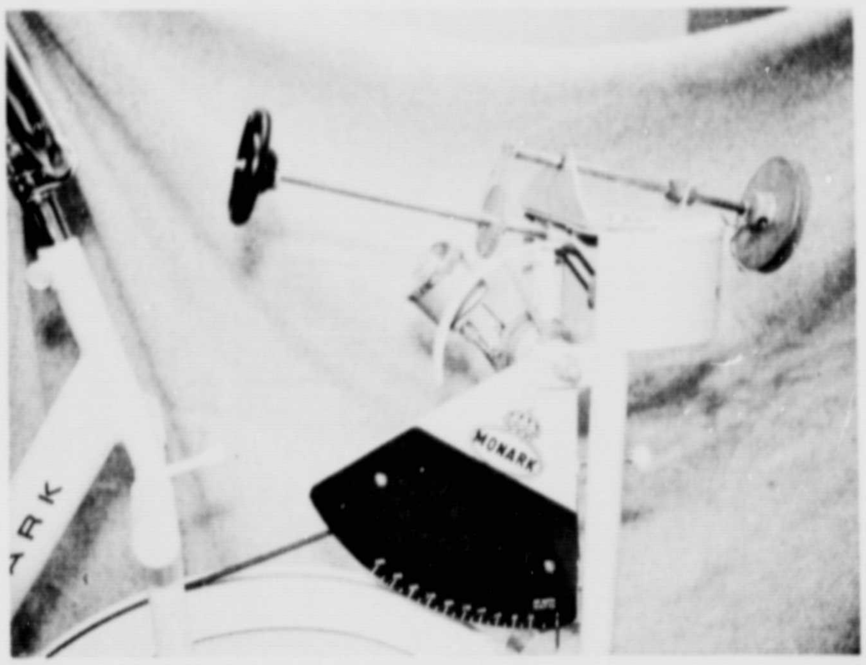

Figure 1 - Monark ergometer with overlay scale and vernier load-adjustment gearing.

Figure 3 - Subject on treadmill, wearing impervious clothing and mask.

leg-muscle fatigue at the higher work loads. Load values in kp were calculated for each of the desired watt-load settings. Based on the 60 rpm pedaling rate, the pendulum loading-force in kiloponds = (work load in watts) x 0.01697. Using this information, an overlay scale was made, with markings for each of the desired watt-load values at corresponding values of load from the original scale. Figure 1 shows this overlay scale in position on the Monark ergometer, with the pendulum at zero load.

It was estimated that the load could be adjusted to a precision of setting of the pendulum index-line to within 1/2 mm (±1/4 mm) with respect to a given scale marking. This would correspond to an accuracy and replicability of ±1/4% of full scale, or an absolute accuracy of ± 1/2 watt (nominal) in the lower range, and even better in the upper range, where scale markings are wider spaced.

Early experience in attempting to use the standard Monark load-adjustment handwheel, in setting the ergometer load to a new level at each minute (after the first 3-minute period) encouraged us to provide a geared-down adjustment, to make the setting easier and quicker. This took the form of a supplementary handwheel on a shaft, with sprockets and ladder-chain providing a 5/1 movement ratio between the supplementary handwheel and the original one. This is shown in Figure 2. The position of the new handwheel was also more convenient of access in the test situation. The setup shown does not interfere at all with regular use of the original handwheel.

<u>Control of Pedaling RPM</u>. To assist a subject in maintaining a desired pedaling rate, it is customary to use a metronome set to a frequency of double the pedal-shaft rpm. While this is satisfactory for a conscientious subject, it complicates monitoring by the test operator. An improved method of monitoring speed was therefore provided. This consisted of means for generating an audible signal, which would have two distinctively different audio patterns for rpm's which were either too slow or too fast. This signal was provided by an electronic unit with a small speaker, audible to both subject and operator.

The electronic speed-sensor employed was a modified "CardioPacer", with magnets on the main cycle sprocket actuating a reed switch to provide three impulses for each pedal-shaft rotation.

The CardioPacer unit was adjusted so that if the input impulses were 180 (3 times the 60-rpm pedal shaft speed), a very faint "beep" signal would be heard. If the speed dropped by a fraction of an rpm, the signal would become louder and would be heard at a frequency three times the pedal-shaft rpm. If the pedaling rate should go over 60 rpm, the signal would also become louder, but would have a frequency just half of that which would characterize a "too-slow" pedaling rate. With very slight experience, subjects found it possible to maintain the pedaling rate within about ± 1/2 rpm from the nominal 60 desired. The test operator had continuous and precise surveillance of the accuracy with which each subject was maintaining the required speed.

Metabolic Instrumentation

The nature of the program imposed unusual requirements on instrumentation for measurement of metabolic heat production (via oxygen uptake) particularly during (1) the crucial heat stress tolerance tests while subjects worked at various levels of energy expenditure without either conductive, convective or evaporative heat loss, and (2) the work tolerance tests used at three places in each subject's schedule.

In view of the high stress which the crucial heat stress tolerance runs would impose on the subjects, it was considered essential that the metabolic instrumentation not add appreciably to the total burden of the subject, either by using a mouthpiece-nose-clip combination, or by any other breathing appliance which would impose appreciable resistance to breathing. An additional unusual requirement was to provide that the subject breathe from an air stream saturated with water vapor at body temperature, to preclude evaporative heat loss via the respiratory tract.

Metabolic measurements during the physical fitness tests (performed on the bicycle ergometer) were desired at the end of third, eighth, and each of the last three minutes. Since the test was to determine the limit of a subject's tolerance for pedaling work, neither the last minute nor the last three were predictable. Furthermore, since the work level was changed minute-by-minute after the initial three minutes, and since oxygen consumption cannot reach an equilibrium level within one minute of a step-change in load, use of the conventional procedure of collecting exhaled air for a period of at least half a minute (followed by a sample analysis) appeared unsuitable, and an "on-line" system vastly preferable. A decision was therefore made to install a proprietary system developed by Physiometrics, Inc., for this type of application, and to validate it against conventional procedures.

On-Line Oxygen System. The system used in this program was developed independently by Physiometrics as an outgrowth of the Metabolic Rate Monitor (MRM) developed by Webb Associates Ohio at its Yellow Springs laboratory.

The MRM employs a polarographic oxygen sensor, cooperating with a servo-control unit which regulates air flow through a light face-piece worn by the subject. The edge of the face-piece is provided with a resilient cushion seal contacting the head across the forehead, down the sides of the face around the chin, leaving the face exposed to a stream of air which enters at the top and leaves at the bottom.

Exhaled air mixes with the air stream, which is then ducted past the oxygen sensor to the air impeller controlled by the sensor via the servo unit. The blower speed is governed so as to maintain a constant oxygen partial pressure in the mixed stream, such that the ratio of total flow to oxygen uptake is constant. A meter on the servo-control cabinet indicates oxygen uptake in liters per minute (STPD), and a recorder output jack provides a 0 to 5 volts signal to operate a strip-chart recorder when a continuous graphic record is desired.

The Physiometrics system is a manually operated, precision laboratory device, similar in general principle to the MRM, and uses an identical facepiece. It employs a different type of oxygen sensor in order to avoid some of the problems inherent in the polarographic cell, principally the need for periodic cleaning and replacement of electrolyte and oxygen-diffusing membranes. The new oxygen sensor is a commercially available fuel-cell type developed by the General Electric Company.

The cell operates at constant temperature within a thermostatically-controlled metal block. A continuous stream of dried sample gas is brought to cell temperature in a labyrinth duct within the block before passing across the face of the cell. Output voltage of the cell varies with partial pressure of oxygen in the gas stream to which it is exposed, and is amplified by a factor of 1000 in an operational amplifier connected to a null-indicating meter. Adjustable bucking voltage is introduced into the circuit to enable setting the null-meter zero to any desired value of oxygen partial pressure in the sample passing through the cell.

A precision calibrating-gas mixture containing 19.9% oxygen (±0.01%) is introduced periodically into the measuring cell to make and check the setting of the null. With the gas sample from the mixed outlet line from the facepiece passing through the measuring cell, the flow rate through the facepiece is adjusted by means of a fine-control diverter valve until the indicating meter is again nulled, while a continuous record of the flow rate is taken. An electrical signal introduced into the flow record by push-button indicates when a null exists in the measuring system. At these instants, the oxygen uptake from the facepiece is one-hundredth (1/100) of the flow rate, plus or minus a small error introduced by any deviation of the respiratory exchange ratio from 1, as shown by the simple balance equation.

$$\dot{V}_{O_2} = \dot{V}_{total} \, (0.209 - 0.199)$$

Flow Rate Measurement. The flow rate of the mixed exhaled gas mixture is measured by the pressure drop across a laminar-flow resistance element (similar to the Fleisch type), in which volume flow is directly proportional to the pressure differential, sensed from points immediately before and after the resistance element. This differential pressure is sensed by an electronic manometer (Mercury Electronics, Glasgow) with a panel meter reading in three ranges: 0-3, 0-10 and 0-30 millimeters of water; the 0-10 range was used routinely in this project. This manometer was used in parallel with a slant-type water manometer with a maximum reading of 1 inch of water and a minimum scale division of 0.01 inch of water with possibility of estimating to one-fifth this value. The calibration and linearity of the electrical manometer was carefully checked against the slant manometer during the initial calibration period of instrumentation set-up, and periodically thereafter. The electronic manometer provides readout not only on its panel meter, but also through an external circuit for strip-chart recording, which was done routinely in this project. One channel of the Sanborn 4-channel recorder is used for this flow readout, which provides the measure of oxygen uptake.

Figure 2 is a pictorial diagram of the HST saturated air breathing system and the instrumentation for measurement of oxygen consumption.

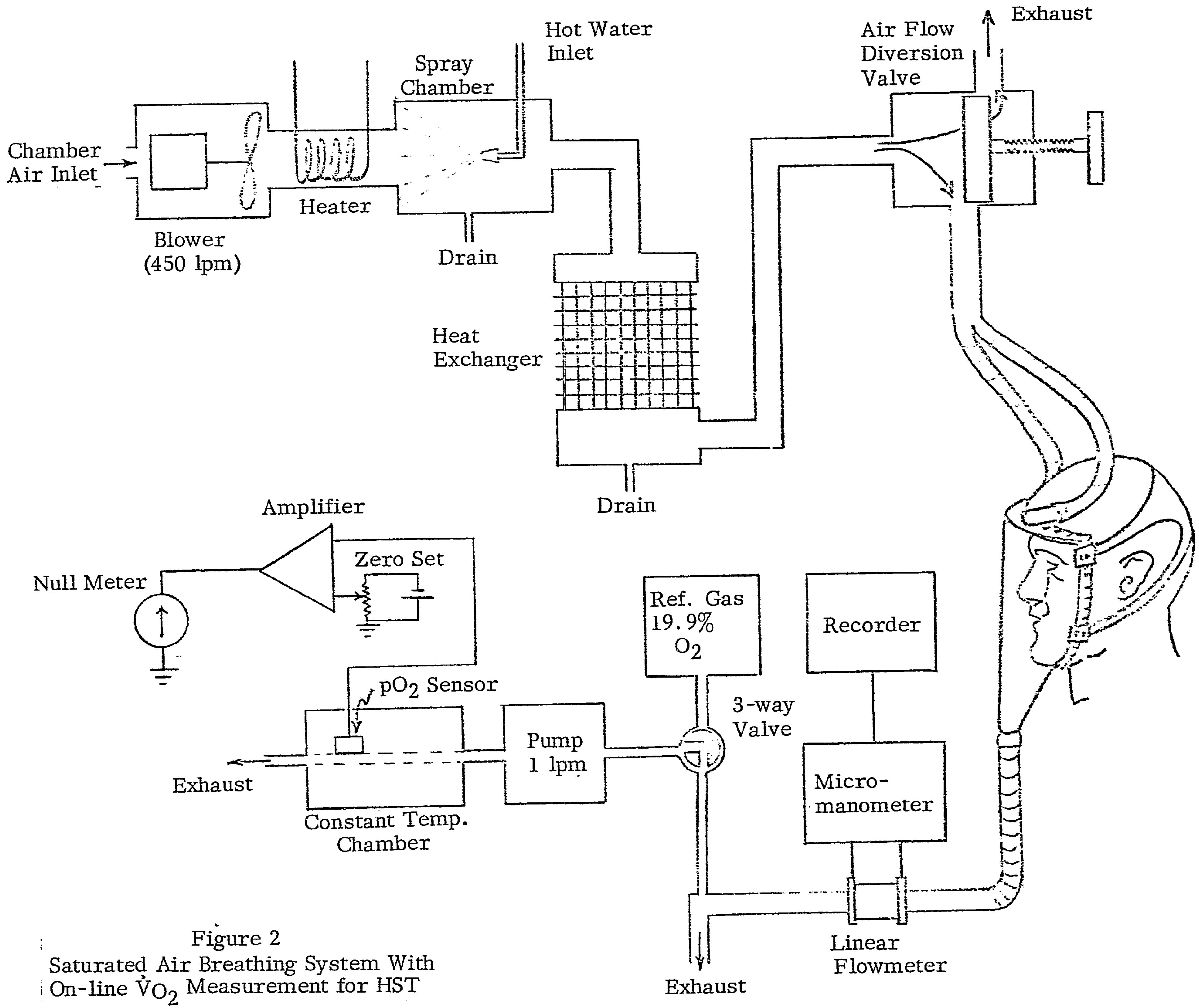

Figure 2
Saturated Air Breathing System With On-line $\dot{V}O_2$ Measurement for HST

Auxiliary Items

Clothing. During the work tolerance and treadmill training tests, subjects wore comfortable light clothing, generally shorts, socks and their choice of shoes (tennis or walking). For the calibration run and the heat stress tests, they wore light cotton long-sleeved and long-legged underwear (to help protect and retain surface thermistors) under an impervious outer garment assembly.

The garment consisted of a vinyl-plastic "exercise suit" which covered the trunk and limbs, and the headpiece section of a skin-diver's "wet suit." Made of impervious, nitrogen-blown neoprene foam, this covered head and neck snugly, with a nimimal cutout for the facial area, and a skirt section extending outward a short distance from the base of the neck, underneath the top of the vinyl exercise suit jacket. Rubber galoshes and plastic gloves completed the impervious assembly.

After all the items were donned, all junctures between clothing sections, at the neck, wrists and ankles, were sealed with surgical adhesive tape. When the facepiece of the respiratory system was donned, its resilient edge seal completed the impervious containment of the body.

Subject Intercom. To assure adequate communication between subject and test personnel, a microphone was installed in the respiration mask, with speakers both in the chamber and at the instrumentation station outside. Speech reception by the subject was adequate without use of an earphone, even with the thermistor ear-plug in place in one ear canal.

Cooling Fan and Tank. To enable rapid cooling of the subject following removal from the chamber to the dressing area and removal of the impervious garment, a 24-inch pedestal-mounted fan was used to direct a stream of air onto the subject as he sat in a chair. A large tank of water was available to permit immersion of the subject in cool water, should the fan not provide sufficient immediate cooling.

Beam Balance. Subject weighing was done by means of a Fairbanks platform beam balance, enabling determination of weights to 0.01 lb.

SUBJECTS

Test subjects were 10 men in good health, with age and physical fitness status approximating that of the NASA astronaut-candidate group. They were volunteers from nearby stations of the Los Angeles County fire department, and participated on schedules adjusted to their available off-time from fire department duty. Vital data for each is as follows:

DATA ON SUBJECTS

SUBJECT	AGE	HEIGHT (inches)	WEIGHT (pounds)
CS	33	68-1/4	165
SR	25	72	163
BD	34	74	165
LS	39	73-3/4	207
RB	33	72	175
FD	36	72-3/4	176
BB	24	72-1/4	185
SA	25	72-3/4	162
GH	25	70	167
RH	23	71	194

All men passed a thorough physical examination including a 12-lead electrocardiogram. They were briefed in detail as to the purposes of the experiment and the nature of the end-point to which they were expected to endure the heat stress to be imposed. The value of the experience in relation to the potential demands of the fire-fighting occupation was stressed.

PROCEDURES

Work Tolerance Test

A thorough medical examination was given each subject prior to administration of a work tolerance or physical fitness test. The latter was also used at two other points in the program: (1) just prior to the heat stress test series, and (2) at its conclusion.

The Monark bicycle ergometer was used to impose a stepwise-increased work load, carried to the subject's endurance limit. The subject pedalled at 60 rpm for 3 minutes at a 50-watt load, which was thereafter increased by 15 watts at the beginning of each successive minute. Oxygen consumption was monitored continuously throughout the test, as was the heart rate and the electrocardiogram.

Criteria for terminating the work tolerance test were a heart rate of 180 beats per minute, inability of the subject to continue pedaling, or other adverse physiological signs. The planned qualifying level for participation in the program was completion of the 14th minute of the test, during which the work level was 215 watts. Three subjects were used who did not reach this level in their initial tests, but whose medical examination records confirmed basic fitness for the program. (This decision was vindicated by the fact that two were in the top group in HST tolerance-time rating, and one rated first at all HST run levels. The third scored well above the qualifying level in his two subsequent work tolerance tests.)

Treadmill Training Runs

Each subject qualified was then given a series of treadmill training sessions. Each consisted of walking on the treadmill at a grade and speed selected for comfortable walking, which would also provide a metabolic rate of approximately 2000 Btu/hr. The latter was verified by periodic determination of oxygen uptake during the 90 minutes' duration of each run and adjustment of speed and grade (if necessary) to keep oxygen uptake approximately 1.6 to 1.7 liters per minute. The speed/grade combinations finally chosen for each of the training runs, for each subject, are shown in Table 1.

Laboratory temperatures were in the cool-to-comfortable range (65° to 78°F) for the most part; maximum temperatures in 10 of the 54 runs were in the 79° to 84° range. These training runs were given in as close and continuous a sequence for each man, as his off-duty schedule permitted. The typical interval was 1 to 5 days between runs. The mean interval was 3.1 days, excluding four atypically long intervals of 14, 33 and 45 days, due to vacations or travel, which were compensated for by additional sessions.

Calibration Runs

Following the tradmill training runs, each subject was given a "calibration run" to determine the walking speeds and grades which would establish, in each of the four heat stress tests, the desired metabolic level. In the calibration run, the subject was dressed and instrumented in exactly the same way as for the heat stress tests.

The subject wore the full complement of impervious clothing, and the mask of the metabolimetric system, through which room air was circulated without humidification. The test chamber was maintained at a temperature between 55° and 60°F, permitting sufficient convective and radiative heat loss from the surface of the body via the clothing to minimize sweating. There was some warming of the air drawn from the room by the blower used to circulate breathing air through the mask of the oxygen system, but since it was not humidified, some body cooling was provided by evaporation in the respiratory tract.

In the calibration run, the subject was started at a comfortable walking speed (about 2 to 2.5 mph) at zero grade. About 5 to 10 minutes were allowed for the subject to reach a substantially steady state, as indicated by heart rate and oxygen consumption. If the latter was not within about 10 per cent of the "target value" of .833 liters/min. (equivalent to the desired metabolic rate of 1000 Btu/hr for the HST-1 level), walking speed was increased or decreased as necessary. Response to any such change was found substantially complete within about 3 minutes.

When the speed and grade for level 1 had been determined, a similar procedure was followed for levels 2, 3 and 4, successively. The optimum walking speed found for level 1 was generally used for the three other levels, the additional metabolic load being provided by increase in treadmill grade. The speed/grade combinations for each subject, at each of the four metabolic levels, are tabulated in Table 1, as are those used in the heat stress runs. In isolated instances, slight changes from the speed and grade for a given level, determined in the calibration runs, were made early in the heat stress runs, if the oxygen consumption was not sufficiently close to the target value for each metabolic level.

Between the treadmill training runs and the heat stress tests, each subject was given his second work tolerance test, generally following the calibration run.

<u>Heat Stress Tests</u>

Procedures for the heat stress tests were identical with those in the calibration runs, except that the chamber was kept substantially at body temperature. Prior to a test, it was "pre-soaked" at 98°F for 1 to 1-1/2 hours. After the test started, air temperature was continually adjusted to be within a fraction of a degree of rectal temperature. In addition, air drawn from the room for the respiration circuit was brought to substantially 100% relative humidity at chamber temperature before it entered the mask.

Preparation of the subject for a heat stress test included positioning of electrocardiographic electrodes and connection to the telemetry transmitter, placement of skin surface, rectal and ear canal thermistor probes, and dressing in the impermeable clothing assembly. These procedures generally required somewhat over half an hour before the start of the test. Recording of temperatures was started during the last stages of the dressing process. The subject then entered the pre-warmed chamber (about 98°F), and stood beside the treadmill while the mask of the oxygen system was installed, and the

Table 1. Speed/Grade Combinations Used in Treadmill Runs
Shown as: Speed(mph)/Grade(%)

Subject	Treadmill Training Run No. 1	2	3	4	5
CS	2.0/10	2.2/10	2.2/10	2.2/10	2.2/10
SR	2.5/10	2.5/10	2.2/10	2.5/10	2.0/10
BD	2.0/10	2.1/10	2.2/10	2.3/10	2.3/10
LS	2.5/8	1.8/9	1.8/9	1.8/9	1.8/9
RB	2.2/10	2.7/10	2.6/10	2.3/10	2.5/10
FD	2.0/8	2.0/8	2.3/8	2.4/8	2.5/8
BB	2.2/9	2.0/10	2.0/10	2.0/10	2.0/10
SA	2.8/10	2.5/10	2.8/10	2.4/10	2.7/10
GH	2.2/10	2.3/10	2.2/10	2.3/10	2.3/10
RH	2.2/10	2.2/10	2.2/10	2.2/10	2.2/10

	Calibration Run Level				Heat Stress Test Run Level			
Subject	1	2	3	4	1	2	3	4
CS	2.2/0	2.2/6	2.2/10	2.2/13	2.2/0	2.2/6	2.2/10	2.2/13
SR	2.2/0	2.2/5	2.2/9	2.2/13	2.2/0	2.2/5	2.2/9	2.2/13
BD	2.6/0	2.6/6	2.5/10	2.5/14	2.6/2	2.6/6	2.5/10	2.5/14
LS	1.8/0	2.5/3	2.5/6	2.5/8	1.8/0	2.5/3	2.5/6	2.5/8
RB	2.7/0	2.6/4	2.6/7.5	2.6/9.5	2.7/0	2.6/4	2.6/7.5	2.6/9.5
FD	2.2/0	2.55/4	2.6/8	2.6/12	2.2/0	2.5/4	2.6/8	2.6/12
BB	2.3/0	2.3/5	2.3/9.5	2.3/13	2.3/0	2.3/5	2.3/9.5	2.3/13
SA	2.6/0	2.7/5.5	2.7/10	2.7/14	2.6/0	2.7/5.5	2.7/10	2.7/14
GH	2.2/0	2.2/4.5	2.2/9.5	2.2/14.5	2.2/0	2.2/4.5	2.2/9.5	2.2/14.5
RH	1.9/0	2.2/4	2.2/8	2.2/11.5	1.9/0	2.2/4	2.2/8	2.2/11.5

thermal, cardiac and oxygen consumption recording systems were checked.

