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THE EFFECT OF COOL AIR INHALATION ON CORE TEMPERATURE ELEVATION IN EXERCISING SUBJECTS UNDER HEAT STRESS

by

Nikolaos Geladas

Bachelor of Ph.Ed., University of Athens, 1981

THESIS SUBMITTED IN PARTIAL FULFILLMENT OF
THE REQUIREMENTS FOR THE DEGREE OF
MASTER OF SCIENCE (KINESIOLOGY)
in the School
of
Kinesiology

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ABSTRACT

This study examined whether an increased Respiratory Heat Exchange (RHE) prevents excessive elevation of rectal temperature during exercise under heat stress. Eight male subjects cycled twice at 45%-50% of their maximum workrate until exhaustion in an ambient temperature and relative humidity of 38 °C and 90-95% respectively. In random order, they inspired either cool air (3.6 °C) or ambient air during several experiments on succeeding occasions.

By breathing cool air during 23 minutes of a standard work task an eight fold increase in total RHE was observed compared with similar exercise during hot air inhalation (1.37 kcal vs 11.44 kcal). Increasing total RHE decreased the core temperature significantly, ($p \leq 0.002$), by 0.4 °C during 23 min of exercise. Although the heart rate during the initial stages of exercise in the hot ambient atmosphere was higher while breathing cool air than breathing hot air, during the latter stages of exercise the reverse was true when cool air inhalation produced a significant ($p \leq 0.05$) decrease in heart rate compared with hot air inhalation. Cool air inspiration decreased the respiratory fequency significantly ($p \leq 0.004$) during exercise under heat stress compared with breathing hot ambient gas. Insignificant changes in oxygen consumption and fluid loss were found between the two experimental conditions.

The decreased core temperature observed while breathing cool air during exercise is not entirely attributable to an increase in RHE rate, and further research is needed to elaborate the underlying mechanisms. These data show that cool air inhalation during exercise in hot-humid ambient conditions diminishes the elevation of core temperature and suggest that performance could be enhanced.

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1. INTRODUCTION

During exercise, heat generated through metabolic activity would quickly injure the athlete, if it were not dissipated. Dissipation of human heat is accomplished through conduction, convection, radiation and evaporation from the skin, (Holman 1976), and by conduction and evaporation in the respiratory tract, (Baltrop, 1954).

However during exercise, heat production exceeds heat loss and core temperature rises indicating heat storage, (Nielsen, 1969).

Pugh (1967) recorded body temperatures as high as 41.1°C in a marathon runner. Elevation of normal body temperature has been associated with decreased physical performance (Adams _et_ _al_., 1975), and can lead to sickness and death (Sohal, _et_ _al_., 1968).

Therefore, maximization of the heat dissipating mechanisms by any means could improve physical performance and protect subjects from heat exhaustion and ultimately stroke.

Indeed there is abundant research available on the effective manipulation of body temperature by modifying ambient temperature or wind velocity, inducing precooling, and rehydration, (Bruck _et_ _al_., 1980; Falls, 1969; Bruck _et_ _al_, 1978; Schmict and Bruck, 1981; Costill, 1977). Producing optimal heat loss from respiratory tract has not been fully explored.

The purpose of this study was to investigate a method of preventing excessive elevation of body temperature during exercise in the heat by promoting increased respiratory heat loss thereby enhancing performance.

1.1 Mechanisms of respiratory heat loss

Inspired air is fully warmed by means of turbulent convection in the nasopharynx and reaches the lungs at a temperature of 37°C (Cole, 1953; Moritz and Weisiger, 1945; Ingelstedt, 1956). Recently, McFadden et al. (1985) thermally mapped the human airways and found that during quiet inhalation of room air (26°C) temperature ranged from 32.0°C in the upper trachea to 35.5°C in the subsegmental bronchi. These data demonstrate that even the periphery of the lungs is involved in thermal exchange. Other than warming, the upper respiratory tract is able to humidify inspired air by evaporation from the mucosa (Walker et al., 1961). Even though this evaporation cools the mucosa, it does not serve to warm the incoming air, merely to saturate it fully.

During expiration, heat is returned from the warm expired air to the cooled mucosa. Turbulent convection promotes a temperature equilibrium between the mucosa and the expired air. As expired air is cooled, its capacity for holding water vapor decreases. This ensures condensation of water vapor on the mucosa. Condensation performs a dual function of rehydrating and rewarming epithelial tissue in the upper respiratory tract. Latent heat is released to the respiratory tract during the process of condensation, (Seely, 1940).

The degree of humidity of the expired air is debatable. McCutchan and Taylor (1951), Mitchell (1977), and Ferrus et al. (1980) claim that the humidity of expired air is closely related to the humidity of the inspired air but only moderately affected by inspired air temperature. Recently, Ferrus et al. (1984) have ascertained that respiratory water loss depends to a large degree on respiratory and environmental conditions.

However, Webb (1955) pointed out that expired air is always saturated or supersaturated with water vapor in cold conditions. Current work, (Deal et al., 1979, Hoke et al., 1976) support the latter opinion. The controversy stems from the difficulty of physically measuring the water content of expired air, since hygrometers absorb heat which in turn affects the air temperature.

Expired air temperature is considered to be a function of inspired air temperature. According to current findings the existing relationship between inspired air temperature and expired air temperature may be summarized in the following predictive equation: (Braithwaite,1972)

$$T_{ex} = 24 + 0.32T_{in}$$

Where T_{in} = temperature of inspired air

T_{ex} = temperature of expired air

Thus, an important feature of upper respiratory tract heat exchange is that the colder the inspired air, the larger is conductive heat loss to it and the smaller is evaporative heat loss from it.

For example, where a man works at steady state, inspiring 100 l/min. of air at 0 °C and 50% Relative Humidity, the temperature of expired is 24°C. This means that the subject loses 0.730 $kcal \cdot min^{-1}$ via respiratory conductive dissipation and 1.118 $kcal \cdot min^{-1}$ through evaporation occurring in the respiratory system. The same individual working at the same workrate where inspired air is −10°C and 50% RH, would have pulmonary ventilation losses from conduction and evaporation occuring in his respiratory tract of 0.936 $kcal \cdot min.^{-1}$ and 0.991 $kcal \cdot min.^{-1}$ respectively. In both cases the expired air is considered to be fully saturated.

The above illustration indicates that the colder inspired air, the greater is heat energy conservation in respiratory tract heat exchange and the greater is overall heat energy loss.

2. PREVIOUS RESEARCH ON COLD AIR INHALATION

The ability of the upper respiratory tract to regulate the heat and water content of inspired air without tissue dysfunction or damage is very impressive and has been demonstrated in a cold environment:

2.1 Effects on tissue damage

Despite inspiration of air at an ambient temperature as low as −100°C, inspired air reaches the lungs at 37°C (Cole, 1954; Ingelstedt, 1956). Moritz and Weisiger (1945) for example, reported that a combat flier flying with his face exposed to a 250 mile per hour windstream at minus 30°C for two hours received no laryngo-trachea injuries.

2.2 Pulmonary function at rest

No changes were observed in timed vital capacity or expiratory flow rates after inhalation of cold air in sitting subjects (Hsieh et al., 1968; Millar et al., 1965; Wells et al., 1960; Ramson, 1977; O'Cain et al., 1980). Additionally, inhalation of cold air at rest, at −30°C for 15 minutes did not produce any significant change in FEV_1 (Forced Expiratory Volume-1sec) and MMEFR (Maximum Mid-Expiratory Flow Rate; Guleria et al., 1969), in contrast to changes observed in asthmatic persons.

2.3 Pulmonary function during exercise

Identical conclusions could be drawn for exercise. Jaeger et al. (1980) showed that temperature in the lower third of the esophagus is identical to rectal temperature and unaffected by the level of respiratory heat exchange during exercise; their subjects were performing at 80% of their predicted maximal oxygen uptake and inspiring cold dry air, (-40°C). Furthermore, Deal et al. (1979) alleged that there is no obstructive response to exercise with cold air inspiration (-12°C) in normal subjects, and Hartung et al. (1980) could demonstrate no changes in respiration rate due to breathing cold air (-35°C) during moderately strenous exercise (65%-75%). Another investigaton showing no cold injury to the respiratory tract, was carried out by Faulkner et al. (1979) who examined cross country skiers performing vigorous ($V_E = 120$ l·min.$^{-1}$) endurance exercise (80km) in temperatures as low as -28°C (-55 °C with Wind Chill factor).

2.4 Effects on body temperature

McFadden et al. (1985) found that the temperature in the retrotracheal esophagus drops remarkably during exercise and hyperventilation. This challenges the utility of indirect techniques such as those of Jaeger et al. (1980) who found no changes in thermal stress in the intrathoracic airways. Spitler et al. (1980) found no exercise induced change in rectal temperature using a cryogenic gas. This was predictable since:

a) the work protocol was a short Vo_2max test.

Thus rectal monitoring, a poor indicator of temperature kinetics did not allow demonstration of heat storage, (Hanson, 1974),

b) there was no demonstrable environmental stress

c) the inspired air was not cold enough to induce reaction as a Helium-Oxygen mixture was inspired which differs in heat capacity, from a Nitrogen Oxygen mixture by only 0.00015 $kcal \cdot l^{-1} \cdot {}^{\circ}C^{-1}$ and

d) maximum Oxygen uptake during respiration of a less dense gas such as Helium is lower implying a decreased heat load, (Saltin and Hermansen, 1966; Davies, 1979).

Similarly, Hartung et al. (1980), noted that rectal temperature was not affected by cold air breathing at (-30°C). Hartung's experiments were performed in a thermally neutral environment and were 10 minutes long. However, a careful consideration of their results by the writer reveals a statistically significant ($p \leq 0.05$), lower rectal temperature achieved while inspiring cold air. These investigators asserted that their calculations of body heat exchange show that a fall in rectal temperature is unlikely in 10 minutes of breathing extremely cold air, even during high ventilatory effort. Thus, the authors conclude that these results probably represent chance error with respect to the small number of subjects. This conclusion may be erroneous. Using the values which are provided by Hartung et al, respiratory heat loss is equal to 21.4 kcal and 8.23 kcal under cold and ambient air inspiration respectively, after 10 min of cycling. Taking into consideration that the specific heat of the human body is equal to 0.83 $kcal \cdot kg^{-1} \cdot {}^{\circ}C^{-1}$, 21.4 kcal of heat loss implies a 0.4°C potential

reduction in body core temperature. In comparison, 8.2 kcal of heat loss is equivalent to a 0.1 °C potential reduction.
With respect to overall thermoregulatory mechanisms and body heat production, the former losses are interpreted by the present writer as a definite 0.3°C (0.4–0.1) difference in core temperature between cold and ambient air inspiration in agreement with the findings of Hartung et al, (1980).

In addition Lind (1955) compared two different self contained breathing apparatus in mine rescue oparation and found that when the temperature of inspired air was higher than the rectal temperature his subjects were thermally stressed.

3. AIM OF THE STUDY

In this study, an attempt has been made to clarify the effects of cold air inhalation on exercise induced increases in body core temperature. The contribution of water losses through respiration to overall body dehydration was also examined. Experiments were conducted under heat stress in order to emphasize any beneficial effect of cold air breathing during exercise. In short, it was assumed that cold air inhalation may cause:

1. diminished rectal temperature elevation, and heart rate for standard endurance exercise, and
2. increased dehydration during long term physical effort.