Stepping onto the treadmill at the predetermined speed and grade established time zero for a given run. Temperature recording was continued, heart rate was observed visually on the cardiotachometer, and recorded on one channel of the Sanborn recorder. Another channel was used for continuous recording of ECG potentials, and a third channel recorded the signal measuring oxygen uptake. The Sanborn recorder was operated at a slow chart speed much of the time, but was periodically brought to a recording speed of 2.5 cm/sec. for observation and recording of the cardiograph wave-form in conventional scale. The ECG was scrutinized for indications of abnormality in cardiac function, particularly during the latter part of each test, as the subject neared his endurance limit.

During the early part of each test, the subject was monitored by the observer either within the chamber, or through the observation window, communicating with the subject via the intercom system. The observer was present in the chamber constantly during the latter portion of each heat stress run. The instrumentation technician kept the observer informed of heart rate and ear canal temperature, and of the approach of these parameters to those established for termination of a test in the event that a subject did not have to stop for other reasons, such as loss of equilibrium, faintness, nausea, or excessive fatigue.

When a subject reached his end-point of endurance in a given test, the treadmill was stopped and the subject assisted to the dressing area. The impervious garments were removed quickly, without interruption of temperature or cardiographic sensing circuits, so that recording of temperatures, heart rate and ECG could continue during the recovery period. The subject was seated in front of a large fan, in light cotton underwear worn under the impervious garment. Since this was saturated with sweat, evaporative cooling was immediate and intense, affording the subject immediate relief. In most cases this was sufficient to terminate adverse physiological reactions and sensations.

In a few instances, however, this was not sufficient to relieve sensations of nausea or faintness, in which case the subject was placed in the tank of cool water. In no case did this fail to start the subject on a course of rapid recovery. In practically all cases, recovery was sufficiently advanced by or before 10 minutes post-run to warrant discontinuance of physiological recording. At this point, sensors were removed and the subject was permitted to shower and dress, though additional rest was permitted or encouraged if desired by the subject.

Following completion of his scheduled series of heat stress tests, each subject was given his final work tolerance test, generally within two or three days.

RESULTS AND DISCUSSION

Because of the prime significance of tolerance time, subject groupings based on this factor have been used as a basic orientation for data analysis. Table 2, Section A, ranks the 10 subjects on the basis of their cumulative tolerance time for all four metabolic levels of the heat stress tests, and indicates each subject's relative cumulative tolerance time as a percentage of the highest cumulative total. It also shows the relative ranking of the subjects in the tests at each of the four levels. Section B lists the actual number of minutes comprising the cumulative and individual-test totals for each subject, with sub-totals for a "high-tolerance" group (the top five subjects) and a "low-tolerance" group (the bottom five). For convenience, these two groups will hereafter be referred to as the H-T and L-T groups. The relationship between these groupings and the physiological data will be developed in subsequent discussion.

It is interesting to note that the scores made by the men in the work-tolerance tests were not predictive of their relative tolerance in the heat stress tests, as is shown in Section C of the table. For purposes of this comparison, the work tolerance test parameter used was the average of the number of minutes completed by each man in all three of the tests administered during the program. The H-T group had a mean of 14.7 minutes completed in the work tolerance tests, while the value for the L-T group was 16.5. The lower average for the H-T group was due to the lower scores of two subjects; otherwise there was little difference between the two groups.

The H-T group comprised the five oldest men, and the L-T group the five youngest.

Work Tolerance Tests

Figure 4 presents consolidated mean data for both heart rate and oxygen uptake for the work tolerance tests. In general, both heart rate and oxygen uptake were slightly higher for the first of the three tests than for the second and the third. Individual variability was greater for the first than for the others, probably due to the fact that for each man it was his first experience of any kind in the test program, engendering varying degrees of tension or apprehension in each.

The oxygen uptake data are of particular interest and significance in that they provide an excellent validation of the accuracy of the novel system employed for continuous measurement of the metabolic rate. In the lower panel of Figure 4, the values for oxygen uptake (mean for the 10 subjects) have been shown minute-by-minute during the program of progressively-increased work load, for each of the three times the work tolerance test was administered in the program.

Dashed lines show the trend, and limits of variation for the central 90 per cent of the data from a study by Luft et al (4) of 63 men of similar age group and physical characteristics, in a closely-similar test which was

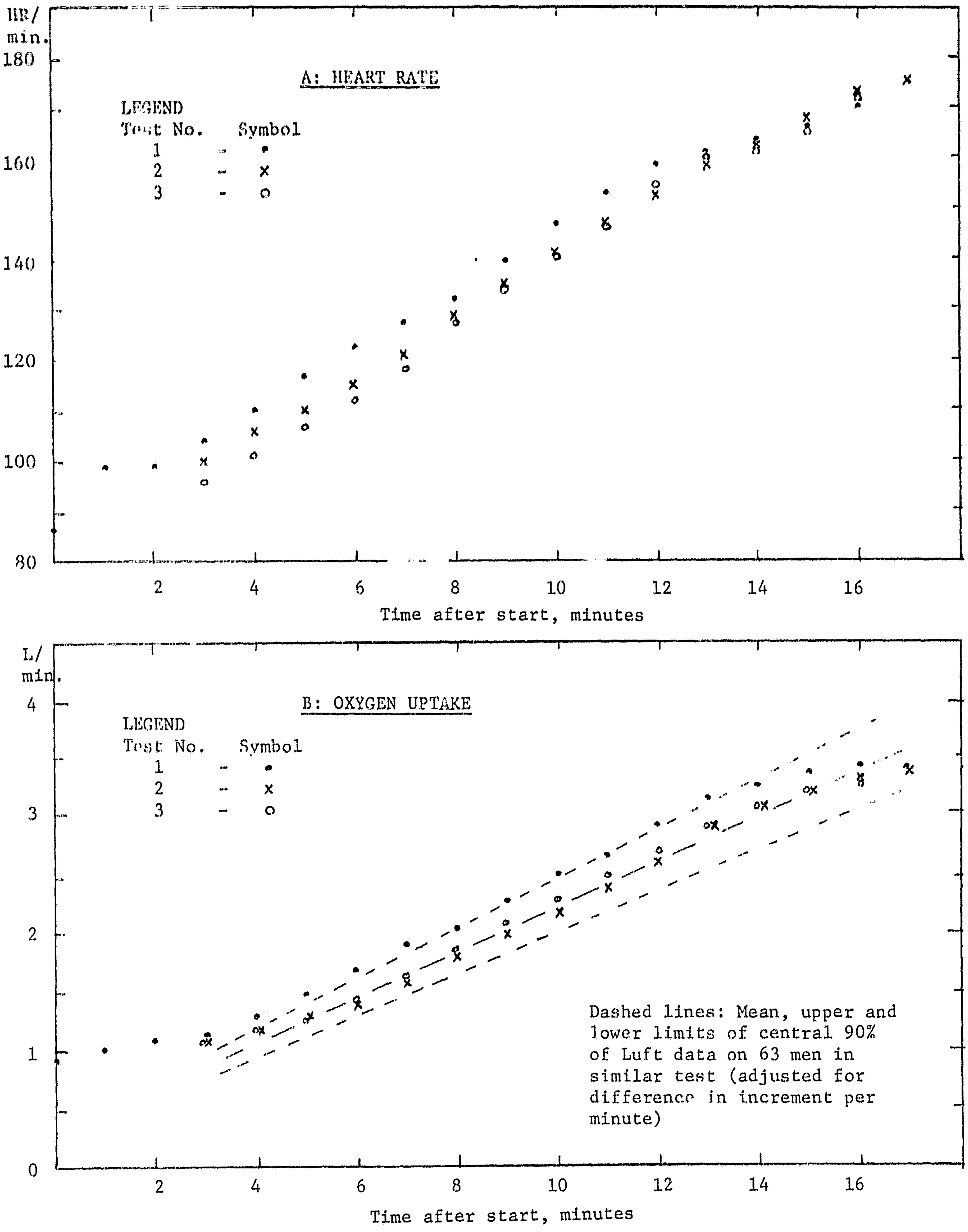

Figure 4 - Heart rate and oxygen uptake in work tolerance tests (three for each subject: (1) at start; (2) mid-program; and (3) at end). Each point shows mean for 10 subjects, minute-by-minute, at each of three times test was used.

the precursor of that used in this program. (The Luft test differed only in using a minute-by-minute increment of 75 kg-m/min., or 12.5 watts, instead of the 15 watts used in this program.) The plotted values of oxygen uptake reflect equal work loads in the two sets of data, compensating for their slight differences in time schedule.

It will be noted that the oxygen uptake for the initial work tolerance test administered in this program closely paralleled the upper limit of the bulk of the Luft data (about 10 per cent above the trend-line). For the second and third tests, values lie remarkably close to the trend-line of the Luft data. The tendency of the values for the highest work levels in this program to level off at about 3.5 liters/min. suggests that our subjects had sufficiently high muscular efficiencies to enable them to approach their maximum oxygen transport capacity. Examination of graphs for individual subjects supports this conclusion.

Tolerance Limit Criteria in Heat Stress Tests

According to the experimental plan, there were four basic reasons for terminating a heat stress tolerance experiment: excessive heart rate, excessive deep temperatures, assessment by the experimenter of incipient collapse, or request of the subject.

The ear canal temperature reached the criterion limit of 103.5°F in only 7 experiments, involving four subjects who were particularly calm, conscientious and emotionally mature. All these cases occurred at the first and second level of work severity, none at levels 3 and 4.

The maximum heart rate criterion for termination was reached by only one subject at level 1, by five men at level 2, and by 6 and 7 respectively at levels 3 and 4.

Two subjects, both of them young and well-built, were particularly vocal in their expressions of subjective distress during the heat stress experiments. In one of these men, the subjective discomfort was reflected in a steeply rising heart rate, suggestive of a strong emotional drive superimposed on the physiological stress. In the other extra-sensitive subject neither heart rate nor deep temperature rise was particularly steep, but he became nauseated and lost his equilibrium earlier than would have been expected on the basis of the superficial physiological response. Both these men complained most bitterly about the hot, humid breathing air.

In general, there was little doubt that all subjects came very close to the point of collapse in every heat stress exposure. Among the more frequent symptoms of impending failure which were volunteered toward the end in response to the question "How do you feel now?" were the following:

- -- air hunger, respiratory distress;
- -- extreme restlessness;
- -- dizziness and loss of equilibrium;
- -- extreme feeling of fatigue.

Individual Factors in Tolerance Time Variability

In the first exposure for each man, at the lowest nominal metabolic load of 1000 Btu/hr, the four men having tolerance or endurance times longer than 47 minutes all reached a final ear temperature above 103°F. The next three men, with endurance times between 45 and 40 minutes reached 102°F or more. The least tolerant men had final ear canal temperatures of 101.3, 100.7 and 100.4.

In the second heat exposure (at the 1500 Btu/hr level) all but two of the subjects maintained essentially the same rank order of endurance time established at level 1. (See Table 2, Section A.) The two exceptions, CS and LS, exchanged places for second and fifth. It developed from subsequent questioning that on the day preceding the first exposure LS had attended an early but convivial banquet, and was experiencing distinct after-effects on the day of the experiment. He remained in second place for endurance in both the remaining heat exposures.

Subject CS held the number 2 position in the first exposure, and position 4, 5, or 6 in all the rest. This essentially median performance is significant in light of the fact that this man's performance capacity on the bicycle ergometer work tolerance test was the poorest of the whole group of 10 men, although he voluntarily attained a more extreme degree of exhaustion in the work tolerance tests than any of the others.

The man displaying the longest endurance time in all four heat exposures was BD, whose work capacity tests were also at the bottom of the distribution. In the case of BD, his short endurance time in the fitness tests was due to leg pain rather than exhaustion of the cardiorespiratory system, aggravated by the fact that the ergometer seat was not quite high enough to accommodate optimally his unusually long legs.

The man with the poorest record of tolerance for the heat stress, BB, is a particularly strong, muscular and rugged-looking individual, who completed 17 minutes of the third fitness test without exceeding a heart rate of 163. He had expressed an intention of setting a record in this test, but he was prevented by leg pain. BB's low heat tolerance was associated with an emotional reaction to the sensations of heat which was reminiscent of descriptions of claustrophobia.

Subject SA, who holds ninth place in heat stress tolerance, is a serious competitive golfer who had recently completed a gruelling tournament for which he had put himself in top condition. Both SR and RH were competitive athletes during their school years, and were in excellent physical condition in terms of their fitness test performance as well as their general appearance.

Turning again to the upper 50% of the group in terms of heat tolerance, it is interesting to note that one man, RB, had just completed his convalescence from the effects of a serious motorcycle collision when he began the training treadmill walks, and had undergone no specific other rehabilitative training before the heat stress tests began. Both this subject and

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Table 2. Comparison of Individual and Group Endurance Times

Subject Grouping		Section A: Ranking in Heat Stress Tests					Section B: Endurance Times					Section C: Work Tolerance Tests				
High-Tol. Group			Relative Ranking at Individual Test Levels				Minutes at Individual Test Levels					Minutes Completed in Each of Three Tests				
												W.T. Test No.				
Subj.	Age	% of Max*	HST-1	-2	-3	-4	HST-1	-2	-3	-4	Cum. Total	1	2	3	Mean	Rank
BD	34	100%	1	1	1	1	70	53	41	34	198	12	12	13	12.3	9
LS	39	83	5	2	2-3	2	47.5	51	36	30	164.5	17	17	16	16.7	4-5
RB	33	79	3	4	2-3	3-4	49	43	36	29	157	14	16	14	14.7	8
FD	36	78.5	4	3	4	5	48	47	32.5	28	155.5	16	18	18	17.3	2-3
CS	33	73	2	5	5	7	58	35.5	30.5	21	145	12	11	13.4	12.2	10
Group Means:		82.7					54.5	45.9	35.2	28.4	164				14.7	
Low-Tol. Group																
SR	25	66.5	6	6	9	3-4	45	33	25	29	132	17	19	18	18	1
RH	23	61.5	8	8	7	6	40	32	28	22	122	17	18	17	17.3	2-3
GH	25	59	7	7	6	10	42.3	31	29	15	117.3	14	16	16	15.3	6-7
SA	25	54.5	9	9	9	9	36	29	25	18	108	13	16	17	15.3	6-7
BB	24	48.5	10	10	10	8	32.5	27	18	19	96.5	16	17	17	16.7	4-5
Group Means:		58.3					39.2	30.4	25.0	20.6	115.8				16.5	
Over-all means for both groups::							46.8	38.2	30.1	24.5	139.9				15.5	

*Percentage of maximum cumulative endurance time of best subject, in all HST runs.

the top tolerance man, BD, are very lean, even thin, individuals.

In general, it may be stated categorically that apart from age the main distinguishing feature separating the more tolerant and the less tolerant 5 men was their mental attitude. The older men projected an image of willingness to accept the discomforts and rigors of the task for which they had volunteered; they appeared to have confidence in the experimenters' qualifications and intentions to take responsibility for their safety and well-being. The younger men, on the other hand, showed a more self-centered concern as to whether the experimental procedures might be painful or harmful, and gave a general impression of mild anxiety.

Body Temperature; General Comment

The time-course of temperatures observed at selected sites, on the surface of and within the body, constituted the primary mass of data for analysis, apart from heart rate. Except for the occasional (and inevitable) technical problems encountered in some tests, the temperature-measurement system functioned satisfactorily. Since the system provided graphic records of temperature values at each surface thermistor once each minute, and of the rectal and ear canal six times a minute for each, the patterns of change could be reliably delineated.

The temperature data have been subjected to a wide variety of analytical treatment. Tabulations and graphs were made of the following temperatures:

-- Rectal, at an insertion depth of 6 cm. (T_r);
-- Ear canal, close to the ear drum (T_e);
-- Mean skin temperature, averaged from the 9 sites observed (T_s);
-- Insulated-forehead skin temperature (T_f);
-- Mean body temperature, derived from the rectal and mean skin temperatures (T_b).

Graphic analyses of most of these were made not only against elapsed time during each run (plotted at 5-min. intervals), but also against per cent completion (i.e., tenths of the total elapsed time during each test). These permitted comparison of patterns of response based on the course of change between the start of a test and its conclusion at a man's endurance limit, without reference to a specific time interval.

Rectal vs Ear Canal Temperature

For general analytical purposes, one of the most instructive graphic treatments was a plot of rectal against ear canal temperature. This was done for each subject, showing values at 5-min. intervals throughout each of the runs at the four metabolic levels, plus the value at the test end-point, wherever it occurred. In addition to their specific informational content, they provide visual comparisons and contrasts not only of differences between subjects, but also of differences in response of each man at the four test levels. Some of the most significant derived information is discussed below:

1. Starting Temperatures. Mean values of rectal and ear canal temperatures at the start of tests at the four HST levels ranged as follows:

	Rectal	Ear
Minimum	97.7	94.8
Mean	98.73	96.55
Maximum	99.7	98.0
Mean for the H-T group	98.49	96.56
Mean for the L-T group	98.97	96.53

While the mean starting ear temperatures of the two groups were almost identical, the mean starting rectal temperature for the H-T group was nearly one-half degree F less than for the L-T group.

More striking than the inter-group differences in starting rectal temperature is the fact that subject BD, who ranked first in each of the four test levels as well as in the cumulative total (20% higher than the next highest, and 42% above the cumulative mean for all subjects at all levels) had characteristically low rectal and ear canal temperatures, averaging, respectively, 97.8 and 95.4, or 0.9 and 1.1°F below average subject values. This man therefore had the potential of storing a greater amount of heat, per pound of body weight, before reaching a limiting peak body temperature at the end of a test.

This potentially favorable influence on tolerance time is also seen in the fact that subject SR, although in the L-T group, shared the rank of 3-4 at the HST-4 level. His rectal and ear temperatures at the start of that test were much lower than in his others, by about 1 and 2 degrees, respectively.

The possibility of increasing tolerance-time by body pre-cooling, in environmental conditions inducing rise of body temperature, has previously been called to attention and demonstrated by Veghte and Webb (5).

2. Final Temperatures. One of the conspicuous characteristics of the H-T group was the subjects' willingness (or determination) to stick through a test to levels of higher body temperature (and, presumably, greater personal discomfort and fatigue) than those in the L-T group. This is clearly seen in their test-end rectal and ear temperatures. For three in the H-T group, final ear temperatures were close to or above 103°F. The other two exceeded 103° in four of their eight tests, and were about 102.5° in three others (one stopped at 101.1° at the HST-4 level, because the heart rate limit was reached).

In contrast, the final ear temperatures of the L-T group exceeded 102° (and then only slightly) in only 8 of their 20 tests, with the rest dominantly about 100-101°. The top-ranking member of the L-T group (almost a candidate for the H-T group) had final T_e values over 102° in all four tests.

The difference between the H-T and L-T groups with respect to final ear temperatures is further shown in Figure 5, in which average T_e values for the two are graphed as a function of per cent completion. Note that both groups had almost identical mean starting temperatures, but that the H-T group averaged 103° at test end, compared with 101.3° for the L-T group. A point of additional interest, whose significance is open to speculation, relates to the range of Te values at successive levels of percentage of completion. For the H-T group, the range narrows at the higher values of per cent completion, while with the L-T group the reverse is true.

3. Patterns in T_r vs T_e Relationship. The lag in response of rectal temperature to environmental conditions which tend to warm the body is well documented. It shows up clearly in graphs of T_r against time, and also in the graphs of T_r vs T_e. Typically, T_r changed by only a fraction of a degree during the first 2 or 3 five-minute time increments, particularly at the lower metabolic levels.

Ear temperature responds much more quickly to both external and internal influences on the body's thermal status. When plotted against time, T_e is almost linear after the first 5 or 10 minutes of a test of this kind, as seen in Figures 6 and 7, which will be discussed more completely later.

Figures 8 and 9 are graphs of T_r vs T_e, at all four metabolic levels, for two subjects, BD and GH, respectively representative of the H-T and L-T groups. BD, who ranked No. 1 in tolerance time in all categories, was a particularly cooperative and consistent subject, as witnessed by the similarity of configuration of the curves for the four metabolic levels. At the HST-3 and -4 metabolic levels, increased slopes, near the end particularly, reflect the tendency of the heat generated by muscular action to accelerate the rise of T_e more than T_r.

Figure 9 is representative of the response of an L-T subject whose limitations were physiological as well as motivational. His curves for HST-1, -2 and -3 are remarkably similar in pattern (disregarding time factors), with the curve for HST-4 again showing the more rapid change of T_e in comparison with T_r.

In both these graphs, successive points represent matching values of T_e and T_r at 5-minute increments of time, up to the last increment which varied with the subject's end-point of endurance. Thus, closer-spaced points indicate a longer run, in which T_r and T_e changed more slowly, and wide spacing indicates a shorter run with more rapidly-changing values.

One conspicuous difference characterizes the records of H-T subjects in comparison with the L-T's. This is the fact that the H-T subjects invariably continued their tests considerably beyond the point at which T_e and T_r became equal (equivalence is indicated by the diagonal dashed line in both graphs.) For the H-T group, the mean temperature at which T_e and T_r became equal was 99.1°; for the L-T group, 99.8°. This difference reflects the higher average starting temperature for the L-T group, and to

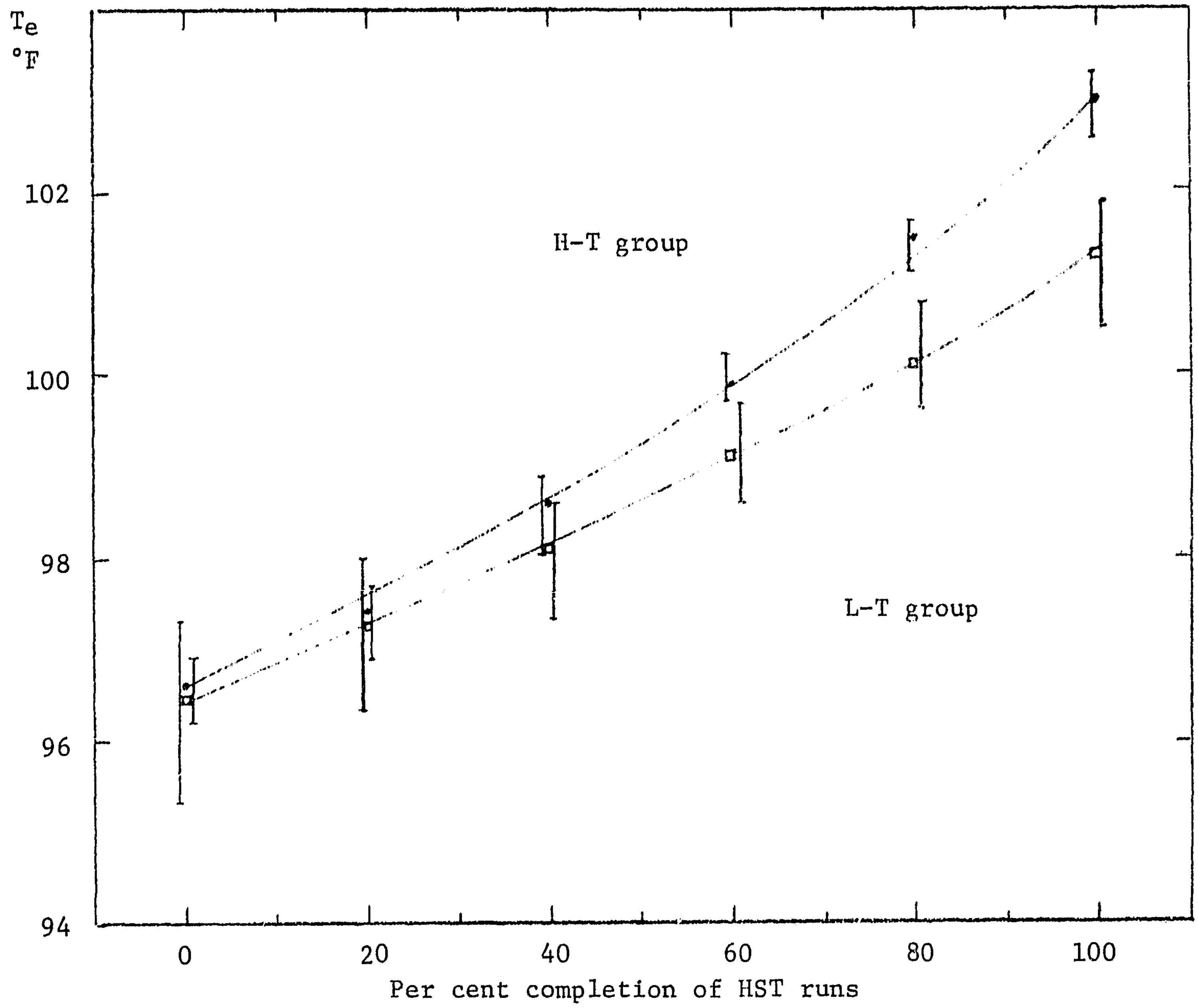

Figure 5 - Ear canal temperatures (by "endurance groups") vs per cent completion of HST runs, at 20% increments. Means and ranges of values for 5 men (4 HST runs each) in each group: high tolerance (H-T) and low tolerance (L-T).