4. MATERIALS AND METHODS

4.1 Protocol

The experiments were conducted on eight healthy males who were selected at random from volunteers in the age range of 24–29 yrs. Their anthropometric characteristics are presented in Table 1.

Each subject executed a ramp test on a Uniwork Quinton-845 electrically braked ergometer to determine maximal oxygen capacity (VO_2*max*.; Table 1). On two other occasions all subjects cycled at 45%–50% of their maximum work rate while:

a) inhaling cool air (3.6°C)

b) inspiring room air, in a random sequence.

In all three experimental protocols, (VO_2*max*, cool air inhalation, ambient room air inhalation), the ambient temperature was maintained at 38°C and 90%–95% relative humidity ensuring minimization of the contribution of sweat evaporation in the thermoregulatory process (Mitchell,1970). Submaximal tests were considered to be completed upon manifestation of exhaustion of the subjects. For comparative purposes subjects were asked to perform on each second occasion for as long as they had lasted in the first.
After cessation of exercise subjects were allowed to recover in a thermo-neutral environment while skin the rectal temperarure were monitored for 30 minutes.

Table 1: Physical characteristics and aerobic power of eight male subjects participating in the experiments.

Subjects (initials)	Age (years)	Height (cm)	Weight (kg)	Body Surface Area (m^2)	Somatotype	Adiposity (%)	Specific heat of tissue ($kcal \cdot kg^{-1} \cdot {}^{\circ}C^{-1}$)	VO_2max ($ml \cdot kg^{-1} \cdot min^{-1}$)
N.A	24.6	181	68.5	1.85	144	20	0.80	59.8
N.G	26.6	180	74.2	2.04	353	28	0.79	45.8
P.J	29.1	183	77.5	1.80	253	23	0.80	42.6
T.L	28.7	186	75.0	1.89	144	20	0.80	61.3
G.D	25.5	190	83.2	1.94	253	20	0.81	54.1
L.B	27.1	181	63.7	1.85	234	21	0.80	75.3
A.L	28.1	184	91.3	2.17	361	31	0.78	47.0
D.V	29.4	178	67.5	1.80	243	23	0.80	53.3
Mean	27.4	183	75.1	1.92	243	23	0.80	54.9
±S.D	1.74	3.8	8.99	0.13		4.1	0.01	10.6

4.2 Instrumentation

All experiments took place in a hot/cold chamber (Tenney Engineering New Jersey) capable of simulating environmental conditions over a wide range of temperature and humidity. Under cool air inhalation condition subjects inspired from a heat exchanger, a modification of the design reported by Guleria et al. (1969), shown in figures 1 and 2. Compressed atmospheric air was driven through two homocentric tubes which were encircled by copper coil filled with liquid nitrogen.

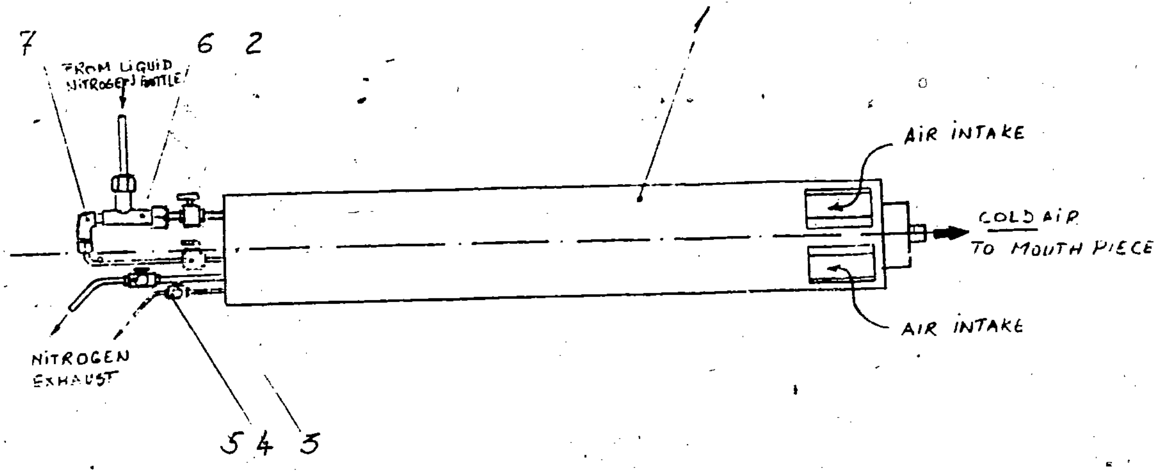
Heart rates were recorded with an electrocardiograph (model Fukuda Danish FD-13).

The volume of respired gas was measured on expiration by an HP 2107EB pneumotach attached to an HP 47304A flow transducer, previously calibrated using a 2667 Collins chain-compensated gasometer. Expired gas was directed to a 9.5 litre mixing box, from which oxygen and carbon dioxide concentrations were determined by S-3A Applied Electrochemistry Oxygen and CD-3A Carbon Dioxide analyzers, respectively. The oxygen uptake instruments were located outside the Environmental chamber and were connected to the mouthpiece with 3.5 m of tubing producing a system response time of 40 seconds. The oxygen uptake system was calibrated twice before each test using prime gas.

A rectal thermistor probe (Yellow Springs instruments co.) was inserted 10cm past the external sphincter in the rectum. The thermistor was connected to a temperature coupler.

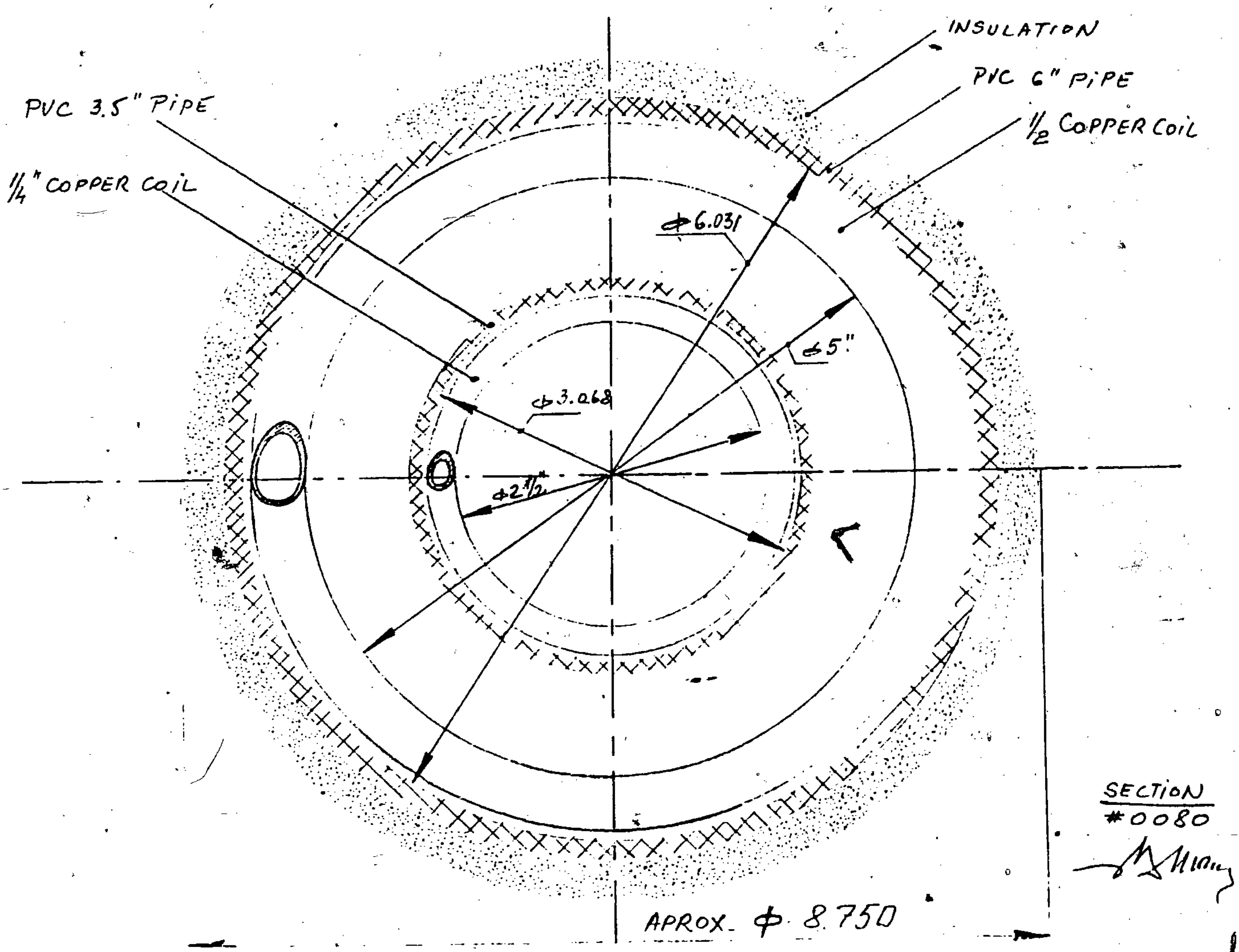
Skin temperatures measurement were obtained from four separate sites, (quadriceps, gastrocnemious, triceps, m. pectoralis), using T-type thermocouples. The end of each thermocouple was held on the skin with an adhesive Scholl

Figure 1: A longitudinal section of the heat exchanger allowing cold air inhalation to an exercising subject.



AIR COOLER #0000
SCALE 1:10
20.09.1984

Figure 2: A sectional view of the heat exchanger allowing cold air respiration to an exercising subject.


INSULATION
PVC 6" PiPE
1/2 COPPER COIL
PVC 3.5" PiPE
1/4" COPPER COIL
Φ6.031
Φ5"
Φ3.068
Φ2 1/2"
APROX. Φ 8.750
SECTION
#0080

scorn plaster in such a manner that the thermosensitive tip was positioned in the center hole in close contact with the skin.

Inspired and expired air temperatures were monitored by a teflon insulated miniature (.005inch) T-type thermocouple with a time constant of 0.1 second measured in air. A PM-8100 Philips recorder was used to record respired air temperatures. The respired air temperature record was also used to record the respiratory frequency. Air humidity of the expired air was measured in the mixing box using a TRH-CX Shinyei digital thermo-hygrometer.

Each variable was recorded by an HP3497A Data acquisition system linked to an HP85 microcomputer, (HP3054 DL). Fluid losses were measured by weighing the subjects, nude, on an accurate weight scale (Accu-Weigh, Metro Equipment Co., CA) prior to and immediately on termination of each experiment.

4.3 Analysis

Body Surface Area.

The equation originated by Jones _et_ _al_. (1985) was used to estimate body surface area.

Skin temperature.

Mean skin temperature was calculated from Ramanathan's formula, (Ramanathan, 1964). In some cases calf skin temperature was lost, due to technical difficulties. In those cases a modified value equivalent to $0.35(T_{ar}+T_{ch}) + 0.30 T_{th}$ was used, where T_{ar}, T_{ch} and T_{th} represent arm, chest and thigh teperatures respectively. The latter formula was derived using regression analysis of skin temperature values measured at four sites in the present study. Moreover, Olesen

(1984). Olesen and Fanger (1973) pointed out that during exposure to heat mean skin temperature derived from the temperature of 2-3 skin sites is reliable.