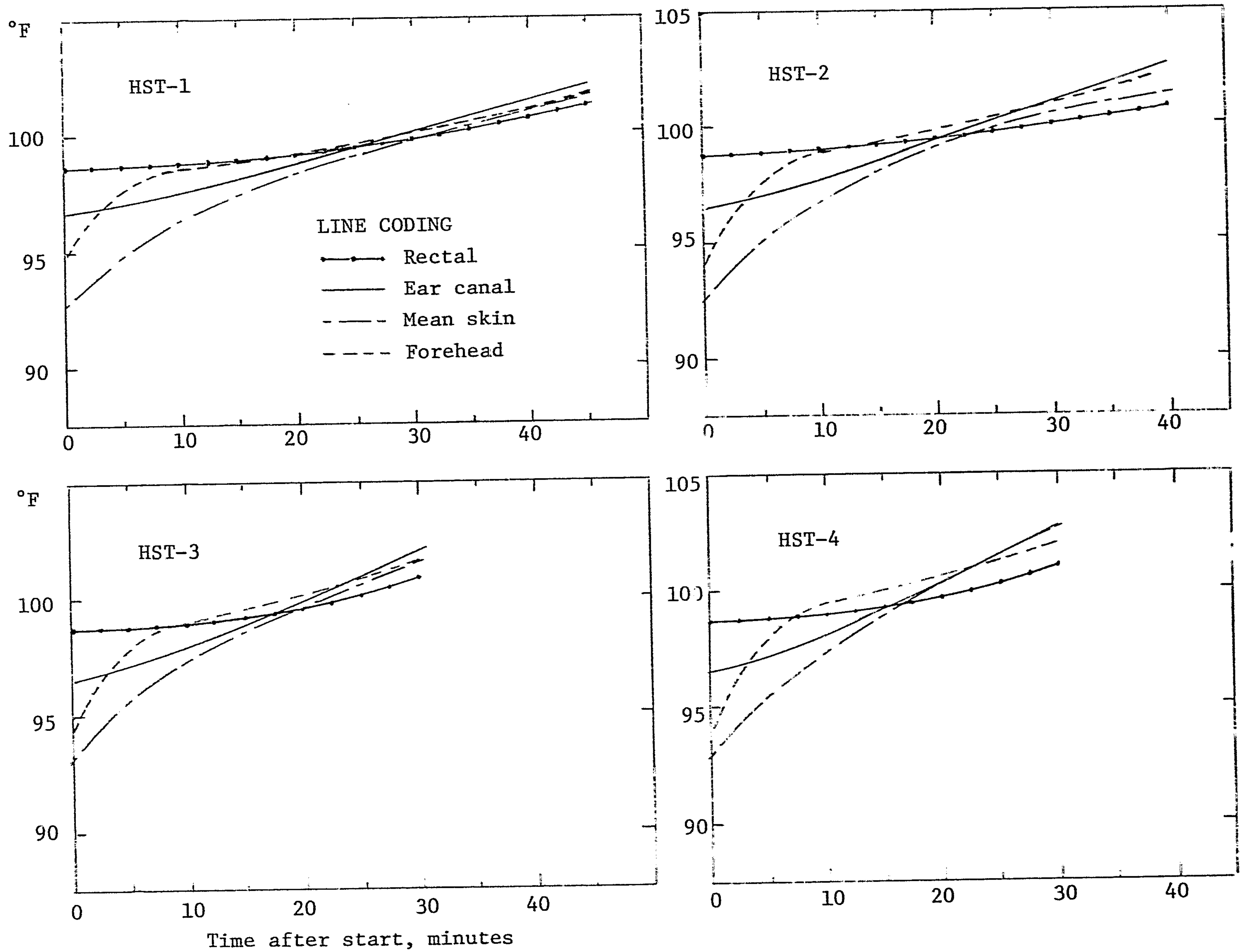

Figure 6 - Relationships between rectal, ear canal, mean skin and forehead temperatures in HST tests. Means for all subjects at 5-minute intervals during test segments prior to progressive dropout due to reaching tolerance limits.

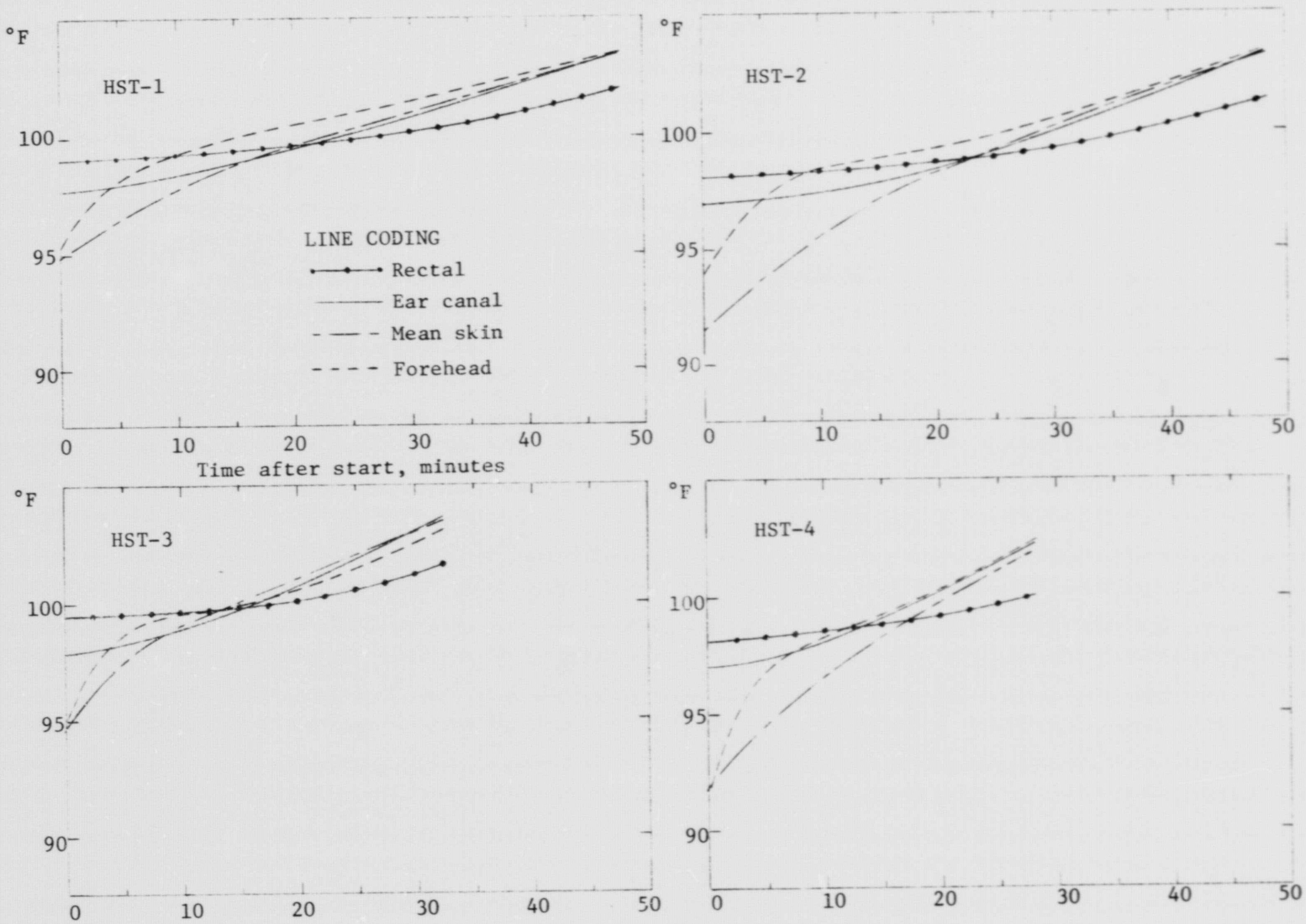

Figure 7 - T_r, T_e, T_s and T_f, vs time, for subject BD, at all HST levels

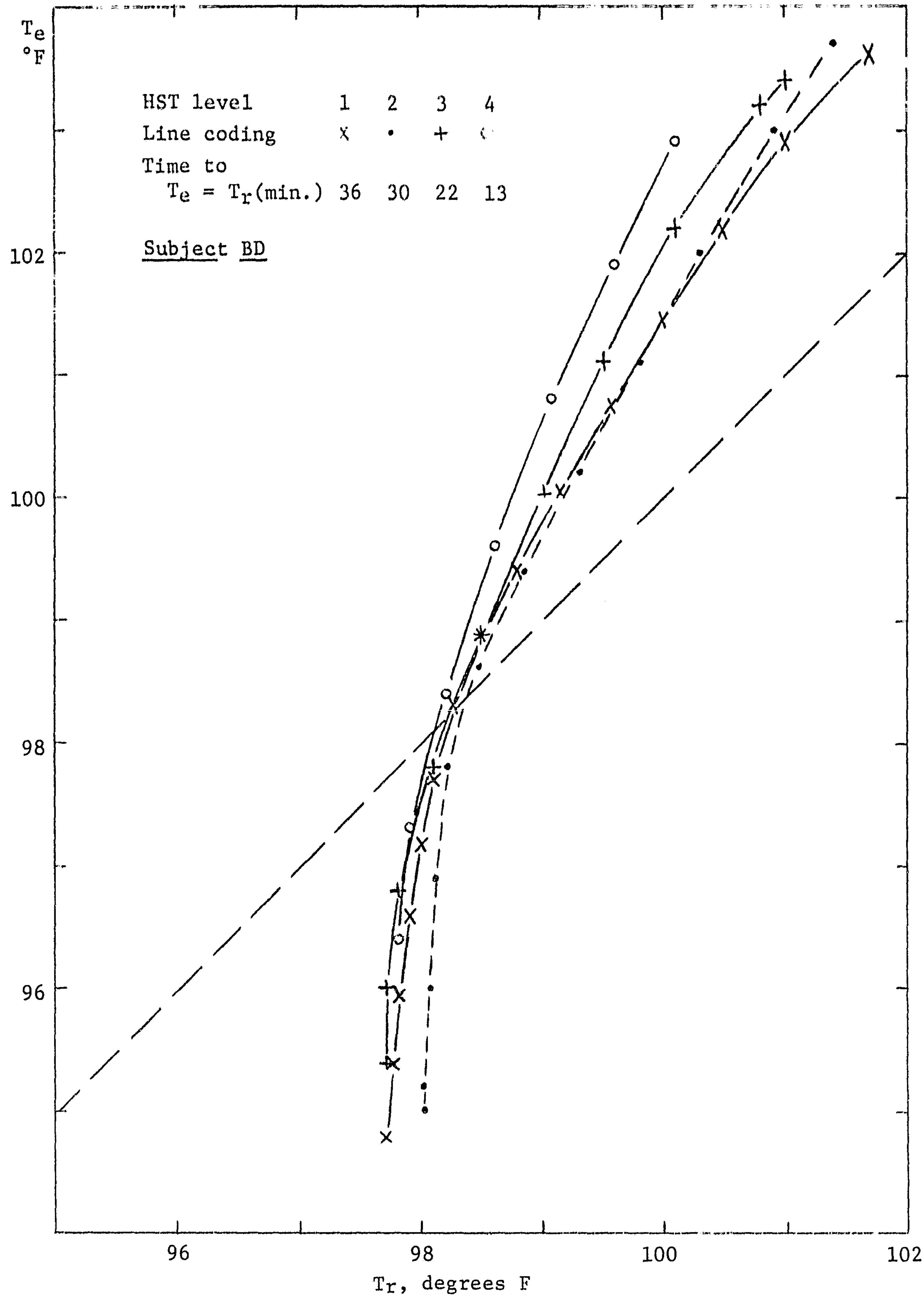

Figure 8 - T_e vs T_r for subject BD, at all HST levels.

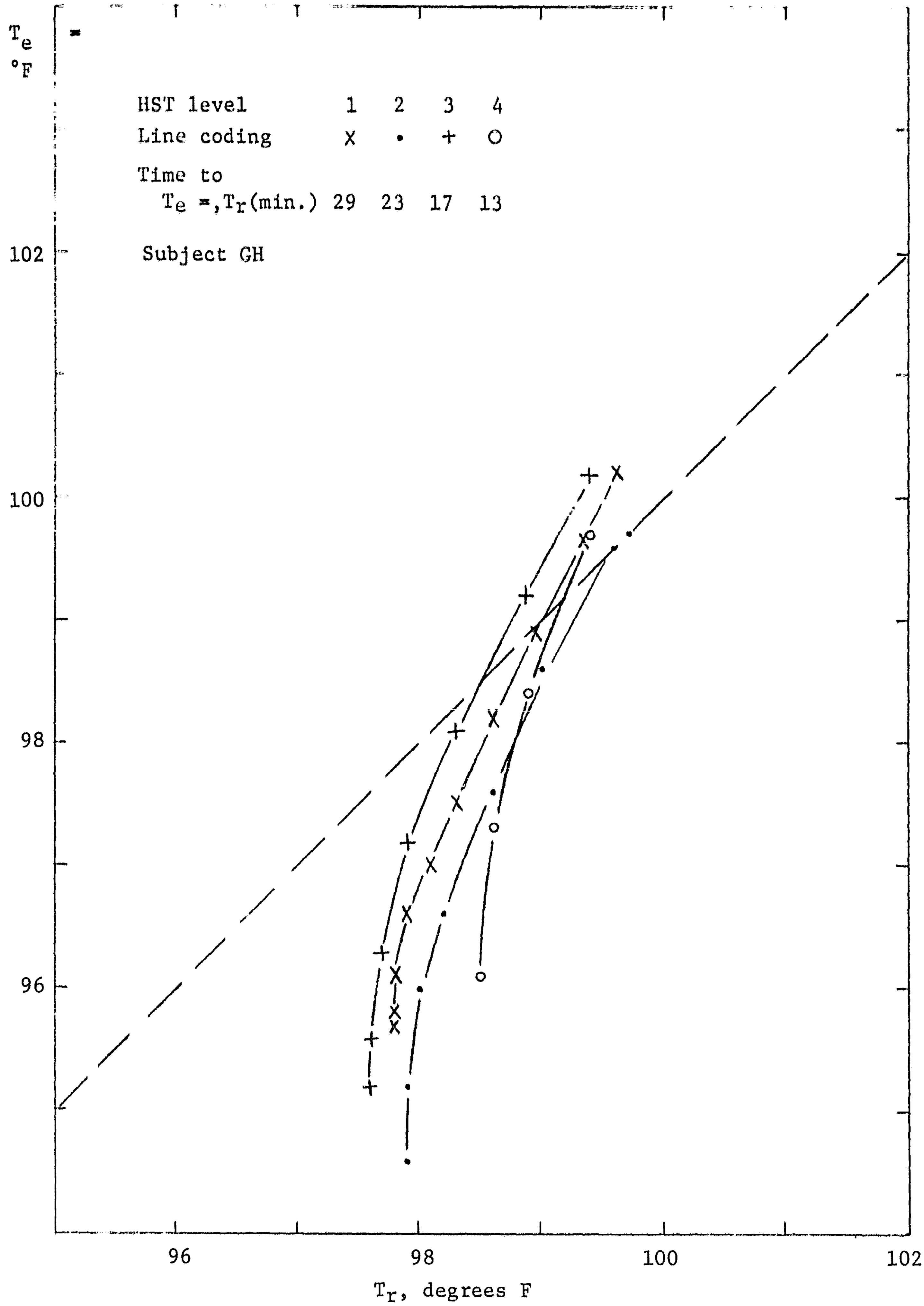

Figure 9 - T_e vs T_r for subject GH, at all HST levels.

a lesser extent their lower average weight (5.5 lb less than the H-T group), whereby they constituted smaller "heat sinks." There appears to be no significant association of the $T_r = T_e$ point with the metabolic rates of the four HST test levels.

In general, the shape of the curve of T_r vs T_e is consistent and characteristic for each subject. Its position on the grid is primarily a function of the overall thermal state (cool or warm) of the body at the start of each test. For each subject, its slope is remarkably similar to others at comparable percentages of the total test time, with the superimposed tendency toward a steeper slope at the end of the test, at the higher metabolic levels, as previously mentioned.

Figure 10 shows mean values at 5-minute intervals at each HST level, for all subjects, in the same manner as Figures 8 and 9.

Rectal, Ear Canal, Mean Skin and Forehead Temperatures

Figure 6 shows the simultaneous courses of mean values of rectal, ear canal, mean skin and forehead temperatures at each HST level. This illuminates further, and in a different manner, the differences in response of rectal and ear canal temperatures, as discussed previously, and adds two other temperature parameters. At all HST levels, the relative lag in response of rectal temperature is evident, as is the fact that equality of rectal and ear canal temperatures is reached at a progressively earlier time as the metabolic level is raised.

Mean skin temperature starts at a typically lower level, between 92° and 93°, and rises to approximate equality with rectal and ear temperatures at a time ranging from about 30 minutes down to about 16, as the metabolic level is raised. The terminal value of mean skin temperature is slightly above rectal and slightly below ear canal temperature.

Forehead skin temperature has been plotted separately, in an effort to explore the possibility of its use as a significant parameter of body temperature, in view of the relative convenience and acceptibility of its measurement. Conceptually, the rich blood supply to the scalp should make forehead temperature (especially if sensed under an adequate layer of thermal insulation) fairly representative of blood temperature, after warming of the head and forehead has offset their usual initially lower temperature compared with that of the body core.

It will be noted that forehead temperature rose fairly rapidly within the first 5 or 10 minutes of a test, and reached equality with rectal temperature in less than 10 minutes. Its mean value in HST-1 remained practically equal to rectal during the rest of the test period. In the other HST runs, forehead temperature rose above rectal by about 1/2° to 1°, and during the latter part of a test remained within a fraction of a degree above ear temperature.

The fact that T_f, starting below T_e, rose substantially above ear canal temperature, in the early portion of a test, undoubtedly reflects

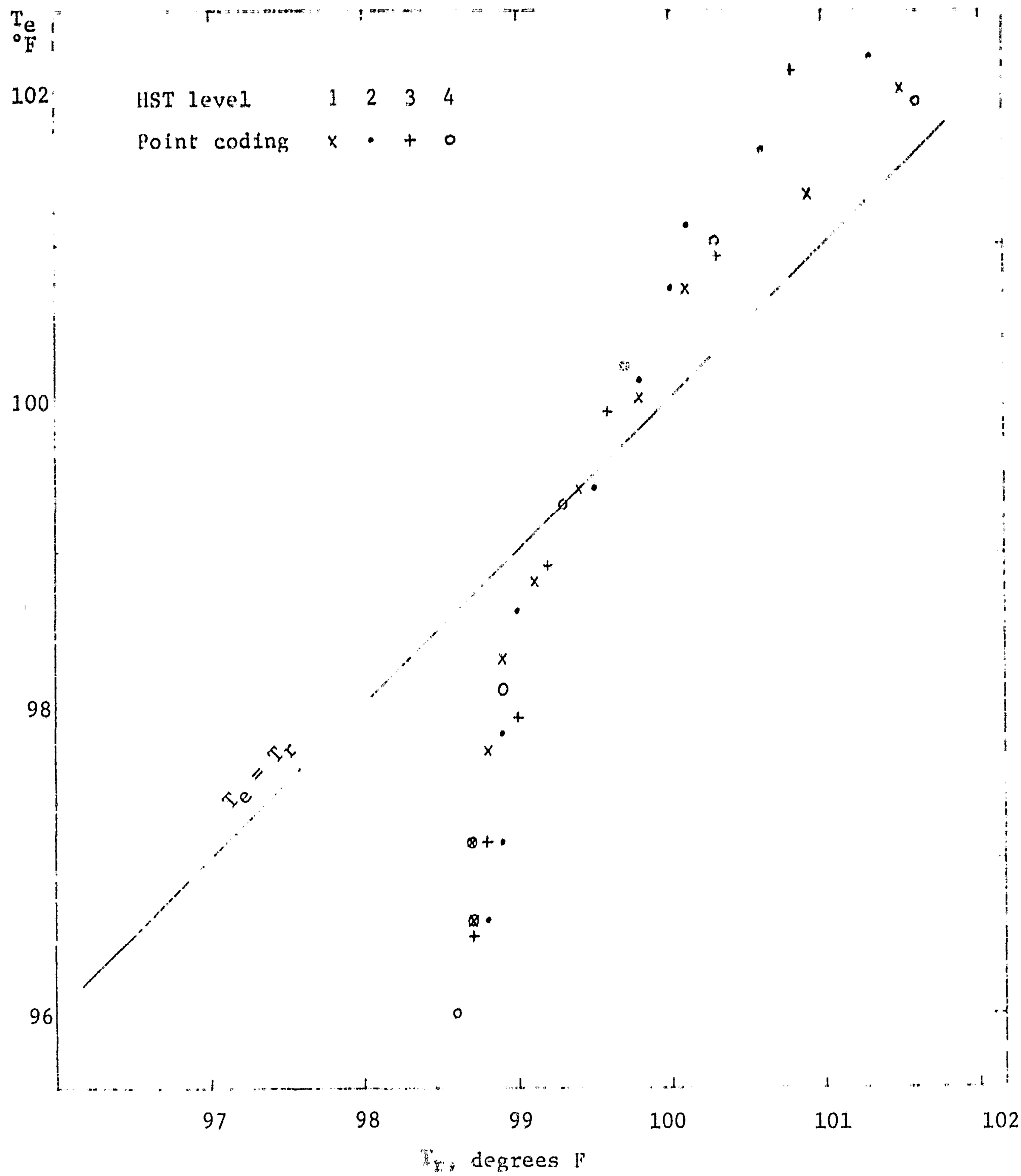

Figure 10 - Ear canal vs rectal temperatures in HST runs. Averages plotted at 5-min. intervals throughout HST run levels 1, 2, 3 and 4. Data from 10 subjects at each point up to minimum tolerance time for each metabolic level, thereafter for progressively fewer subjects, resulting in greater scatter of data-points. Point of equal ear canal and rectal temperatures was reached, on the average, at between 15 and 20 minutes.

the greater total flow of blood to the forehead area, in comparison with that to tissues surrounding the ear canal.