Respiratory heat exchange (RHE)

RHE was computed from the temperature and humidity of the inspired and the expired air respectively (Appendix 3), according to the following formula, (American Thoracic Society, 1962; Gagge et al., 1969):

$$RHE = \dot{V}_E \{H_c(T_{in} - T_{ex})+\lambda\ (P_{wi} - P_{we})\} \times 69.8 \qquad (1)$$

where,

RHE = Respiratory heat exchange in Watts

$\dot{V}_E$ = Minute ventilation in $l \cdot min^{-1}$

H_c = Heat capacity of air in $kcal \cdot l^{-1} \cdot {}^{\circ}C^{-1}$

T_{in} = Inspired air temperature in °C

T_{ex} = Expired air temperature in °C

λ = Latent heat of vaporization of water, 0.58 $kcal \cdot g^{-1}$

P_{wi} = Water content of inspired air, $g\ H_2O \cdot l^{-1}$

P_{we} = Water content of expired air, $g\ H_2O \cdot l^{-1}$

69.8 = conversion factor of $kcal \cdot min^{-1}$ to Watts

Heat capacity is defined as the product of specific heat (c) and density (ρ). Specific heat was considered to be equal to $0.24 \cdot 10^{-3}$ $kcal \cdot g^{-1} \cdot {}^{\circ}C^{-1}$ and insignificantly affected by temperature. In contrast $\dot{V}_E$ and ρ must be expressed at the same temperature. Relative Humidity of expired air at the mouth was calculated according to the RH of expired air in the mixing box and the corresponding temperature of the air in the mixing box and at the mouth respectively. The water content of inspired (P_{wi}), expired air (P_{we}) and ρ of expired air in $g \cdot l^{-1}$ were calculated from tables reported by Weast (1976).

Body heat storage, (S)

S was computed from: (Flyn et al . 1974)

$$S = M \pm RHE \pm C \pm R - E \tag{2}$$

where,
S = Body heat storage in Watts
M = Metabolic heat production in Watts
RHE = Respiratory heat loss/gain in Watts
C = Convective heat loss/gain in Watts
R = Heat loss/gain via radiation in Watts
E = Evaporative heat loss in Watts

Metabolic heat production, $(\dot{M})$

M was calculated from the relationship between oxygen consumption and calories yielded. One liter of oxygen was equivalant to 5 kcal of a Respiratory Quotient (R) equal to 1. Mechanical efficiency of cycling was considered to be 25% (Fanger, 1972).

Convection..

Convective heat loss was calculated from Kerslake, (1972):

$$C = h_c \times BSA \times (T_s - T_a) \tag{3}$$

C = Convective heat loss, Watts
h_c = convective heat transfer coefficient, $W \cdot m^{-2} \cdot {}^{\circ}C^{-1}$

BSA = body surface area, m^2

T_a = ambient temperature, °C

T_s = mean skin temperature, °C

The heat transfer coefficient was estimated to be 7.2 $W\cdot m^{-2}\cdot{}^{\circ}C^{-1}$ by extrapolating Nishi and Gagge's (1970) experimentally defined heat transfer coefficient under slightly different experimental conditions. Only 0.8 of the total surface area was accounted for in the convective exchange as Flyn et al (1974) have reported that only 80% of the total body surface area contributes to convective heat exchange, (termed effective BSA for convective heat loss).

Radiation, (R).

Radiative heat loss was calculated from Kerslake, (1972), Fanger, (1972) :

$$R = \epsilon \times \sigma \times (T_s^4 - MRT^4) \times f_c \times BSA \tag{4}$$

R = Radiative heat loss, Watts

ϵ = Emissivity of the skin, dimensionless

σ = Stephan-Boltzmann constant, $W\cdot m^{-2}\cdot{}^{\circ}C^{-4}$

T_s = Skin body temperature, °C.

MRT = Mean radiant temperature, °C.

f_c = configuration factor, dimensionless

BSA = Body serface area, m^2

Hardy (1939), Mitchell (1970), and Fanger (1972) proposed that skin emissivity and configuration factor approximate a value of 1 and 0.7 respectively. Hodgman (1965) found the constant, σ, has the value 5.67×10^{-8}. The mean radiant temperature was assumed essentially equal to the ambient temperature (Flyn et al., 1974).

Evaporation, (E).

Heat loss from sweat evaporation was calculated from:

$$E=h_D\{\phi s(C_s-C_a)\}\lambda \times BSA \times 69.8 \qquad (5)$$

where E = Evaporative heat loss, Watts

h_D = mass transfer coefficient, $m\cdot min.^{-1}$

ϕs = relative humidity of skin, (dimensionless).

C_s = water vapour concentration, $g\cdot m^{-3}$

C_a = ambient water vapour concentration, $g\cdot m^{-3}$

λ = latent heat of vapourization, 0.58 $kcal\cdot g^{-1}$

BSA = body surface area, m^2

69.8 = conversion factor of $kcal\cdot min^{-1}$ to Watts.

The mass transfer coefficient analogous to the convective heat transfer coefficient (h_c) was equal to 0.377 according to the equation proposed by Kerslake (1972):

$$h_D=h_c\cdot(\rho c)^{-1} \text{ (by approximation)} \qquad (6)$$

where ρ and c represent the density and specific heat of air respectively and are equal to 1.13 $kg\cdot m^{-3}$ and 0.242 $kcal\cdot kg^{-1}\cdot {}^{\circ}C^{-1}$ The convective heat transfer coefficient was assumed to be 0.1032 $kcal\cdot min^{-1}\cdot m^{-2}\cdot {}^{\circ}C^{-1}$, (Rapp 1970). The relative humidity of the skin was computed after taking into account that skin wettedness, even at 100% RH, is only 75%, (Mitchell J, 1977). The relationship between relative skin humidity (ϕs) and wettedness (W) is given by:

$$\phi s=W+(1-w)pa/ps \qquad (7)$$

where ps indicates the saturated water vapor pressure at skin temperature and pa the ambient water vapour pressure.