Examination of individual-subject plots of these four temperature parameters reveals general conformity of their pattern to that shown in the mean-value plot just discussed. An example is Figure 7, for subject FD.

Ear Canal Temperature in Relation to Tolerance Time

Exploration of numerous temperature parameters in relation to tolerance time finally led to the conclusion that ear canal temperature provides better correlation, in relation to the whole range of metabolic levels studied, than any other. The possibility of using mean body temperature was first probed thoroughly, using the conventional formula (after Burton):

$$T_b = \frac{2T_r + T_s(\text{mean})}{3}$$

to determine the change in mean body temperature from start to end of a test. Linearity of the plotted results was distinctly inferior to analysis based solely on ear canal temperature.

Graphs of all subjects' ear canal temperatures, vs time, both individually and arranged by HST run level, disclose that except for an initial period of stabilization (the first 5 to 10 minutes of a test run) ear canal temperature showed almost exactly linear change with time, and that the slopes of the averaged data for each HST level are directly related to the metabolic level of the test. There are of course inter-individual differences in slope, at each level, but these are relatively small. The high degree of linearity of the T_e data with time is seen in Figure 6, previously discussed.

Figure 11 is a graph of mean T_e at all HST levels, at 5-minute time increments. This also exhibits the linearity of T_e vs time, following the initial stabilization period mentioned, up to the point where mean values begin to be distorted by the absence of values from those subjects who reach tolerance limits at lower times. It has previously been noted that those subjects having higher cumulative tolerance times (the H-T group) also had lower body temperatures at the start. Therefore, as the values for the L-T subjects started dropping out of the mean, this became more and more dominated by the values for the H-T subjects. This caused an apparent distortion of the linearity of T_e vs time, which is highlighted in this figure.

Figure 12 is a similar graph, in which this distortion at the higher values of tolerance time at each level is avoided, through basing the slope evaluation only on the "steady-state" rise of ear temperature, during that portion of each run level data when all subjects were represented. Note that mean values at the start of the test, at all levels, were between 96.5° and 96.7°F, and that at the 5-minute point they were all 97.1°. Thereafter, each HST level exhibited its own characteristic slope of mean T_e vs time, changing only slightly during the next 5-minute period or two,

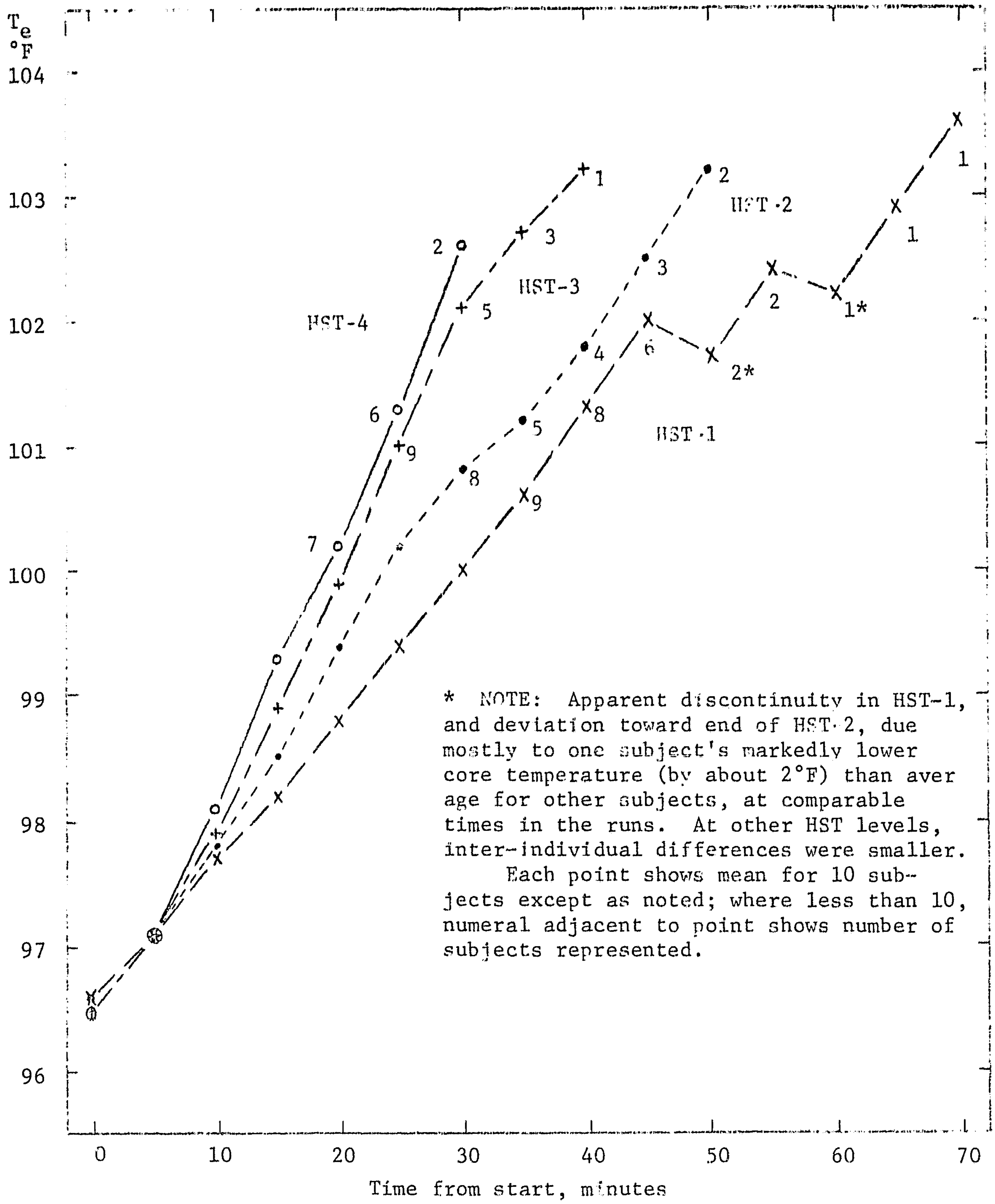

Figure 11 - Mean T_e vs time, at all HST levels. Note apparent (not real) distortion of T_e linearity, due to the combined effects of (1) inter-subject variability in general temperature level, and (2) resultant shift of mean as number represented declines due to dropout of subjects having lower tolerance limits.

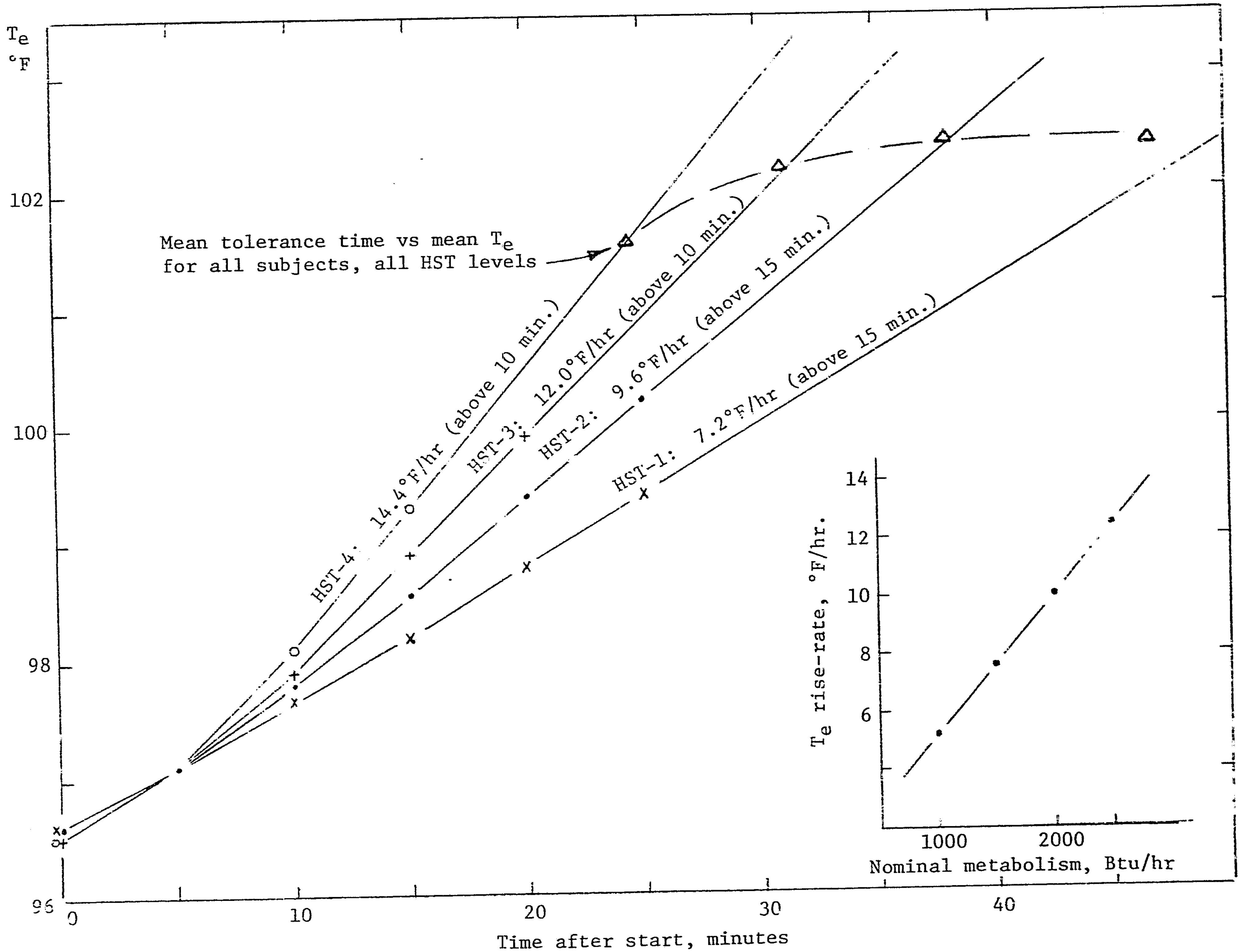

Figure 12 - Mean T_e vs time at all HST levels, showing basic linearity after initial stabilization, rise-rates at each HST level, and relation of rise-rates to metabolic levels

until attainment of a constant slope which prevailed during the time interval when all subjects were still represented in the data for that stress level.

For the respective HST levels 1, 2, 3 and 4, these slopes represent rates-of-rise of ear canal temperature of 7.2, 9.6, 12.0, and 14.4 degrees F per hour. A small inset graph in the lower right of Figure 12 expresses these rates-of-rise in terms of the nominal metabolic levels; the linearity of the relationship is obvious.

The slope lines of T_e vs time were projected into the upper area of the graph, in which symbol "$\triangle$" designates, for the four HST levels, the mean final ear canal temperature for each HST level, plotted against the mean tolerance time for that level. With the exception of HST-1, all these points lie almost exactly on the projections of the four slope lines.

Derived from the foregoing data, Figure 13 is a graph of tolerance time against the rate of rise of ear canal temperature in °F/hr. The slope of the resultant curve is -3.13 minutes/°F/hr. The equation for this curve is:

$$\text{Tolerance time (min)} = 68.7 - 3.13\ (dT_e/d\theta)$$

in which $dT_e/d\theta$ is the rate of rise of ear temperature in °F/hr (after ten minutes.)

We believe that the relationship between tolerance time and rate of rise of ear temperature, as presented above, constitutes the most useful approach to the evaluation of the hazard presented by a situation in which a man has to work with minimal or no opportunity for loss of metabolic heat to the environment. The mean values shown in Figure 13 provide an indication of average probabilities, and the line representing the minimum tolerance-time values would provide a rather conservative estimate.

Estimates of Heat Storage

The change in heat content of the body can be estimated in several different ways. Table 3 is based on the difference between the initial and final mean body temperatures, computed from ear canal temperature (representing the core) and skin temperature, weighted in the ratio 2 to 1. The ear temperature is selected rather than the rectal because of the excessive lag in the latter under the special circumstances of these conditions.

The change in weighted mean body temperature is multiplied by the body weight in pounds and the C_p for body tissues, 0.83 Btu/lb,°F to yield the change in heat content in Btu.

It can be seen from table 3 that the L-T group tended to store about 200 to 300 Btu less heat than the H-T group, with the lowest storage figure being 600 Btu and the highest 1415 Btu, and the overall grand mean for 40 experiments 973 Btu. The L-T group's average storage was 827 Btu, and the

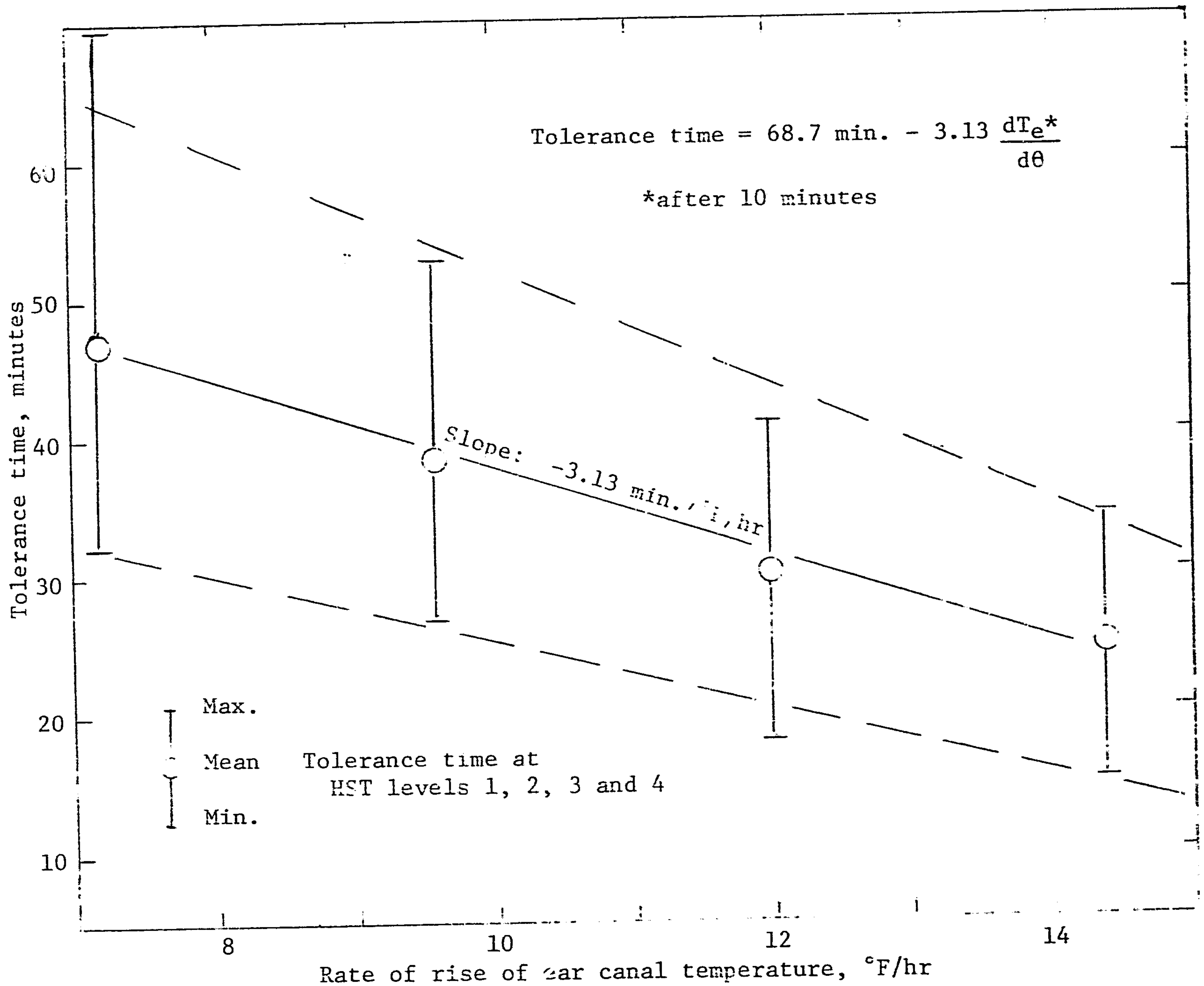

Figure 13 - Graph and equation for tolerance time as function of T_e rise-rate (as latter is determined by metabolic level.)

TABLE 3

Change in heat content during each Heat Stress Test based on mean body temperature change, ΔT_b. (ΔT_b computed from ear and mean skin temperature.)

	H-T GROUP					Group	L-T GROUP					Group
Subject	BD	LS	RB	FD	CS	Mean	SR	RH	GH	SA	BB	Mean
Net Weight (lbs)	165	207	175	176	165	177.6	172	194	167	162	185	176
	Over-all mean weight: 176.8 lbs.											
HST-1 Change in heat content (Btu)	1415	1080	1230	920	985	1126	815	965	915	792	706	838
	Mean for ten subjects: 982 Btu											
HST-2	1394	1440	1220	1140	972	1283	820	870	873	887	722	834
	Mean for ten subjects: 1034 Btu											
HST-3	1220	1165	1190	1050	915	1108	345	950	915	940	600	850
	Mean for ten subjects: 979 Btu											
HST-4	1025	1100	1132	1020	765	1008	1070	775	623	765	690	785
	Mean for ten subjects: 896 Btu											

Grand mean 973 Btu

H-T group averaged 1131, almost exactly 300 Btu greater. This difference of course reflects the longer duration of exposure of the more heat-tolerant group.

A second means of estimating the change in heat content of the body during heat stress exposure is to multiply the rate of change of body temperature by the C_p and by the exposure duration. On the assumption that the weighted mean temperature of the body mass was rising at a constant rate throughout the exposure (which seems reasonable since the work load was constant and there was no heat loss) we postulated that this rate of increase was identical to that of the ear canal temperature after 10 to 15 minutes (when all temperatures seemed to be moving essentially together).

Table 4 shows the group mean values for change in heat content of the body obtained from the overall average rate of rise in ear temperature and the sub-group mean exposure times.

Table 4

Change in body heat content, in Btu (means for tests at each HST level) by high-tolerance and low-tolerance subject grouping, compared with corresponding metabolic heat production (total metabolism less external work) in Btu.

	High-Tolerance Subject Group				Low-Tolerance Subject Group			
	HST-1	-2	-3	-4	HST-1	-2	-3	-4
Δ H	964	1082	1038	1005	687	711	730	722
M - W	1002	1145	958	982	754	815	874	739

Oxygen Consumption Data

The continuous monitoring of oxygen uptake produced data of great potential interest which will require considerably more study before firm conclusions can be drawn. Figure 14 illustrates the type of data which can be obtained, showing the oxygen uptake histories for representatives of both H-T and L-T subject groups. Data for the other four men in each group are displayed in Figures 15 and 16.

The method used does not distinguish between oxygen consumption and CO_2 wash-out (i.e., R greater than 1) so that when the apparent $\dot{V}O_2$ increases in the latter half of a heat stress exposure we cannot be sure what portion of the increase is a true rise in oxygen uptake and what portion represents a rise in respiratory exchange ratio. In future studies we plan to monitor R continuously so that such a distinction can be drawn.

In the figures, the target $\dot{V}O_2$, i.e. that uptake equivalent to a metabolic rate of 1000, 1500, 2000 and 2500 Btu/hr, is shown on the ordinate as a box. Of the H-T group, only one subject, LS, shows a definite tendency to increase oxygen intake and/or CO_2 output in the second half of the ex-

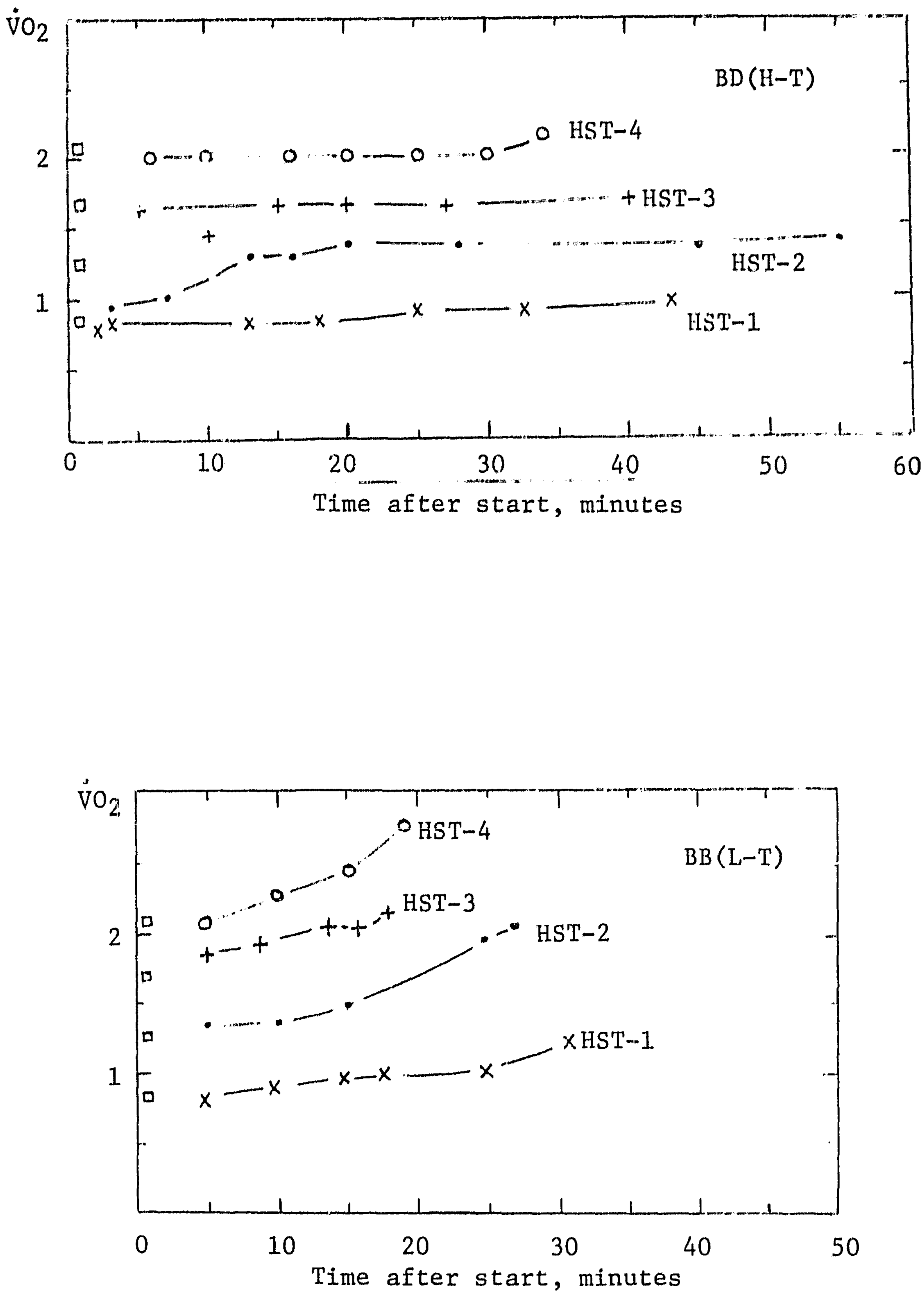

Figure 14 - Oxygen consumption for subjects BD and BB, at designated HST levels.