Body heat storage (S)

S was calculated from Kakitsuba and Mekjavic (1986):

$$S = 0.84 \times BW \times (X \times \Delta T_r + Y \times \Delta T_s) \times 69.8 \qquad (8)$$

where $S =$ body heat storage, Watts

$X = 0.38 + 0.25 \times \alpha^{.5} + 0.38 \times \alpha$

$Y = 0.38 - 0.25 \times \alpha^{.5} + 0.13 \times \alpha$

$\alpha = 1 -$ fraction of adiposity

$0.84 =$ revised specific heat of tissue, $\mathrm{kcal \cdot kg^{-1} \cdot {}^{\circ}C^{-1}}$

$BW =$ body mass, kg

$BSA =$ Body Surface Area, m^2

$T_r =$ rectal temperature, °C.

$T_s =$ skin temperature, °C.

$69.8 =$ conversion factor of $\mathrm{kcal \cdot min^{-1}}$ to Watts

Average body temperature (Tb).

Two methods were used to calculate the average body temperature.

a) *Calorific:*

Heat calculated from oxygen uptake measurements, was divided by the heat capacity (C) of tissue, (the product of specific heat, c, of the tissue and the body mass, Table 1). The mean specific heat of tissue was computed by fractioning the total body mass into different tissues and then summing the product of the individual composition mass and the appropriate specific heat thermal characteristic, (Mitchell et al., 1945; Kakitsuba and Mekjavic, 1986).The fractionation of body mass was based on a model developed by Drinkwater, (1984).

b) *Thermic*:

This method relies on measurements made of the skin and core temperature, (Burton, 1935). The coefficients were determined to be 0.5 each since 50%-54% of total body mass and volume is distributed at the periphery of the body and that average body temperature is logically related more to skin temperature when skin temperature is higher than to core temperature, (Hardy and DuBois 1937).

Statistics.

Data were analysed using Analysis of Variance with Repeated measures; variation in body weight under different experimental conditions was tested by a matched t-test, (BMDP, 1981).

The null hypothesis (H_0) that there was no difference in any physiological parameter due to cool or warm inhalant gas breathing during exercise was set at $\alpha \leq 0.05$ confidence level. Missing values of variables were estimated by regressing those variables on up to two variables selected by stepwise iterative regression, serially measured close to the missing value, (BMDP, 1981).

5. RESULTS

Raw and derived data are presented in Appendix 1. Table 2 shows the mean values and standard deviation of rectal temperature, skin temperature, heart rate, and ambient temperature during a time period of 19 minutes which represents the minimum common endurance of all the subjects during exercise. Figure 2 illustrates data which are presented in table 2. Figures 3, 4, 5, and 6 depict individual data for rectal, skin and ambient temperature and heart rate of all the subjects.

Heart rate (HR)

Heart rate data for two subjects (P.J, G.D) were not recorded due to technical difficulties. Group mean heart rate was not significantly different, ($p \leq 0.34$), between experimental conditions. However, as it may be seen, (table 2, Fig. 2), the final heart rate for hot inhalation is higher compared to the cool one. Indeed, statistical analysis of the last two minutes of exercise revealed a significant difference of $p \leq 0.05$ (onesided).

Ambient temperature.

There was no statistically significant difference between the group mean temperature of the surrounding ambient conditions under the different experimental conditions of breathing hot, (mean 38.3 ± 0.19), and cool air, (mean 37.9 ±0.24). However, there is a large variance in ambient temperature between hot and cool inhalation in two of the subjects, (L.B., T.L.).

Skin temperature.

Skin temperature is statistically insignificant different and almost identical under both experimental conditions except in subjects L.B. and D.V., (37.97 ±1.47 vs 37.82 ±1.30). The time course of mean change in skin temperature is characterized by an initial dramatic increase during the first five minutes followed by a slow rise which leads finally to a skin temperatures higher than the hot ambient temperature.

Rectal temperature.

All subjects' rectal temperature constantly increased during exercise under both experimental conditions. The rate of increase during the first six minutes of exercise was small becoming gradually greater as exercise duration increased. Rectal temperature increased during hot air inhalation in a exponential fashion after the fifteenth minute of exercise. On the contrary, the onset of rectal temperature increase during cool air respiration was delayed and the rate of its increment was reduced below that occuring during hot air inhalation. Rectal temperature while breathing cool air is significantly lower ($p \leq 0.002$) than under hot air inhalation during the entire exercise period.

Respiratory frequency.

Table 3 and figure 8 show changes in respiratory frequency caused by hot and cool air inhalation. Cool air inhalation induced reduction of the respiratory frequency in all the subjects except G.D. . Subject A.L. attained a maximum difference of 10 cycles·min^{-1} between hot and cool air inhalation treatment. Table 3 shows that breathing cool air progressively decreases mean respiratory frequency during exercise in hot–humid ambient conditions below that occurring while breathing hot air. The range of differences in respiratory frequency between hot and cool inhalation varies from 2 cycles·min^{-1} during the first minute to almost 5 cycles·min^{-1} during the last minute of the exercise period, (39.5 ±5.2 vs 34.7 ±4.3). Analysis of variance during the time course showed significant differences between the two experimental conditions at $p \leq 0.004$.

Respiratory Heat Exchange.

Changes in the Respiratory Heat Exchange, pulmonary ventilation, and temperature of inspired and expired air under hot and cool inhalation treatments are shown in table 4 for eight subjects. During cool air breathing there was an eight fold greater heat loss through the respiratory system than under similar exercise breathing hot air. It seems that the respiratory system sometimes possesses an exceptional ability to dissipate heat even in a hot humid environment as may be observed in the special cases of subjects N.A, T.L, A.L., and D.V.

Body Weight.

Loss of body weight due to exercising in a hot humid environment was not significantly greater ($p \leq 0.08$) while breathing cool air, (1.33kg), compared with weight loss breathing hot ambient air (1kg, table 6). However this difference should be carefully interpreted because the distribution of weight changes throughout the various conditions was not normal. Subject D.V.'s weight loss was exceptionally great during cool air inhalation. Thus a non-parametric test (sign test) was used to test the difference. This resulted in an similar non significant difference ($p \leq 0.08$) between the two conditions.

Mean body temperature and body heat storage.

Mean body temperature and body heat storage were calculated both directly and indirectly in an attempt to reconcile existing prediction equations with present data. Appendix 2 shows such calculations for subject N.A. As table 5 shows there is close agreement in predicted values between the calorific method used here and the Hardy DuBois equation, (2.67°C vs 2.61°C during hot air inhalation and 2.28°C vs 2.20°C under cool air inhalant condition). The Kakitsuba and Mekjavic equation shows a large overestimation of body heat storage during hot inspiration (+15.25kcal) and an insignificant underestimation of body heat storage under cool inspiration (-6.16kcal) compared with the present calorific method. The contribution of each dissipating mechanism in body heat storage calculations is shown in table 6 for six exercising subjects working under heat stress and breathing cool and ambient air.

Oxygen uptake.

The values of oxygen uptake which are showed in table 5 for six subjects are representative of the twelfth minute of exercise. Individual measures of VO_2 at specific time points were compared rather than serial measurements because in some experiments there was free flow of respired air towards the end of exercise due to freezing of the breathing valve flaps. Oxygen uptake was insignificantly ($p \leq 0.10$) lower (1.9 ±0.33 $l \cdot min^{-1}$) while breathing cool air than during breathing hot air (2.08 ±0.25 $l \cdot min^{-1}$).

Rectal temperature during recovery.

Rectal temperature changes during recovery are shown in Appendix 1. Figures 9 and 10 depict these results pooled in two arbitrary groups for all subjects, depending on the severeness of the change. Rectal temperature during recovery continued to increase even when the heat stress and exercise stimulus were removed. The rise ranged from 0.1° to 5.2° C with a mean group value of 1.8 °C. In seven cases the final rectal temperature reached 40° C. These results remain unexplained.

Table 2: Changes in skin, ambient, rectal temperature and heart rate during hot and cool air inhalation under hot–humid environment . Values are means, ±SD, n=8 except in the case of heart rate where n=6; T_r, rectal temperature in °C, T_s, mean skin temperature in °C, T_a, ambient temperature in °C, H.R., heart rate in beats• min^{-1}. *$p \leq 0.002$, **$p \leq .05$ (for only last 2 min. of exercise).

Variable/ Condition	TIME (min) 1	 7	 13	 19
*T_r/Hot	0.0 ±0.0	0.2 ±0.2	0.6 ±0.3	1.1 ±0.5
*T_r/Cool	0.0 ±0.0	0.1 ±0.1	0.4 ±0.2	0.7 ±0.4
T_s/Hot	36.1 ±0.5	37.6 ±0.6	38.7 ±0.6	39.5 ±0.7
T_s/Cool	36.1 ±0.5	37.6 ±0.6	38.7 ±0.6	39.1 ±0.6
T_a/Hot	38.1 ±1.8	38.2 ±1.5	38.3 ±1.4	38.6 ±1.6
T_a/Cool	37.6 ±1.5	37.7 ±1.5	38.0 ±1.6	38.4 ±1.8
H.R/Hot	124 ± 24	147 ± 9	165 ± 7	179 ± 15**
H.R./Cool	142 ± 23	149 ± 13	162 ± 12	170 ± 10**

Fig. 3: Changes (mean ±S.D.), in rectal temperature, skin temperature, and heart rate during cycle ergometry (45%–50% $\dot{V}O_2max$) induced by cool inhalant gas or ambient gas breathing under hot ambient condition (38 °C - 95 %RH).