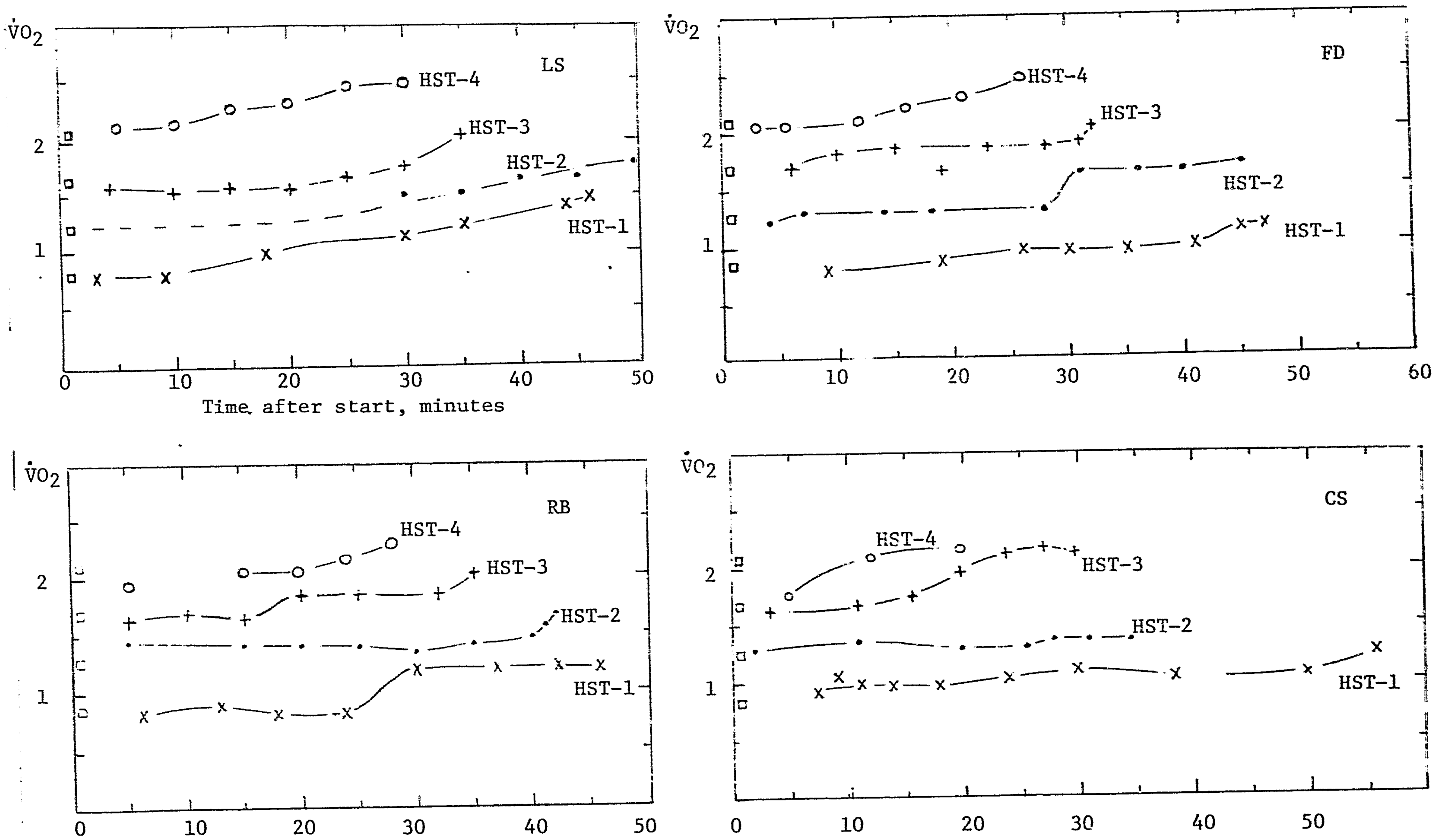

Figure 15 - Oxygen consumption for subjects LS, FD, RB and CS (of H-T group) at designated HST levels.

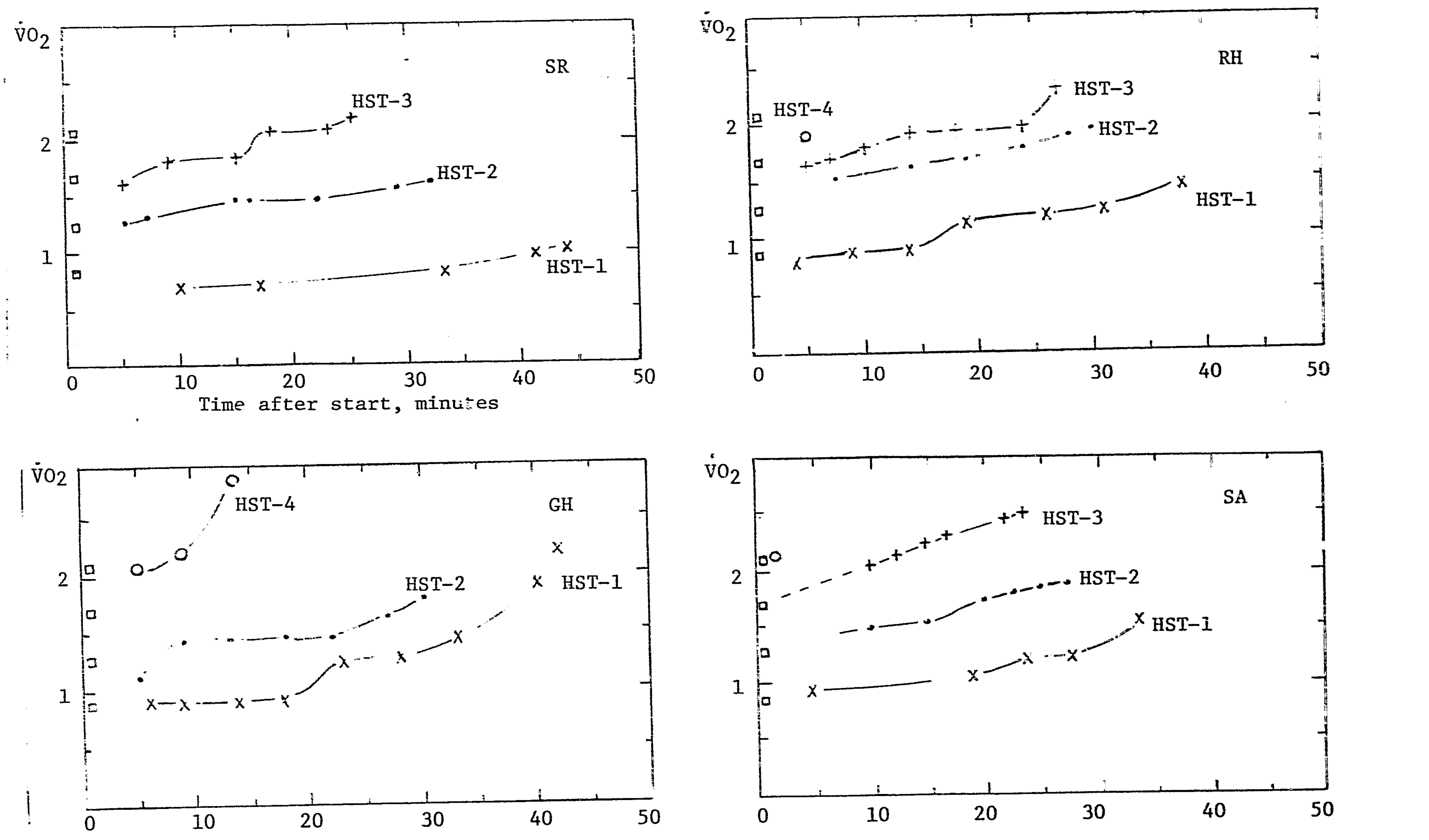

Figure 16 - Oxygen consumption for subjects SR, RH, GH and SA (of L-T group) at designated HST levels.

posures, although CS shows a late increase in the two more severe runs.

Among the L-T group, on the other hand, steep rises in apparent $\dot{V}O_2$ were the rule rather than the exception. The magnitude of these increases in O_2 uptake or CO_2 output were frequently of the order of 20 to 30 per cent, approximating the interval between the nominal metabolic rate levels. Toward the end of the series of experiments, some extremely high readings were obtained, raising a suspicion that the O_2 analysis cell had deteriorated and was malfunctioning; these data have been omitted from the graphic presentations.

In Table 4 are presented the average $\dot{V}O_2$ for the H-T and L-T groups at the beginning, mid-point and end of the heat stress tests. The tendency for elevated final values for $\dot{V}O_2$, particularly in the L-T group, is clearly indicated. This observation is consistent with an old report of Robinson[6], and may be closely correlated with a reduction in efficiency as the exhaustion point is approached.

Comparison of Heat Storage and Heat Production Estimates

Figure 17a is a graphic representation of the balance between heat production (metabolism less external work) and the estimated increase in body heat content during the heat stress tests. Total energy expenditure was estimated from the oxygen consumption using a conversion factor of 19.15 Btu per liter oxygen consumed. Individual values for the latter, for each HST run, were obtained by integration (using a planimeter) of the graphic records of oxygen consumption exhibited in Figures 14, 15 and 16.

External work expended in walking on a grade was estimated by the conventional method of taking the product of body weight in pounds, the treadmill speed in feet per minute, treadmill grade in vertical rise per foot of belt travel, and the conversion factor from foot-pounds to Btu. Increase in body heat content was derived as previously discussed.

The Figure includes data from all HST runs except four, in which the data for oxygen consumption appeared questionable. The open symbols are the data from the H-T group of subjects, those with dots, data from the L-T group. The dashed line indicates the locus of exact balance of the two quantities plotted, and dotted lines showing the range of 10% variation of one from the other. Some 23 of the 36 plotted points fall within that approximate limit, with all but one of the rest indicating a greater increase in body heat content than energy input.

Figure 17b shows the product of group mean tolerance time and the overall average rate of change of ear temperature (from Fig. 12), with separate symbols for the high-tolerance and low-tolerance groups at each of the four metabolic levels of the heat stress tests. The data for the high-tolerance group shows a very high degree of heat balance, well within 10% limits of variation. The data for the low-tolerance group suggest the possibility that the actual oxygen consumption may have been about 10% lower than the measurements indicated. Such an error could arise if the CO_2 output of this group were excessive, due to greater anxiety and lesser muscular efficiency due to nervous tension. Such excess CO_2 (beyond an R of 1.0) would register in our system as increased O_2 consumption.

TABLE 5

Oxygen consumption results from continuous monitoring data (liters per minute)

H-T Group	First 10 minutes Mean	Min.	Max.	Mid-point Mean	Min.	Max.	Last 5 minutes Mean	Min.	Max.
HST-1	0.79	0.76	0.92	0.94	0.85	1.05	1.14	0.95	1.36
HST-2	1.31	1.26	1.44	1.33	1.27	1.38	1.50	1.35	1.65
HST-3	1.65	1.58	1.70	1.70	1.60	1.76	1.90	1.67	1.88
HST-4	2.05	2.00	2.12	2.10	2.01	2.25	2.21	2.06	2.45
L-T Group									
HST-1	0.80	0.65	0.93	1.00	0.72	1.25	1.37	0.95	1.93
HST-2	1.35	1.28	1.50	1.50	1.43	1.65	1.76	1.58	1.90
HST-3	1.67	1.60	1.70	1.97	1.90	2.13	2.17	2.04	2.40
HST-4	2.12	2.11	2.13	2.26	2.21	2.30	2.58	2.55	2.60

TABLE 6

Sweat loss (lbs)

Subject	HST-1	HST-2	HST-3	HST-4	Mean
CS	2.03	1.56	1.46	2.15	1.80
SR	1.24	2.09	1.85	1.73	1.72
BD	2.18	2.05	1.69	1.66	1.89
LS	2.50	2.82	2.61	2.51	2.61
RB	1.50	1.49	1.47	1.20	1.41
FD	2.48	2.30	2.97	1.79	2.38
BB	1.79	2.07	1.38	1.16	1.60
SA	1.73	1.72	1.60	1.54	1.68
GH	1.54	1.44	1.46	1.06	1.37
RH	2.00	1.97	1.57	1.33	1.71
Mean	1.90	1.95	1.81	1.61	1.81

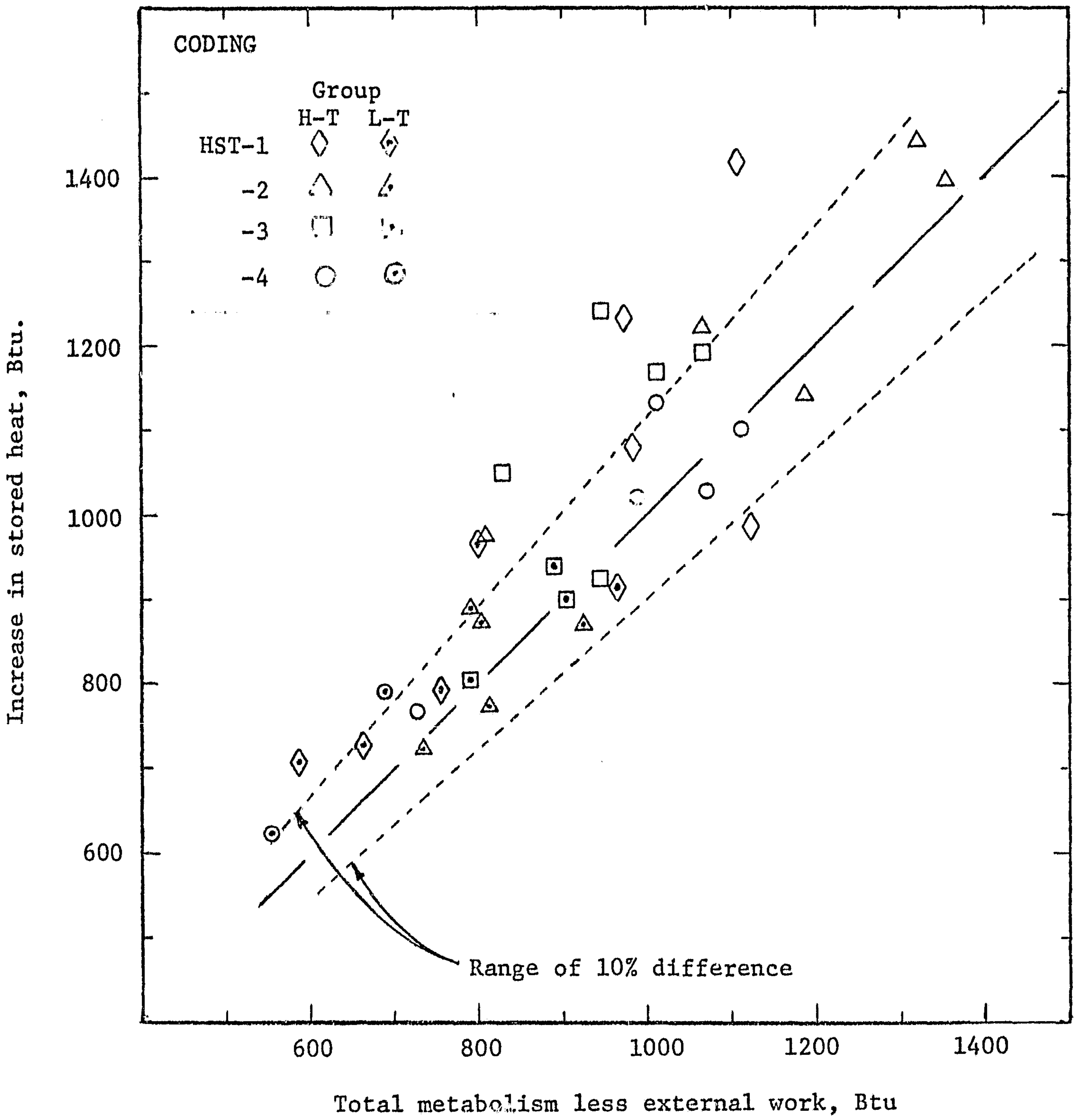

Figure 17a-Balance between calculated heat production (metabolism less external work) and heat storage (computed from the rise in mean body temperature during a test). The estimate of weighted mean body temperature uses mean skin temperature, with ear rather than rectal temperature representing the core temperature, in the conventional formula: mean body temperature = 2/3 core temperature + 1/3 skin temperature. Metabolism is calculated from continuous recordings of oxygen consumption.

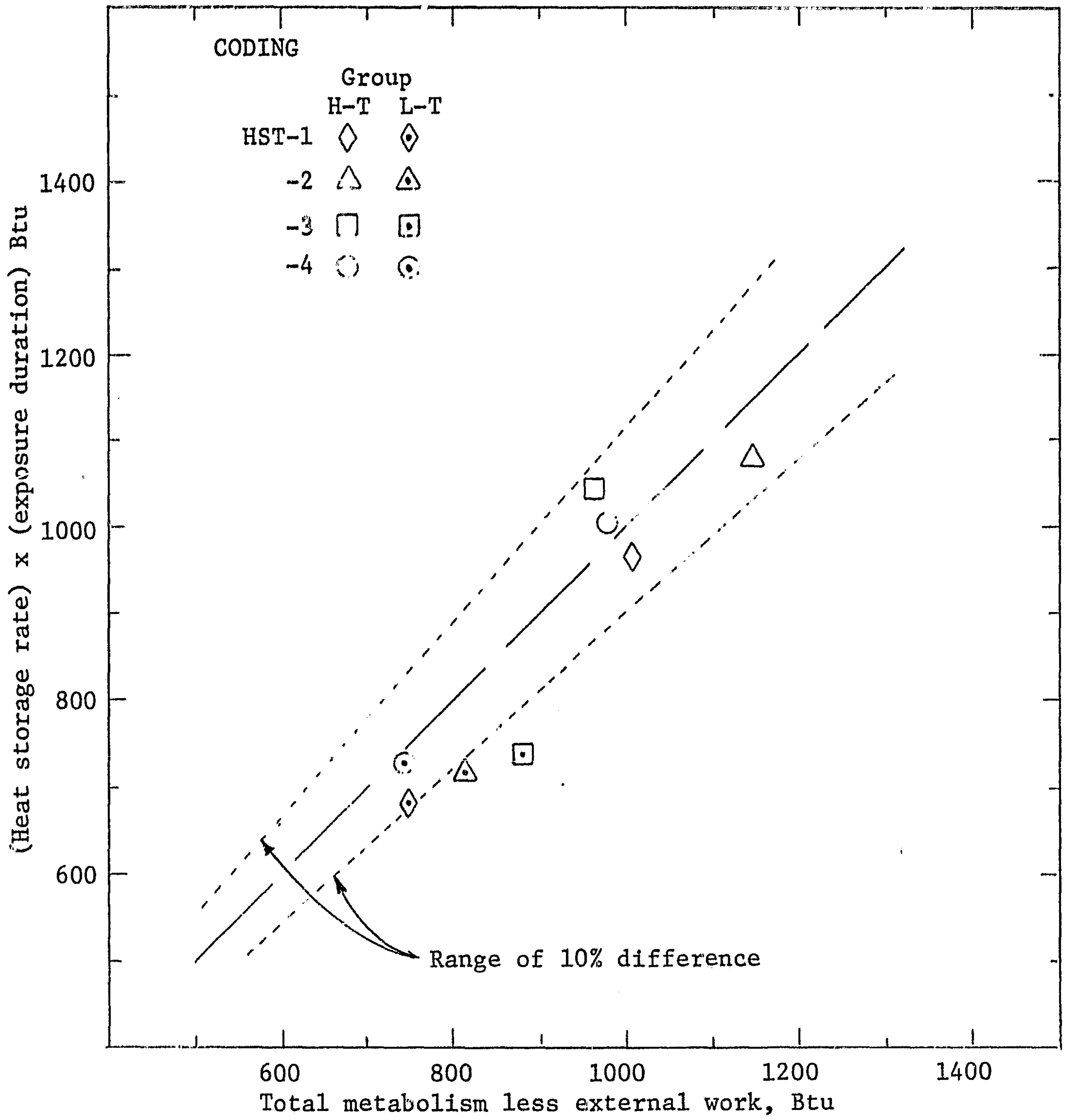

Figure 17b - Balance between calculated heat production (metabolism less external work) and heat storage (computed from the rate of rise of ear canal temperature, body weight, and exposure duration.) The storage computation assumes that the weighted mean body temperature rose at the same rate throughout as did the ear canal in its final steady-state rate of change. Metabolism is calculated from continuous recordings of oxygen consumption.

Sweat Production

Table 5 presents the complete data for the change in nude weights in all 40 heat stress tests. While these data include the losses during the dressing and in the recovery period following removal from the heat stress situation, it is believed that the bulk of the measured change in weight occurred during the heat stress period itself.

There is no reason to believe that the differencesbetween one heat stress level and another are significant, and the data bear a striking resemblance to the also homogenous sweat loss data in the resting heat stress tolerance studies of Blockley et al[3].

These weight losses represent a dehydration of from 0.8 per cent to 1.7 per cent. Dehydration stress of this magnitude is normally considered of only marginal concern, the apparent threshold for disturbances of thermoregulation being 1 per cent, as reported by Blockley[8].

However, even mild dehydration when coupled with extreme vasodilatation and overheating may represent a significant additional complication.

Heart Rate Response

In the analytical study of heart rate response in the heat stress tests, individual graphs for each subject were prepared, showing heart rate vs time at all HST levels. Derived groupings were then made, to determine the extent to which heart rate response was related to either cumulative or single-level tolerance time rankings, in a manner analogous to the analysis of ear canal and other body temperature data.

In general, the heart rate data correlated rather closely with the tolerance-time rankings, somewhat more so based on the individual-level rankings (as listed in Table 1) than for the cumulative-time rankings. At each HST level, the subjects' heart rate curves were categorized into H-T and L-T groupings, on the basis of both configuration (slope pattern) and the overall comparative levels of heart rate vs time. Analysis of these groupings yielded the following findings:

1. The rise of heart rate from start to end of a test followed a pattern which reflected both the metabolic level of the test, and the tolerance characteristics of the subject. This response pattern, regardless of metabolic level, showed two dominant aspects:

   a. An initial-response rise, generally complete by 10 minutes after the start of a test, more rapid than that prevailing thereafter. (An exception was the H-T group at the HST-1 level, whose rise-rate was substantially linear throughout, without an initially-greater rise-rate; in fact, two subjects showed lower rise-rates, to 10 minutes, than thereafter.)

      (1) This initial-response rise was directly related to the meta-

bolic level; i.e., it was least at HST-1 and greatest at HST-4; at each level, it was also greater for the L-T group than for the H-T.

b. After the first 10 minutes (approximately), a substantially linear rate of rise (a "prevailing slope") was established, which continued up to the tolerance end-point, regardless of whether this was determined by heart rate, core temperature or fatigue. (In a few cases, the rise-rate near the end declined slightly.)

c. The "prevailing slope" (rise-rate after 10 minutes) was not greatly different from one HST level to another, but tended to be slightly greater at the higher metabolic levels, also higher for the L-T group than for the H-T.

Quantitation of the rates-of-rise of heart rate, as above discussed, is rather difficult to state with much certainty on account of the small size of the sample involved. It is this which has necessitated visual fitting of slope-lines rather than mathematical derivation from the consecutive 5-minute data.

Figure 18 is presented to enable convenient comparisons both between the H-T and L-T groups, and of the differences which are a function of the HST metabolic level. The solid lines in each of the four panels (for HST-1, -2, -3 and -4), represent the approximate "envelopes" of the grouped data for the subjects classified as H-T, at each level; the broken lines are similar envelopes of the data for the L-T groups.

In the panel for HST-1, the envelope for the H-T group does not include the data for the two best men, whose heart rates were substantially lower throughout, and are shown as dotted lines. Note that these men showed lower rise-rates early in the test at that level, than they did in the later portion; also that their "prevailing slopes" are parallel to the trend shown by the other four who comprised the H-T group at the HST-1 level.

Figure 19 is a larger-scale plot, in which the four solid lines show the slope trends for the H-T group at all four HST levels, and the four dashed lines show trends for the L-T group. Each line was visually fitted to approximate the central trend of the data for each group, at each level.

With regard to the "initial-response" rise-rates, note that these vary from 1.6 beats per minute per minute (bpm/min.) for the H-T group at the HST-1 level, (which slope continued to the end, as before mentioned), to a value of 9 bpm/min. equivalent rise-rate for the first 5 minutes at HST-4, for the L-T group. For the second 5 minutes, this group's rise-rate was 4 bpm/min., and after 10 minutes, 2.4 bpm/min. to the end.

The foregoing rough quantitation is presented somewhat hesitantly, but we believe that the picture presented is reasonably representative of what would be seen if the sample were larger.

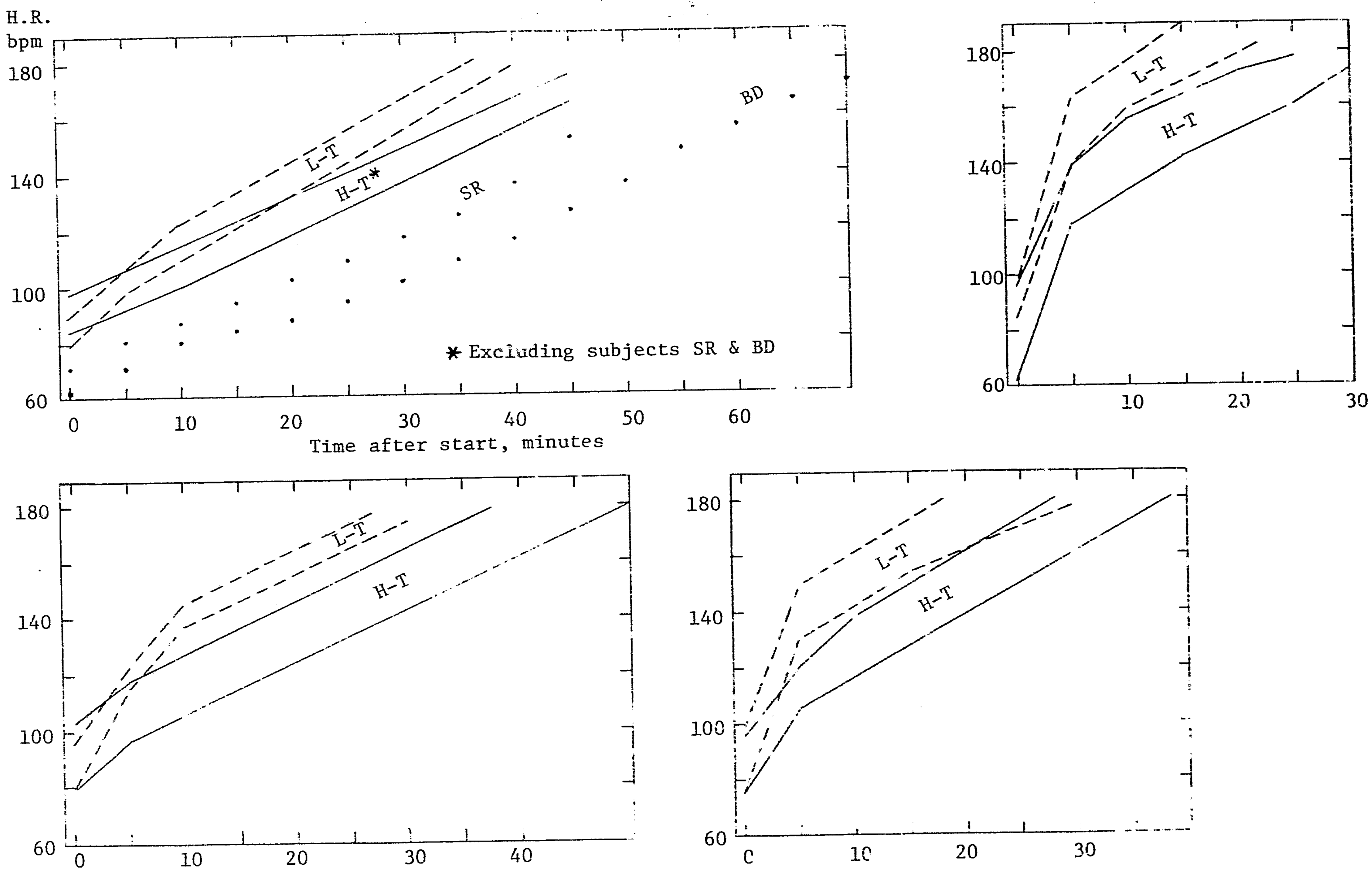

Figure 18 - Heart rate vs time, based on curves grouped into high-tolerance (H-T) and low-tolerance (L-T) categories. Pairs of solid lines show locus of data from H-T groups, dashed lines from L-T groups. Two exceptional subjects plotted separately in HST-1.

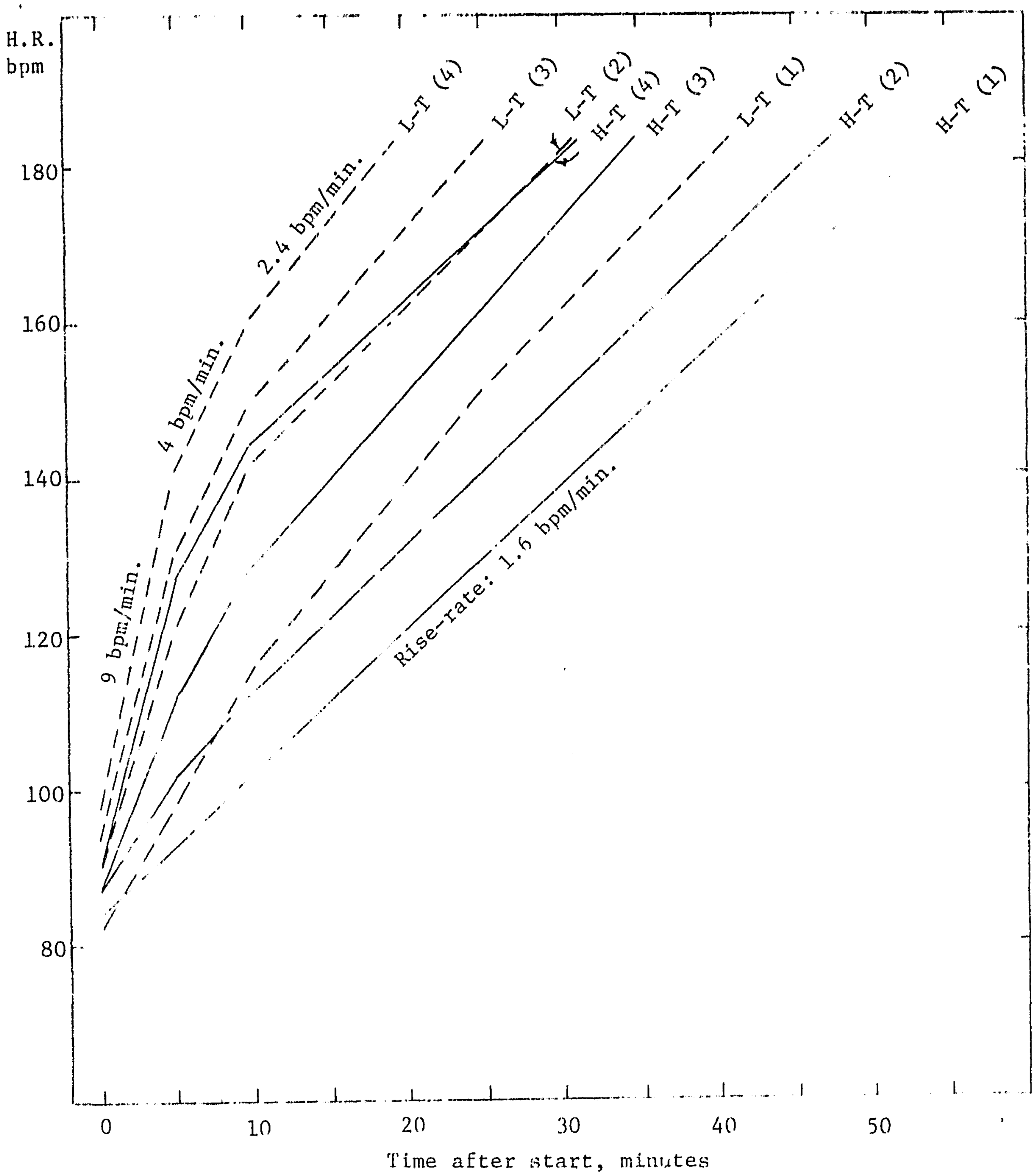

Figure 19 - Trend-lines of heart rate vs time, derived from H-T and L-T grouped curves, showing: (1) initial response rise (magnitude dependent on both metabolic level and subject's relative stress tolerance), and (2) time-dependent linear rise-rate phase, only slightly influenced by metabolic level. Trend-line H-T (1) excludes SR and BD, whose curves were substantially lower, but parallel (see Fig. 14.)

In any event, we believe the following observations are in order:

1. Subjects who have superior tolerance to the kind of stress presented in this test situation show a smaller initial rise of heart rate (during the first 5 to 10 minutes) than do less-fit subjects, and reach an ensuing "prevailing slope" rise-rate sooner.

2. Following the "initial response" heart rate rise, both H-T and L-T subjects exhibit a substantially constant rise-rate to the end of their tolerance (with minor exceptions), quantifiable in terms of a "prevailing slope" expressed as beats per minute per minute.

3. The "prevailing slope" does not differ greatly between H-T and L-T groups, but is slightly higher (about 20 to 25 per cent) for the L-T groups.

4. Because of both their higher "initial-response" rise, and their greater "prevailing slope", L-T subjects would reach a limiting value of peak heart rate sooner than H-T subjects, providing they do not reach their tolerance limits sooner for other reasons.

5 The heart rate response of H-T subjects generally parallels their superior performance in other respects, both physiological and psychological.

Mean Heart Rates vs Per Cent Completion

The comparative effects on heart rate, elicited by the four progressive metabolic levels of the heat stress tests, is seen in Figure 20, in which mean values of heart rate are plotted against per cent completion. This again shows the basic linearity of rise of heart rate throughout the HST-1 level, and at the other levels for a substantial proportion of the total test time, after the initial-response rise yields to the "prevailing slope".

With regard to the effects of differences in metabolic level, note particularly the relatively greater effect of an increment of 500 Btu/hr, between levels 1 and 2, than the same increment produced between levels 3 and 4. In fact, from the standpoint of terminal values of heart rate near or at the endurance limit, there was little difference between mean heart rates for levels 3 and 4, for nearly the last 50 per cent of the test time at each level from the standpoint of relative test completion. This might be taken as indication that both these metabolic levels are highly stressful, and readily bring men near to their performance endpoint, within individual time periods determined by their basic ability to withstand high stress.

The comparability of mean heart rates for the final portions of tests at levels 3 and 4 should not obscure the existence of individual differences, and the fact that the less resistant subjects reached high heart rates sooner than did the more resistant ones.

Heart rates for individual subjects for their tests at all HST levels are shown in Figures 21a, 21b and 21c.

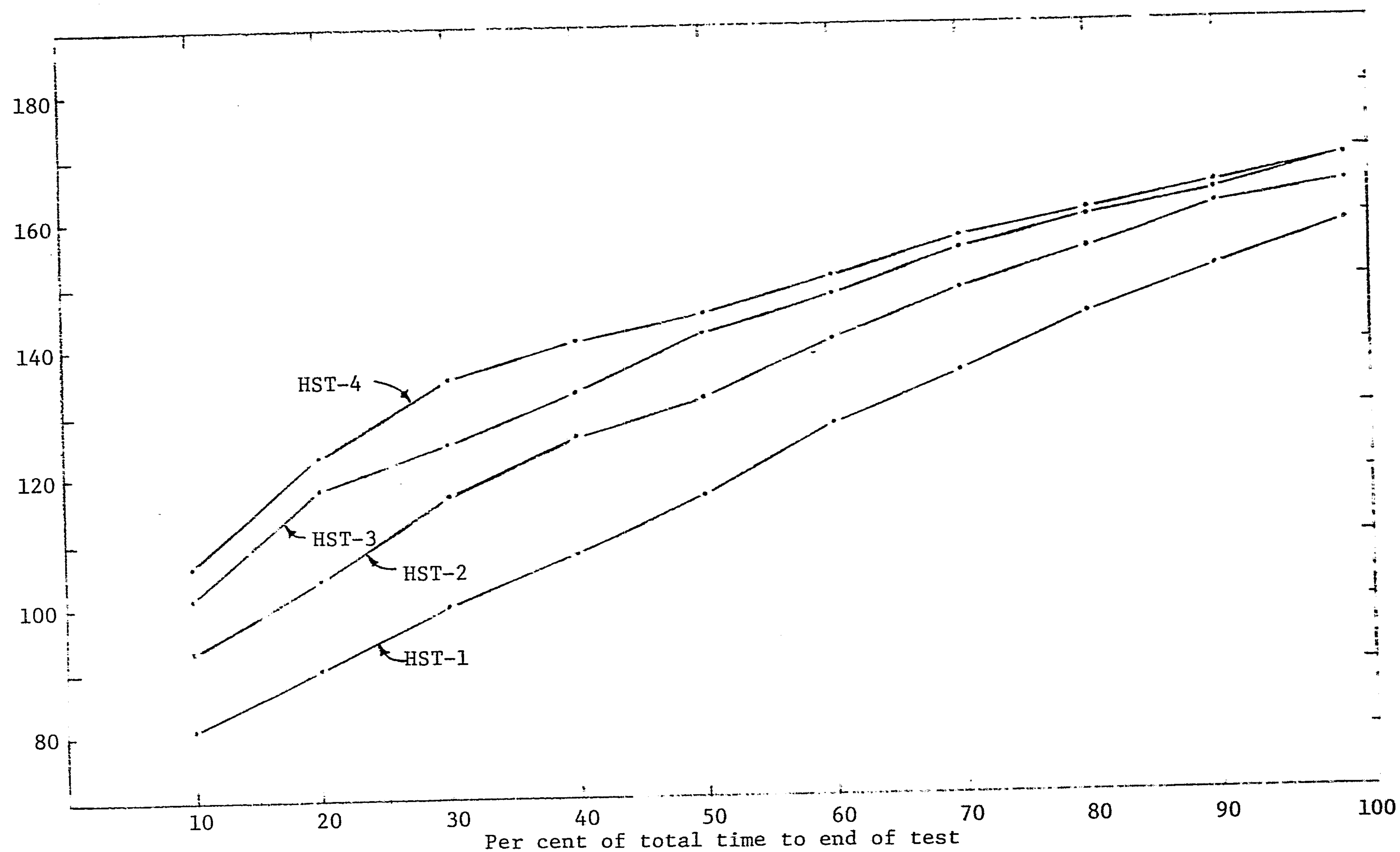

Figure 20 - Heart rate vs per cent completion of test; 10-subject means at all HST levels.

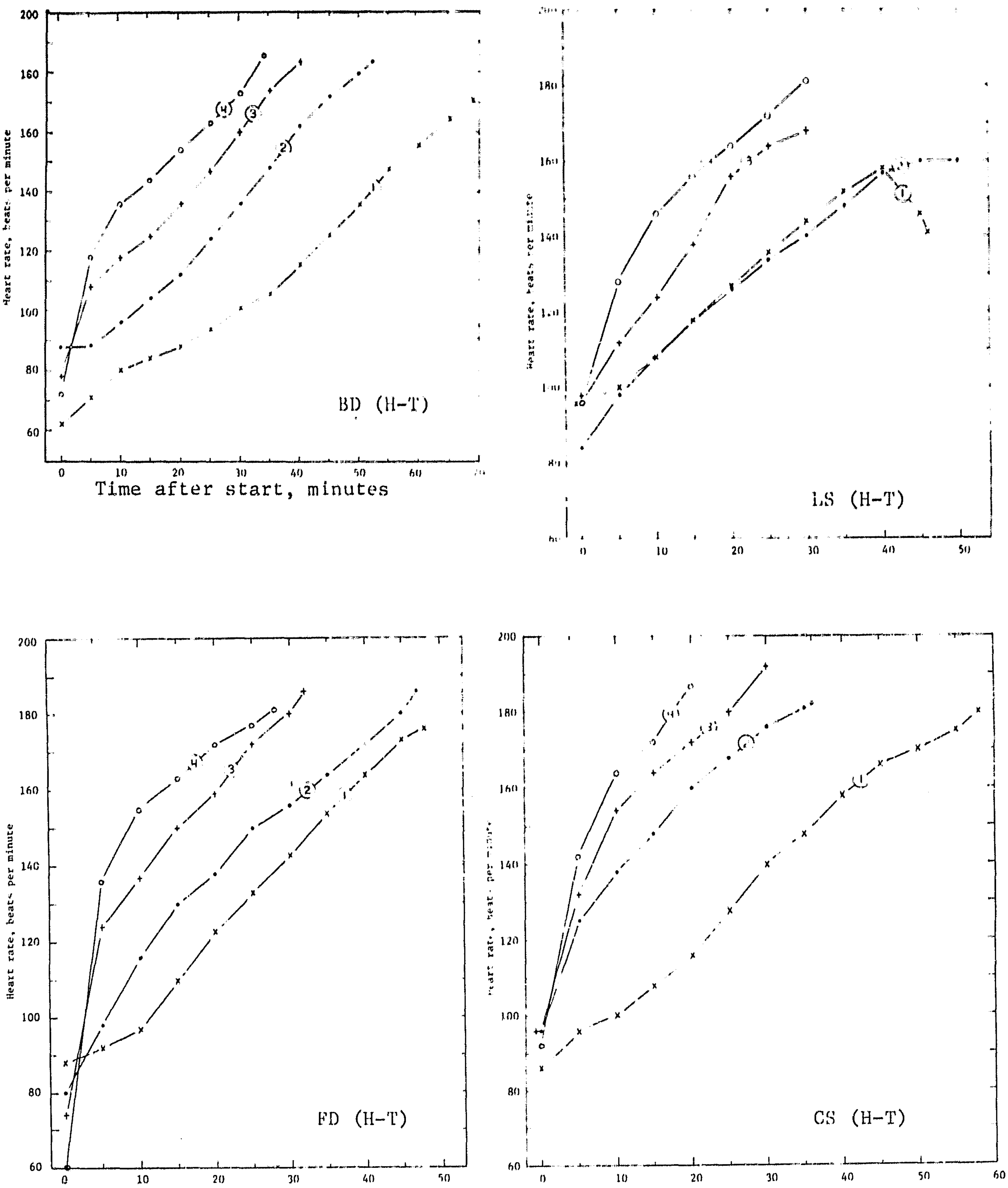

Figure 21a - Individual heat rates in heat stress tests, at indicated levels. Subject LS, near end of level 1 test, showed incipient faint and required resuscitation by cold water immersion.

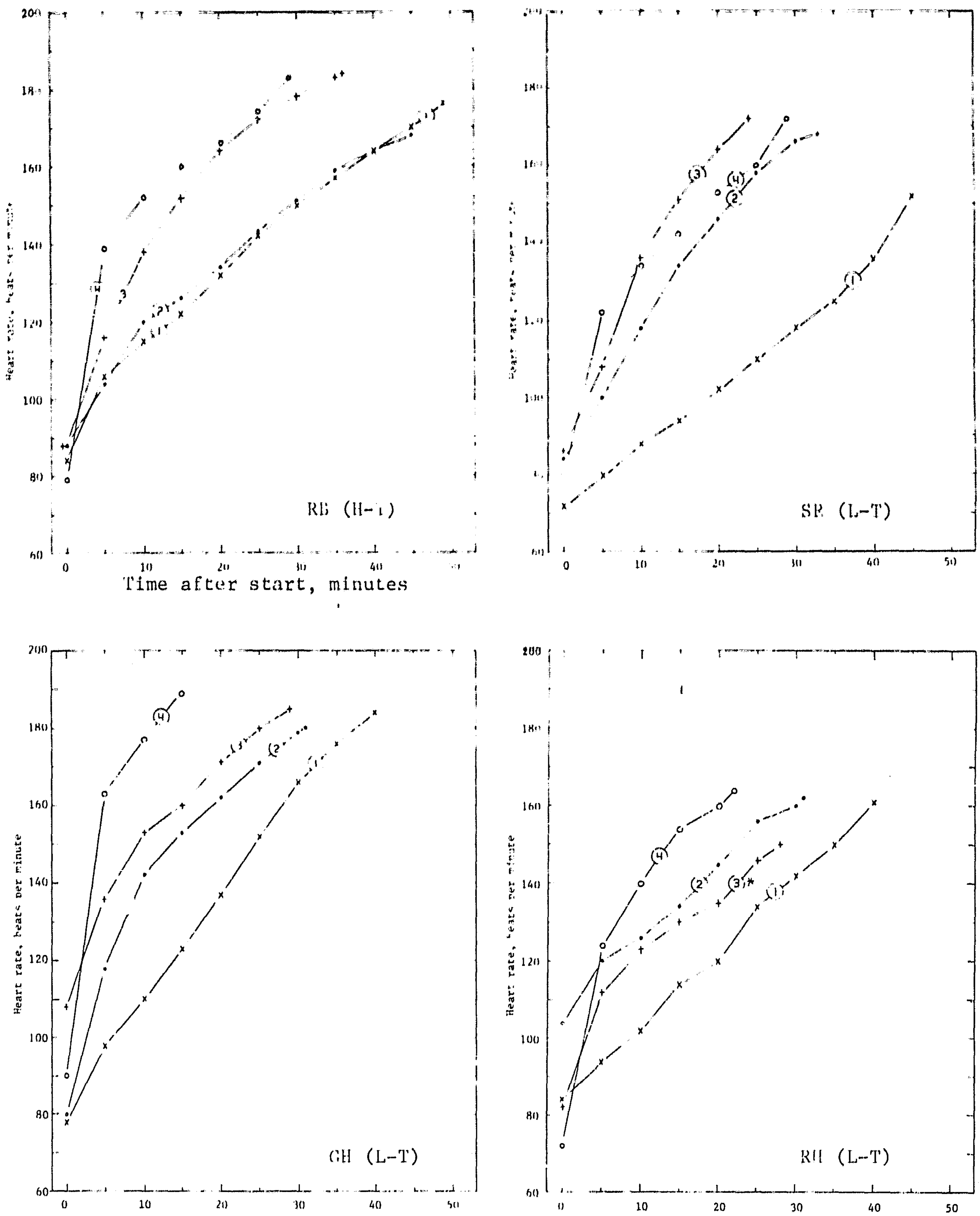

Figure 21b - Individual heart rates in heat stress tests, at indicated levels.

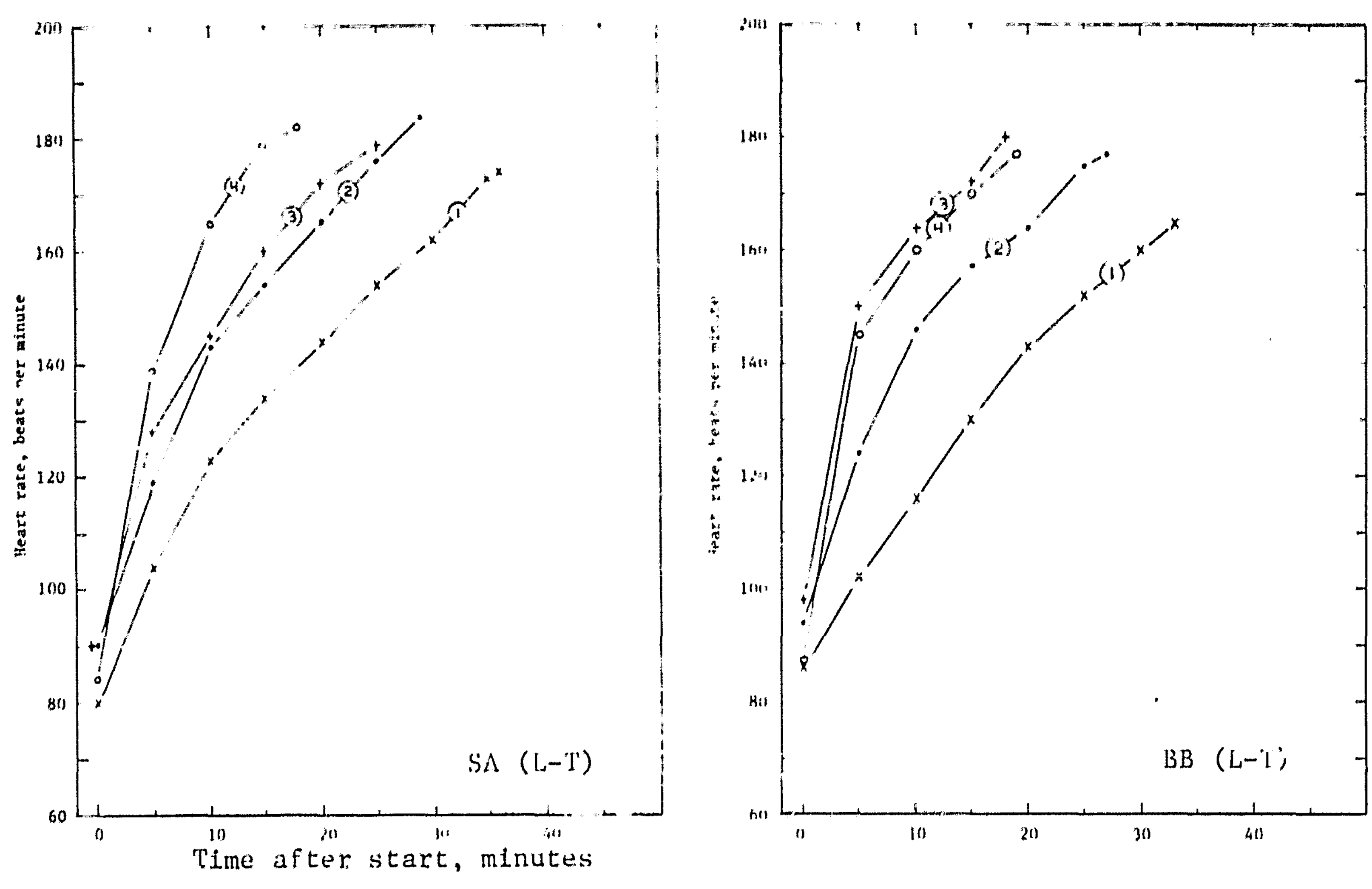

Figure 21c - Individual heart rates in heat stress tests, at indicated levels.

CONCLUSIONS

This initial investigation of the consequences of work in an environment which totally prevents heat loss has as its most dramatic finding the demonstration that individual differences in heat stress tolerance, even among highly fit young men, are extremely great. Not only is heat stress tolerance during work not correlated with the performance on a standard work capacity evaluation test, but a fitness status at the bottom of the distribution of acceptable values was associated with a distinctly superior performance in terms of heat stress resistance, while the individual with close to the highest work capacity had the lowest heat stress tolerance.

On the basis of the data provided by this study, it is not possible to make a definitive statement as to whether age, personality, or attitude was the most important factor in determining relative heat stress tolerance. It is certainly a fact that the five most resistant subjects were all over the age of 32 and the five less resistant subjects were all under the age of 26, but this cannot be taken as conclusive evidence that age and maturity alone was the determining factor. On the other hand, it is well known that young people show greater instability in circulatory control than older men.

There were no distinguishing features to separate the high tolerance group from the low tolerance group in appearance; the former included two tall and lean men, two medium height, heavy set men, and one stocky heavily muscled man who was a former weight lifter. The one characteristic which could be said to be common to the five men in the high tolerance group was their air of calm self-assurance and a conscientious attitude which seemed to express a desire to perform in the manner that was expected of them.

The low tolerance group as a whole seemed to be more self-centered, expressed frequent concern as to their ability to withstand the stressful conditions to which they were exposed, and displayed a certain amount of "bravado". Speculation as to what proportion of the range of characteristics found in our subject population might occur in the astronaut population would be inappropriate in the present context. However, it would seem reasonable to suppose that most of the active astronaut group would fall in the category of the high tolerance group.

Heat Storage and Tolerance Time

The accumulation of roughly 1000 Btu of heat brought the subjects in the high tolerance group close to the collapse point. However, measurements of internal body temperature rise indicate heat storage as high as 1400 Btu is possible in the milder work load conditions with 1200 Btu possible at the higher work levels. On the basis of the present evidence it is not possible to say whether heat storage acquired at rates other than those experienced in these experiments would be terminated by incipient collapse at the same absolute level of added heat content. However, it is encouraging that the tolerable increase in heat content for working men seems to be somewhat greater than that observed for resting men receiving heat from the external environment; the studies of Blockley published in 1954 indicated a mean change in heat content of 584 Btu at the tolerance end point in such sedentary heat exposures. In the 20 experiments in the H-T group only five showed terminal heat accumulations of less than 1000 Btu, based on change in mean body temperature computed from ear canal and skin. In contrast, all of the 20 experiments of the L-T group had final increases in heat content of less than 1000 Btu, with 9 experiments having final accumulations less than 800 Btu.

Calculations of the net heat production, expressed as metabolic rate less work output, show good agreement between this parameter and estimates of body heat storage. The lowest heat production recorded was 586 and the highest was 1356 Btu, with group average values of 1022 Btu for the 5 high-tolerance men and 795 Btu for the 5 low-tolerance men.

There was no consistent relationship between the rate of heat storage (i.e. work severity) and the limiting heat accumulation. However, there was a distinct tendency in the low-tolerance group for the tests at the highest metabolic rate to be terminated at lesser heat contents. We suspect that this is a reflection of a psychological rather than a physiological phenomenon.

Prediction of Tolerance Limits in the Individual Case

Rate of change of ear canal temperature seems to be the most stable and reliable indicator of endurance time. After the 10th minute, ear canal temperature showed a linear increase with time and the slope of this relationship could be used to predict the tolerance limit by means of the following equation:

$$\text{Tolerance Time (minutes)} = 68.7 - 31.3\ (dT_e/d\theta)$$

Data for the forehead skin temperature in the insulated condition, while not as fully analyzed as the data for core temperature, suggest strongly that a well insulated forehead skin temperature might be nearly as effective as ear canal temperature for estimating the probable tolerance time under heat stress conditions. This possibility will require further exploration.

Another useful indication of the imminent approach of a heat stress end point appears to be the attainment of 160 beats per minute with a rising trend at the rate of 1.5 or more beats per minute per minute. At high work loads heart rate can rise more rapidly than this in the early stages of adjustment to the load, but continued acceleration of the heart past the 160 beats per minute level is probably a reliable sign that exposure should be terminated quickly.

Unanswered Questions

Further work will be needed to determine how close to the end point used in this study it is safe to approach when immediate resuscitation by drastic cooling is not feasible. The question posed is: for the practical case where termination of a working heat stress will consist of dropping the metabolic rate to the resting level without any increase in the heat removal rate, what is the maximum allowable increase in body heat content?

It will also be important to know, in the practical context, whether the cessation of heat removal is substantially more serious when it occurs after equilibrium has been attained following a step function increase in metabolism, as compared to the case tested in this study where work begins and heat loss ceases at essentially the same point in time. It should not be overlooked that the heat storages reported here include an amount which is normally associated with the attainment of thermal equilibrium when working in "comfortable environments".

Of theoretical, and possibly practical, interest is the question of whether a continuous intake of fluids to balance sweat loss can have a significant effect on the tolerance time under various heat stress conditions.

Finally, the overriding question remains whether the development of a slight imbalance between heat production and heat loss, which produces a very slow rate of heat storage, can be tolerated until the 1000 Btu limitation found in the present study is reached, or whether some lesser or greater accumulation limit is associated with the more gradual build-up of heat.

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APPENDIX

Tables of values, at 5-minute intervals throughout all heat stress test levels, for all subjects, of (1) rectal temperature, (2) ear canal temperature, (3) mean skin temperature, (4) forehead skin temperature and (5) heart rate.

RECTAL TEMPERATURE VS. TIME

HST #1 (1000 Btu/hr)

Time:	0	5	10	15	20	25	30	35	40	45	50	55
Subj.												
CS	98.7	98.7	98.8	98.9	99.1	99.4	99.7	100.2	100.6	101.1	101.7	102.2
SR	99.2	99.2	99.2	99.3	99.5	99.8	100.2	100.6	101.1	101.7		
BD	97.7	97.7	97.8	97.9	97.9	98.1	98.2	98.5	98.8	99.2	99.5	100.0
LS	98.6	98.7	98.7	98.8	99.0	99.4	99.8	100.3	101.0	101.8		
RB	98.8	98.8	98.8	98.9	99.2	99.5	100.0	100.5	101.1	101.8		
FD	99.0	99.1	99.2	99.4	99.6	99.9	100.2	100.6	101.1	101.6		
BB	98.1	98.2	98.4	98.6	98.9	99.3	99.8					
SA	98.8	98.8	98.9	99.0	99.2	99.4	99.7	100.1				
GH	98.8	98.8	98.8	98.9	99.1	99.3	99.6	99.9	100.4			
RH	99.2	99.2	99.3	99.5	99.8	100.1	100.5	100.9	101.3			
MEAN:	98.69	98.71	98.79	98.92	99.13	99.43	99.77*	100.16	100.67	101.2		

*Note: Subsequent means reflect diminishing sample; significance lessened.

HST #1 continued

Time:	60	65	70	Final & Time	R-1	R-2	R-4	R-6	R-8	R-10
Subj.										
CS				102.5-58	102.5	102.6	102.7	102.7	102.7	102.5
SR				101.7-45	101.8	101.8	102.0	102.1	102.1	102.1
BD	100.5	101.0	101.7	101.7-70	101.8	101.8	101.9	102.0	102.2	
LS				102.2-47.3	102.2	102.6	103.9	103.1		
RB				102.4-49	102.7	102.9	103.1	103.1	103.1	
FD				102.0-48	102.3	102.7	103.0	103.1	103.1	
BB				100.0-32.5	100.1	100.2	100.3			99.6
SA				100.1-36	100.2	100.4	100.5			100.8
GH				100.6-42.3	101.3	101.3	101.2	101.2	101.1	
RH				101.3-40	101.4	101.5				101.6
MEAN:				101.43	101.63	101.78	102.06	102.47	102.38	101.3

RECTAL TEMPERATURE VS. TIME

HST #2 (1500 Btu/hr)

Time:	0	5	10	15	20	25	30	35	40	45	50
Subj.											
CS	98.8	98.8	98.8	98.9	99.3	99.8	100.3	100.9			
SR	99.1	99.3	99.6	99.8	100.2	100.6	101.2				
BD	98.0	98.0	98.0	98.1	98.2	98.5	98.8	99.3	99.7	100.3	100.9
LS	98.8	98.8	98.8	98.9	99.2	99.6	99.8	100.2	101.5	102.3	103.1
RB	98.3	98.4	98.5	98.7	99.0	99.6	100.1	100.7	101.3		
FD	98.0	98.1	98.2	98.4	98.6	98.8	99.2	99.6	100.2	100.8	
BB	99.7	99.7	99.8	100.0	100.3	100.8					
SA	98.9	98.9	99.0	99.2	99.5	99.9					
GH	98.9	98.9	99.0	99.2	99.6	100.0	100.6				
RH	99.5	99.6	99.8	100.0	100.4	100.9	101.4				
MEAN:	98.82	98.86	99.0	99.12	99.43	99.85*	100.15	100.45	100.7	101.1	

*Note: Subsequent means reflect diminishing sample; significance lessened.

HST #2 continued

Time:	Final & Time	R-1	R-2	R-4	R-6	R-8	R-10
Subj.							
CS	100.9-35.5	101.0	101.0	101.2	101.3	101.4	101.4
SR	101.6-33	101.8	102.0	102.0	102.0	102.0	
BD	101.4-53	101.6	101.8	102.0	102.0	102.0	
LS	103.2-51	103.4	103.9	104.1	104.1	103.5	
RB	101.7-43	101.9	102.5	102.4	102.3		
FD	101.0-47	101.4	101.6	101.9	102.1		
BB	101.0-27	101.1	101.2	101.3	101.4	101.5	
SA	100.2-29	101.3	100.5	100.7	100.9	100.9	101.0
GH	100.7-31	100.8	101.0	101.2	101.4		100.8
RH	101.6-32	101.8	101.9	102.2	102.4	102.6	
MEAN:	101.33	101.6	101.7	101.9	1C2.0	102.0	101.1

RECTAL TEMPERATURE VS. TIME

HST #3 (2000 Btu/hr)

Time:	0	5	10	15	20	25	30	35	40	Final & Time
Subj.										
CS	98.7	98.7	99.1	99.5	100.0	100.7	101.4			101.5-30.5
SR	99.6	99.6	99.8	100.2	100.6	101.1				101.1-25
BD	97.7	97.7	97.8	98.1	98.5	99.0	99.5	100.1	100.8	101.0-41
LS	98.8	98.9	99.0	99.4	99.9	100.4	101.0	101.7		101.8-36
RB	98.2	98.4	98.7	99.1	99.6	100.2	101.1	102.1		102.3-36
FD	99.4	99.5	99.6	99.8	100.1	100.6	101.2			101.6-32.5
BB	98.6	98.7	98.9	99.2						99.4-18
SA	98.9	98.9	99.1	99.4	99.7	100.1				100.1-25
GH	98.6	98.6	98.7	98.9	99.3	99.9				100.4-29
RH	98.8	98.8	98.9	99.1	99.4	99.9				100.2-28
MEAN:	98.74	98.79	98.97	99.27	99.67*	100.21	100.82	101.3	100.8	100.94

*Note: Subsequent means reflect diminishing sample; significance lessened.

HST #3 continued

Time:	R-1	R-2	R-4	R-6	R-8	R-10
Subj.						
CS	101.6	101.5	101.7	101.8	101.8	101.9
SR	101.3	101.5	101.8	101.7	101.6	
BD	101.2	101.5	102.0	102.0	102.0	
LS	101.9	102.0	102.1	102.3	102.4	102.1
RB	102.5	102.6	102.7	102.6	102.5	102.3
FD	101.9	102.1	102.4	102.6	102.7	102.8
BB	99.5	99.7	99.9	99.9	99.8	99.8
SA	100.3	100.3	100.6	100.7	100.8	100.9
GH	100.6	100.9	101.1	101.1	100.9	100.7
RH	100.2	100.3	100.4	100.5	100.5	100.6
MEAN:	101.10	101.24	101.47	101.52	101.50	101.38

RECTAL TEMPERATURE VS. TIME

HST #4 (2500 Btu/hr)

Time:	0	5	10	15	20	25	30	Final & Time
Subj.								
CS	98.9	99.0	99.1	99.3	99.8			999.9-21
SR	98.2	98.3	98.5	99.0	99.8	100.6		101.3-29
BD	97.8	97.8	97.9	98.2	98.6	99.0	99.6	100.1-34
LS	99.2	99.2	99.4	99.9	100.6	101.3	102.2	102.2-30
RB	98.1	98.3	98.7	99.2	99.8	100.6		101.3-29
FD	98.2	98.3	98.5	98.7	99.1	99.5		99.9-28
BB	98.4	98.6	98.8	99.2				99.6-19
SA	98.9	98.9	99.0	99.3				99.4-18
GH	99.5	99.6	99.9	100.4				100.4-15
RH	99.4	99.4	99.5	99.7	100.0			100.2-22
MEAN:	98.65	98.74	98.93	99.29	99.67*	100.28	100.9	100.41

*Note: Subsequent means reflect diminishing sample; significance lessened.

HST #4 continued

Time:	R-1	R-2	R-4	R-6	R-8	R-10
Subj.						
CS	100.0	100.2	100.4	100.4	100.4	100.3
SR	101.4	101.4	101.3	100.8	100.5	100.0
BD	100.4	100.8	101.1	101.3	101.3	101.3
LS	102.5	102.9	103.2	103.2	103.1	103.0
RB	101.5	101.7	101.9	101.9	101.8	101.6
FD	100.2	100.5	100.8	101.0	101.2	101.4
BB	99.7	99.9	100.1	100.2	100.2	100.1
SA	99.5	99.6	99.8	100.0	100.1	100.2
GH	100.5	100.6	100.7	100.8	100.7	100.5
RH	100.3	100.4	100.5	100.6	100.7	100.7
MEAN:	100.68	100.79	100.97	101.02	101.[illegible]	100.91

EAR TEMPERATURE VS. TIME

HST #1 (1000 Btu/hr)

Time:	0	5	10	15	20	25	30	35	40	45	50	55
Subj.												
CS	98.0	98.1	98.3	98.7	99.0	99.4	99.9	100.6	101.3	101.9	102.6	103.3
SR	97.3	97.7	98.2	98.7	99.3	99.8	100.4	101.1	101.7	102.3		
BD	94.8	95.4	95.8	96.6	97.2	97.7	98.3	99.9	99.4	100.0	100.8	101.4
LS	96.5	97.0	97.5	98.0	98.4	99.1	99.9	100.5	101.2	101.9		
RB	95.3	96.9	97.6	98.4	99.0	99.8	100.5	101.4	102.1	103.1		
FD	97.7	98.0	98.4	98.9	99.5	100.2	100.8	101.6	102.3	103.2		
BB	96.9	97.2	97.7	98.2	98.8	99.5	100.1					
SA	96.2	96.9	97.6	98.2	98.9	99.6	100.2	101.1				
GH	96.7	96.8	97.1	97.6	98.0	98.5	99.2	99.9	100.7			
RH	96.6	97.4	98.4	98.9	99.6	100.2	100.8	100.5	102.2			
MEAN:	96.6	97.1	97.7	98.2	98.8	99.4	100.0*	100.6	101.3	102.0	101.7	

*Note: Subsequent means reflect diminishing sample; significance lessened.

HST #1 continued

Time:	60	65	70	Final & Time	R-1	R-2	R-4	R-6	R-8	R-10
Subj.										
CS				103.7-58	102.1	101.8	100.6	99.4	98.7	98.3
SR				102.3-45	102.2					
BD	102.2	102.9	103.6	103.6-70	103.8	102.5	99.3	97.6	96.9	
LS				102.2-47.5	101.9	101.2	100.1			
RB				103.9-49	102.6	100.4	98.0			
FD				103.7-48	103.8	103.4	102.4	101.5	100.6	
BB				100.4-32.5	100.5	100.3	96.2			
SA				101.3-36	101.5	100.6	98.7			96.5
GH				101.2-42.3	101.4	101.3	99.9	97.8	96.6	
RH				102.2-40	101.9	101.6	99.8			96.0
MEAN:				102.4	102.2	101.5	99.4	99.1		

EAR TEMPERATURE VS. TIME

HST #2 (1500 Btu/hr)

Time:	0	5	10	15	20	25	30	35	40	45	50
Subj.											
CS	97.0	97.4	98.1	98.9	99.7	100.5	101.4	102.3			
SR	96.9	97.8	98.6	99.4	100.1	100.9	101.6				
BD	95.0	95.2	96.0	96.9	97.8	98.6	99.4	100.2	101.1	102.0	103.0
LS	96.3	96.9	97.4	98.2	98.8	99.5	100.3	101.1	101.9	102.7	103.5
RB	96.2	96.8	97.6	98.4	99.4	100.2	100.9	101.8	102.6		
FD	96.8	97.0	97.3	97.7	98.4	99.2	99.9	100.8	101.7	102.7	
BB	97.4	98.0	98.6	99.3	100.0	100.9					
SA	96.7	97.4	98.4	99.2	100.1	101.0					
GH	95.6	96.2	97.0	97.6	98.6	99.6	100.6				
RH	98.0	98.4	99.0	99.8	100.6	101.4	102.2				
MEAN:	96.6	97.1	97.8	98.5	99.4	100.2*	100.8	101.2	101.8	102.5	103.2

*Note: Subsequent means reflect diminishing sample; significance lessened.

HST #2 continued

Time:	Final & Time	R-1	R-2	R-4	R-6	R-8	R-10
Subj.							
CS	102.4-35.5	102.5	102.5	99.7	99.3	98.6	98.1
SR	102.1-33	102.3	101.6	99.0	98.3	97.8	96.6
BD	103.5-53	103.4	102.1	99.8	98.5	97.5	96.7
LS	103.7-51	103.7	103.6	102.0	101.0	99.8	
RB	103.1-43	102.0	98.9	95.6	94.6	93.8	
FD	103.1-47	103.3	102.7	101.9	100.0	99.5	
BB	101.2-27	101.4	101.3	99.4	98.6	97.8	
SA	102.0-29	102.3		95.2	99.4	96.2	93.5
GH	100.7-31	100.8	99.5	98.1	97.0	96.6	95.8
RH	102.5-32	102.7	101.4	100.0	99.4	98.4	
MEAN:	102.4	102.4	101.5	98.8	98.6	97.6	95.8

EAR TEMPERATURE VS. TIME

HST #3 (2000 Btu/hr)

Time:	0	5	10	15	20	25	30	35	40	Final & Time
Subj.										
CS	96.9	97.4	98.3	99.3	100.3	101.4	102.5			102.7-30.5
SR	96.7	97.1	98.6	99.8	100.9	102.1				102.1-25
BD	95.4	96.0	96.8	97.8	98.9	100.0	101.1	102.2	103.2	103.4-41
LS	96.7	97.3	97.7	98.6	99.6	100.6	101.6	102.7		102.9-36
RB	96.7	97.3	98.1	99.1	100.0	101.1	102.2	103.4		103.6-36
FD	97.8	98.2	98.8	99.7	100.8	102.0	103.2			103.7-32.5
BB	96.4	97.1	98.1	99.3						100.0-18
SA	95.3	96.5	97.7	99.0	100.4	101.9				101.9-25
GH	96.2	96.6	97.3	98.2	99.1	100.2				101.2-29
RH	96.5	96.9	97.7	98.4	99.4	100.4				101.0-28
MEAN:	96.5	97.1	97.90	98.91	99.9*	101.0	102.1	102.7		102.23

*Note: Subsequent means reflect diminishing sample; significance lessened.

HST #3 continued

Time:	R-1	R-2	R-4	R-6	R-8	R-10
Subj.						
CS	102.8	102.6	101.0	100.6	99.7	98.8
SR	102.1	101.3	99.6	98.2	97.4	
BD	103.7	100.5	96.7	95.9	95.3	
LS	103.1	102.3		99.6	98.2	96.6
RB	101.6	100.0	97.9	96.2		
FD	103.9	103.4	102.3	101.3	100.2	99.3
BB				97.1	96.9	96.8
SA	101.0	100.5	99.7	98.1	97.1	96.5
GH	101.4	100.4	98.1	96.4	95.8	95.3
RH	101.2	101.0	99.7	98.6	97.6	97.0
MEAN:	101.63	100.4	99.4	98.2	97.5	97.2

EAR TEMPERATURE VS. TIME

HST #4 (2500 Btu/hr)

Time:	0	5	10	15	20	25	30	Final & Time
Subj.								
CS	96.6	97.2	98.2	99.4	100.9			101.1-21
SR	94.6	95.9	97.2	98.4	99.6	100.8		102.1-29
BD	96.4	96.6	97.3	98.4	99.6	100.8	101.9	102.9-34
LS	97.4	97.9	98.8	99.9	100.9	102.0	103.2	103.2-30
RB	96.2	96.9	98.1	99.1	100.3	101.6		102.6-29
FD	96.9	97.2	98.0	99.0	100.2	101.5		102.3-28
BB	96.8	97.1	98.2	99.3				100.3-19
SA	96.1	96.9	98.2	99.7				100.7-18
GH	97.1	98.3	99.4	100.7				100.7-15
RH	96.6	97.2	98.0	98.9	100.0			100.4-22
MEAN:	96.5	97.1	98.1	99.3	100.2*	101.3	102.6	101.55

*Note: Subsequent means reflect diminishing sample; significance lessened.

HST #4 continued

Time:	R-1	R-2	R-4	R-6	R-8	R-10
Subj.						
CS	101.2	100.6	99.4	98.3	97.5	96.7
SR	101.4	100.1	97.6	95.6	94.7	94.2
BD	103.1	102.0	100.0	98.7	97.7	96.8
LS	103.3	102.2	100.0	99.7	98.9	98.1
RB	102.8	101.8	98.1	96.2	94.9	94.3
FD	102.4	102.2	101.3	100.1	99.0	98.2
BB	100.5	99.0	97.5	96.7	96.3	
SA	100.5	99.9	98.8	98.1	97.8	97.5
GH	101.0	100.9	99.2	98.1	97.3	97.1
RH	100.6	100.2	99.1	98.1	97.2	96.5
MEAN:	101.6	101.9	98.9	97.8	97.8	97.2

MEAN SKIN TEMPERATURE VS. TIME

HST #1 (1000 Btu/hr)

Time:	0	5	10	15	20	25	30	35	40	45	50	55
Subj.												
CS	93.2	94.9	96.1	97.6	98.5	99.1	99.7	100.3	100.9	101.4	102.1	102.8
SR	94.2	95.3	96.9	97.8	98.5	99.2	99.8	100.3	100.8	101.2		
BD	88.7	91.2	92.7	94.2	95.5	96.2	97.0	97.7	98.5	99.2	99.8	100.5
LS	92.6	95.5	96.6	97.4	98.1	98.7	99.4	99.8	100.4	100.9		
RB	92.1	94.1	96.1	97.8	98.7	99.5	100.3	101.1	101.9	102.7		
FD	94.9	96.1	97.8	98.9	99.7	100.3	101.0	101.8	102.4	103.1		
BB	93.5	95.8	97.4	98.0	98.7	99.3	100.0					
SA	93.1	94.6	96.1	97.5	98.4	99.1	100.3	101.0				
GH	90.4	93.0	95.4	97.0	98.0	98.6	99.3	100.0	100.7			
RH	95.4	97.2	98.4	99.1	99.7	100.3	100.9	100.6	101.7			
MEAN:	92.7	94.8	96.4	97.5	98.4	99.0	99.8	100.3*	100.9	101.4		

*Note: Subsequent means reflect diminishing sample; significance lessened.

HST #1 continued

Time:	60	65	70	Final & Time	R-1	R-2	R-4	R-6	R-8	R-10
Subj.										
CS				103.1-58	100.0	100.2	100.2	93.2	87.2	87.2
SR				101.2-45	99.2	93.4	93.1	91.2	87.8	87.5
BD	101.0	101.6	102.3	102.3-70	101.7	101.7	102.1			
LS				101.0-47.3	100.5	94 4	92.2			
RB				103.3-49	96.6	91.6	90.7			
FD				103.5-48	95.6	94.2	93.2			
BB				100.2-32.5	96.3	92.2	88.8			
SA				101.2-36	94.3	92.7	90.0			
GH				101.2-42.3	100.7	94.0	89.8	89.2		
RH				102.2-40	97.1	93.8	91.8			91.1
MEAN:				101.6	97.2	94.8	93.2			

MEAN SKIN TEMPERATURE VS. TIME

HST #2 (1500 Btu/hr)

Time:	0	5	10	15	20	25	30	35	40	45	50
Subj.											
CS	92.0	95.1	97.5	98.6	100.0	100.8	101.6	102.3			
SR	95.0	97.1	98.3	99.0	99.6	100.3	100.9				
BD	89.3	91.6	93.4	95.0	96.3	97.3	98.1	99.1	99.9	100.8	101.6
LS	92.5	95.5	96.8	97.7	98.7	99.4	100.1	100.8	101.5	102.2	102.8
RB	92.1	94.1	96.0	97.7	98.8	99.7	100.6	101.5	102.4		
FD	91.7	93.6	95.6	97.0	98.2	99.2	100.0	100.9	101.8	102.7	
BB	93.9	96.2	98.0	99.2	100.0	100.8					
SA	93.0	95.5	97.5	98.7	100.1	101.1					
GH	92.0	94.4	97.2	98.2	99.2	100.0	100.9				
RH	95.2	97.6	98.3	99.7	100.5	101.2	102.0				
MEAN:	92.7	95.1	96.9	98.1	99.1	100.0	100.5*	100.9	101.4	101.9	

*Note: Subsequent means reflect diminishing sample; significance lessened.

HST #2 continued

Time:	Final & Time	R-1	R-2	R-4	R-6	R-8	R-10
Subj.							
CS	102.3-35	98.4	91.2	92.4	92.8	92.0	92.0
SR	101.4-33		94.1	93.2	92.7	98.1	
BD	102.2-53	102.1	99.3	97.6	95.4		
LS	102.8-50	102.7	97.6	95.3	92.6	98.1	
RB	103.1-43	98.3	93.1	90.0	88.1		
FD	103.1-47	98.4	94.1	90.9	88.7		
BB	101.1-27	96.1	94.4	91.0	88.0		
SA	101.9-29	91.1	94.6	90.4	88.6		
GH	101.1-31	95.0	92.9	92.1	90.0		
RH	102.3-32	101.0	94.6	93.3	91.4	90.1	
MEAN:	102.1	99.0	94.6	92.6	90.8		

MEAN SKIN TEMPERATURE VS. TIME

HST #3 (2000 Btu/hr)

Time:	0	5	10	15	20	25	30	35	40	Final & Time
Subj.										
CS	92.4	95.1	97.5	98.5	99.6	100.5	101.4			101.4-30.5
SR	94.8	97.3	98.3	99.2	100.0	100.9				100.9-25
BD	90.9	92.5	94.5	96.0	97.3	98.5	99.5	100.5	101.5	101.7-41
LS	94.1	96.0	97.5	98.7	99.6	100.5	101.2	101.8		101.8-36
RB	91.9	94.2	96.6	98.1	99.8	100.8	101.8	102.8		103.0-36
FD	94.6	97.5	99.1	100.1	101.1	102.2	103.2			103.7-32.5
BB	95.2	97.2	98.3	99.4						99.8-18
SA	92.9	95.0	97.2	99.0	100.4	101.4				101.4-25
GH	92.3	94.1	97.0	98.5	99.6	100.7				101.2-29
RH	92.4	96.1	97.5	98.6	99.8	100.7	- -	-	-	101.1-28
MEAN:	93.1	95.6	97.3	98.6	99.7*	100.6	101.4			101.6

*Note: Subsequent means reflect diminishing sample; significance lessened.

HST #3 continued

Time:	R-1	R-2	R-4	R-6	R-8	R-10
Subj.						
CS	94.3	93.2	93.1	91.2	90.3	92.6
SR	99.9	96.6	92.5	91.6	90.5	
BD	99.6	96.2	92.1		85.1	
LS	95.8					
RB	98.6	93.8				
FD	101.8	96.7	93.2			
BB	94.1	92.3	91.4	91.2		
SA	96.8	93.5	90.2			
GH	96.9	92.4		90.4		
RH	97.0	92.9		89.3		
MEAN:	97.5	94.1	92.1	90.7		

MEAN SKIN TEMPERATURE VS. TIME

HST #4 (2500 Btu/hr)

Time:	0	5	10	15	20	25	30	Final & Time
Subj.								
CS	91.8	95.3	97.3	98.6	99.7			99.7-21
SR	91.3	94.0	96.0	97.5	98.6	99.5		100.2-29
BD	92.8	94.9	96.9	98.1	99.3	100.5	101.6	102.3-34
LS	95.9	98.0	99.4	100.5	101.6	102.5	103.3	103.3-30
RB	91.6	93.7	96.0	98.2	99.7	100.9		101.8-29
FD	91.9	94.6	96.6	98.3	99.7	101.1		101.8-28
BB	93.7	95.6	97.5	99.2				100.2-19
SA	92.0	94.2	97.3	99.1				100.0-18
GH	95.0	98.3	100.0	101.1				101.1-15
RH	93.2	95.2	97.0	98.5	99.8			100.0-22
MEAN:	93.0	95.4	97.4	98.9	99.8*	101.2	102.5	101.0

*Note: Subsequent means reflect diminishing sample; significance lessened.

HST #4 continued

Time:	R-1	R-2	R-4	R-6	R-8	R-10
Subj.						
CS	98.7	91.9	88.0	87.6	87.4	
SR	96.5	90.6	89.2	86.8		
BD	94.7	93.1	92.0	89.8		
LS	96.7	93.7	92.1	89.9		
RB	98.3		91.4	88.6		
FD	101.1	95.4	90.6	87.4		
BB	99.2	92.2	90.3	87.1		87.4
SA	97.2	94.9	92.5	87.3		90.4
GH	99.3	94.5	92.6	91.9		90.6
RH	95.4	93.5			89.0	
MEAN:	97.7	93.3	90.9	88.5		

FOREHEAD SKIN TEMPERATURE VS. TIME

HST #1 (1000 Btu/hr)

Time:	0	5	10	15	20	25	30	35	40	45	50	55
Subj.												
CS	97.3	98.2	98.8	99.1	99.4	99.8	100.0	101.0	101.6	102.2	102.9	103.3
SR	97.5	98.4	99.2	99.2	99.4	99.8	102.0	100.6	101.0	101.3		
BD	92.2	96.5	97.0	97.4	97.8	97.9	98.2	98.6	99.0	99.3	99.9	100.4
LS	93.6	96.5	97.0	97.0	97.1	97.3	97.4	98.0	98.6	98.9		
RB	94.4	97.5	98.4	99.2	99.7	100.0	100.0	100.3	101.0	102.4		
FD	95.2	98.2	99.2	100.0	100.5	101.0	101.5	102.2	102.7	103.2		
BB	94.8	98.1	98.6	99.2	99.9	99.8	100.3					
SA	94.3	98.0	98.6	99.1	99.5	100.1	100.8	101.3				
GH	93.0	96.6	97.6	97.9	98.8	98.9	99.2	100.2	101.1			
RH	96.5	99.3	100.2	100.6	101.0	101.5	102.0	102.7	103.1			
MEAN:	94.6	97.7	98.5	98.9	99.3	99.6	100.1	100.5*	101.4	101.2		

*Note: Subsequent means reflect diminishing sample; significance lessened.

HST #1 continued

Time:	60	65	70	Final & Time	R-1	R-2	R-4	R-6	R-8	R-10
Subj.										
CS				103.7-58	94.0					
SR				101.2-50	96.0	93.2	89.1	88.1	87.9	87.8
BD	100.9	101.7	102.5	102.6-70	100.0	99.1	86.6	82.2	74.9	
LS				99.3-47.5	98.9	89.6	86.8			
RB				103.2-49	101.0	88.8	85.8			
FD				103.4-48	85.0	86.0	83.1			
BB				100.5-32.5	91.8	88.0	86.8			
SA				101.4-36	88.0	84.4	83.5			
GH				101.4-42.3	100.6	93.6	88.3	87.1		
RH				103.1-40	99.1	92.4	91.2			89.0
MEAN:				101.88	95.4	90.5	87.3			

FOREHEAD SKIN TEMPERATURE VS. TIME

HST #2 (1500 Btu/hr)

Time:	0	5	10	15	20	25	30	35	40	45	50
Subj.											
CS	93.5	99.0	100.9	100.1	100.6	101.2	102.0				
SR	96.6	99.2	99.6	99.8	100.0	100.6	101.2				
BD	92.1	96.2	97.1	97.6	98.1	98.9	99.6	100.0	100.5	101.5	101.8
LS	91.0	93.2	95.0	96.4	97.4	98.0	98.7	99.0	99.9	100.5	101.0
RB	93.7	97.7	99.4	99.2	99.2	100.1	100.9	102.0	102.9		
FD	94.0	97.2	98.4	98.8	99.1	99.8	100.4	101.2	102.0	102.8	
BB	95.4	97.8	99.1	99.7	100.6	101.4					
SA	93.4	98.7	100.6	101.2	101.8	102.4					
GH	94.1	97.6	98.6	99.8	100.1	101.0	101.7				
RH	95.6	99.2	99.8	100.6	101.2	101.9	102.4				
MEAN:	93.9	97.6	98.9	99.3	99.8	100.5	100.7*	100.8	101.3		

*Note: Subsequent means reflect diminishing sample; significance lessened.

HST #2 continued

Time:	Final & Time	R-1	R-2	R-4	R-6	R-8	R-10
Subj.							
CS	102.0-35	100.8	92.2	92.2	92.6	92.1	88.7
SR	101.6-33	101.0	90.2	90.0	89.1	88.4	
BD	102.2-53	102.6	93.2	91.2	89.0		
LS	101.0-51	101.1	100.3	98.3	97.2		
RB	103.2-43	97.0	88.2	85.6	84.4		
FD	103.0-47	94.4	86.4	85.0	84.5		
BB	101.7-27	95.8	95.8	84.4	84.8		
SA	103.0-29	99.4	94.2	93.1	91.6		
GH	101.8-31	94.6	93.1	92.3	91.0		
RH	102.8-32	99.2	94.6	93.0	92.5	91.6	
MEAN:	102.23	98.5	92.8	91.5	90.7		

FOREHEAD SKIN TEMPERATURE VS. TIME

HST #3 (2000 Btu/hr)

Time:	0	5	10	15	20	25	30	35	40	Final & Time
Subj.										
CS	94.8	99.2	99.6	99.8	100.2	101.1	101.8			102.0-30.5
SR	95.2	98.4	99.2	99.8	100.4	101.2				101.2-25
BD	94.5	96.0	97.6	98.4	99.2	99.9	100.6	101.7	102.4	102.6-41
LS	95.0	97.4	98.2	98.6	99.2	99.8	100.5	101.0		101.2-36
RB	93.8	98.4	98.8	99.0	100.2	101.0	101.8	102.6		102.8-36
FD	94.9	98.6	99.3	99.8	100.5	101.5	102.6			103.0-32.5
BB	95.6	98.0	99.0	99.8						99.3-18
SA	93.8	98.6	100.3	101.0	101.7	102.4				102.4-25
GH	93.5	96.6	99.6	99.6	100.5	101.8				102.4-29
RH	92.0	98.2	99.6	100.0	100.7	101.4				101.9-28
MEAN:	94.3	97.9	99.1	99.6	100.4*	101.0	101.4			101.8

*Note: Subsequent means reflect diminishing sample; significance lessened.

HST #3 continued

Time:	R-1	R-2	R-4	R-6	R-8	R-10
Subj.						
CS	96.0	92.2	91.6	91.0	91.0	91.1
SR	101.4	95.8	90.0	90.0	91.0	
BD	94.1	87.2	84.3			
LS	91.4	86.3	85.0			
RB	94.2	86.3	84.1			
FD	97.4	86.2	84.0			
BB	85.3	84.4	85.7			
SA						
GH	97.5	92.8		90.7		
RH	96.8	91.4		87.6		
MEAN:	94.9	92.5	89.2			

FOREHEAD SKIN TEMPERATURE VS. TIME

HST #4 (2500 Btu/hr)

Time:	0	5	10	15	[illegible]	25	30	Final & Time
Subj.								
CS	93.1	97.8	98.6	99.5	100.2			100.2-21
SR	93.2	98.4	98.8	98.8	99.4	100.2		100.7-29
BD	94.4	97.5	100.7	101.1	101.4	101.7	101.8	102.6-34
LS	95.8	99.4	100.2	100.7	101.6	102.4	103.2	103.2-30
RB	94.0	98.0	98.4	99.5	100.4	101.3		101.9-29
FD	91.3	96.8	98.3	99.2	100.3	101.6		102.3-28
BB	93.8	97.0	98.6	99.7				99.6-19
SA	94.2	98.2	99.6	100.2				100.7-18
GH	95.0	98.5	101.0	102.0				102.0-15
RH	94.0	99.0	100.6	101.0	101.6			102.0-22
MEAN:	93.9	97.9	99.5	100.1	100.7*			101.5

*Note: Subsequent means reflect diminishing sample; significance lessened.

HST #4 continued

Time:	R-1	R-2	R-4	R-6	R-8	R-10
Subj.						
CS	100.1	89.3	88.0	86.2	87.0	87.2
SR	97.3	89.8	85.4	85.0		
BD	84.4	84.4		85.4	88.0	89.2
LS	95.0	90.3	90.6			
RB	98.0	94.2	87.4			
FD	99.4	89.6	87.1	85.2		
BB	84.4	84.4	84.2	84.2	84.8	85.0
SA	99.4	90.6	89.2	88.8	88.4	88.0
GH	100.4	99.3	97.2	95.1	93.4	92.3
RH	98.3	92.3	91.1	89.9	89.4	
MEAN:	95.2	90.4	87.8	87.6	88.5	88.3

HEART RATE SUMMARY

HST #1 (1000 BTU/hr

Time:	0	5	10	15	20	25	30	35	40	45	50	55	60	65	Final & Time
Subj.															
CS	86	96	100	108	116	128	140	148	158	166	170	175			180-58
SR	72	80	88	94	102	110	118	128	138	152					152-45
BD	62	71	80	84	88	94	101	106	116	126	136	148	156	165	171-70
LS	96	100	108	118	127	136	144	152	158	146					141-47.5
RB	84	106	115	122	132	142	150	157	164	170					176-49
FD	88	92	97	110	123	133	143	159	154	173					176-48
BB	86	102	116	130	143	152	160								165-32.5
SA	80	104	123	134	144	154	162	173							176-36
GH	78	98	110	123	137	152	166	176	184						184-42.3
RH	84	94	102	114	120	134	142	150	161						161-40
MEAN:	82	94	104	114	123	134	143*	150	154	156					169

*Note: Subsequent means reflect diminishing sample; significance lessened.

HST #2 (1500 BTU/hour)

Time:	0	5	10	15	20	25	30	35	40	45	50	Final & Time
Subj.												
CS	96	125	138	148	160	168	176	181				182-35
SR	84	100	118	134	146	158	166					168-33
BD	88	88	96	104	112	124	136	148	162	172	180	184-53
LS	84	98	108	118	126	134	140	148	157	160		160-51
RB	88	104	120	126	134	143	151	159	164			168-43
FD	80	98	116	130	128	150	156	164	172	180		186-47
BB	94	124	146	157	164	175						177-27
SA	90	119	143	154	165	176						184-29
GH	90	118	142	153	162	171	179					180-31
RH	104	120	126	136	145	156	160					162-32
MEAN:	90	109	125	136	145	155*	158	160				175

*Note: Subsequent means reflect diminishing sample; significance lessened.

HEART RATE SUMMARY

HST #3 (2000 BTU/hr)

Time:	0	5	10	15	20	25	30	35	40	Final & Time
Subj.										
CS	96	132	154	164	172	180	192			192-30.5
SR	86	108	136	151	164					172-25
BD	78	108	118	125	136	147	160	174	184	184-40
LS	98	112	124	138	156	164	168	163		163-36
RB	88	116	138	152	164	172	178	183		184-36
FD	74	124	137	150	159	172	180			186-32.5
BB	98	150	164	172						180-18
SA	90	128	145	160	172	179				179-25
GH	108	136	153	160	171	180				185-29
RH	82	112	123	130	135	146				150-28
MEAN:	90	123	139	152*	159	168	176			178

*Note: Subsequent means reflect diminishing sample; significance lessened.

HST #4 (2500 BTU/hour)

Time:	0	5	10	15	20	25	30	35	40	Final & Time
Subj.										
CS	92	142	164	172	185					185-21
SR	80	122	134	142	153	160				172-29
BD	72	118	136	144	154	163	173			186-34
LS	96	128	146	156	164	172	181			181-30
RB	79	139	152	160	166	174				183-29
FD	60	136	155	163	172	177				181-28
BB	87	145	160	170						177-19
SA	84	139	165	179						182-18
GH	90	163	177	189						189-15
RH	72	125	140	154	160					164-22
MEAN:	81	136	153	163*	167	169				181

*Note: Subsequent means reflect diminishing sample; significance lessened.