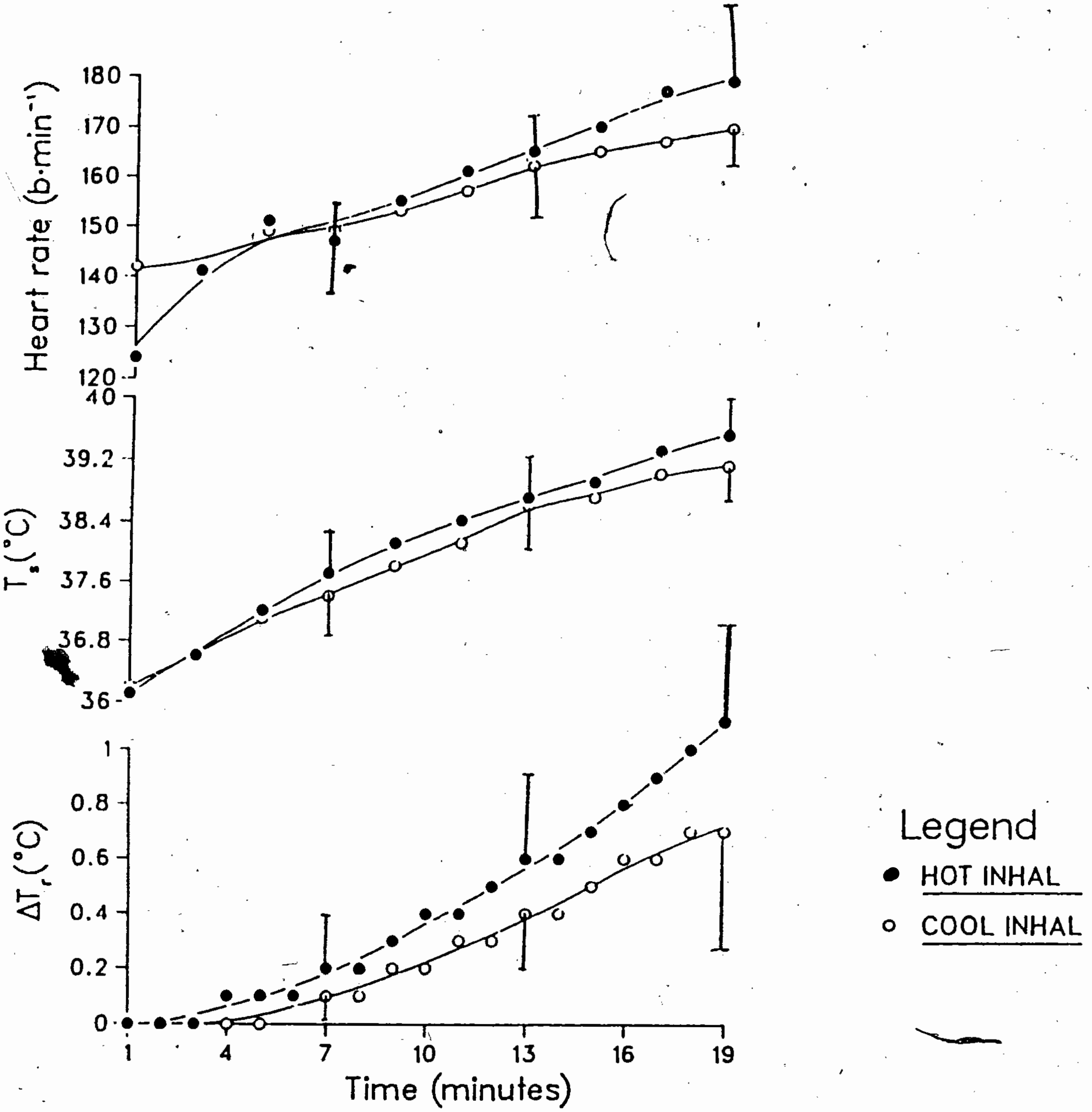
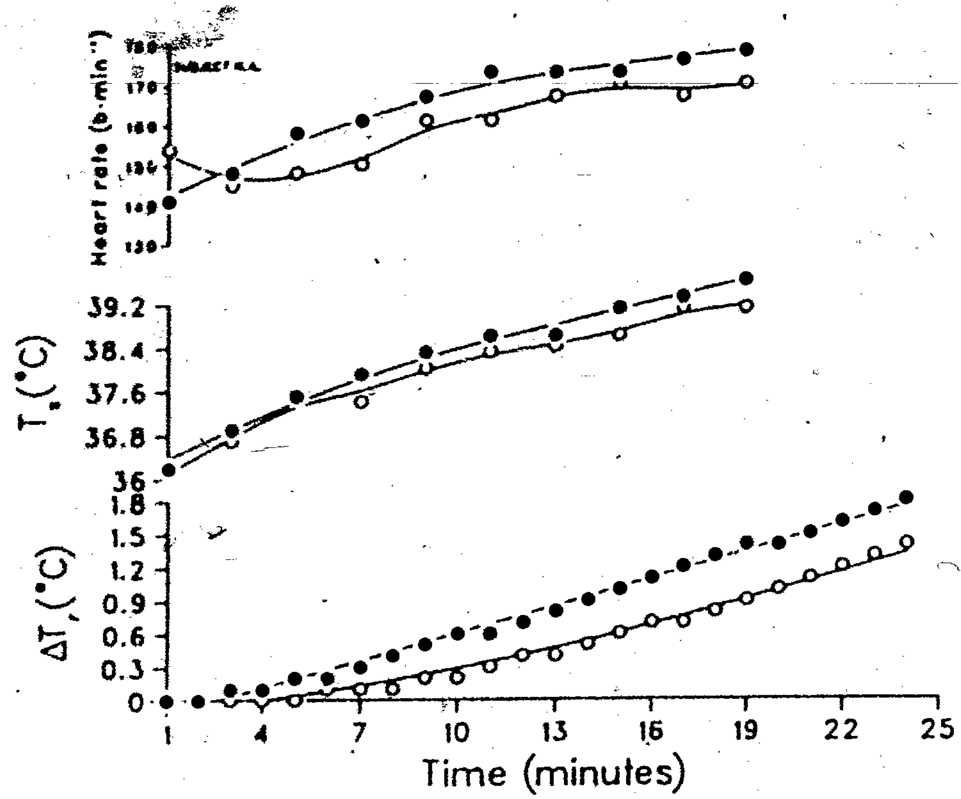

Heart rate (b·min⁻¹)
180
170
160
150
140
130
120
T_s (°C)
40
39.2
38.4
37.6
36.8
36
ΔT_r (°C)
1
0.8
0.6
0.4
0.2
0
1
4
7
10
13
16
19
Time (minutes)
Legend
● HOT INHAL
○ COOL INHAL

Fig 4: **Time course of individual changes in rectal temperature, skin temperature, and heart rate during submaximal (45%-50%$\dot{V}O_2$) exercise during inhalation of hot and cool air in the subjects N.A. (top) and N.G (bottom).** Ambient temperature and Relative Humidity for N.A were 37.6 °C. under hot inhalation and 37.2 °C.- 95% under cool inhalation respectively. For N.G., they were 38.9 ° C. - 95% and 38.1 ° - 95% respectively.


Heart rate (b·min⁻¹)
180
170
160
150
140
130
SUBJECT
T (°C)
39.2
38.4
37.6
36.8
36
ΔT (°C)
1.8
1.5
1.2
0.9
0.6
0.3
0
1
4
7
10
13
16
19
22
25
Time (minutes)

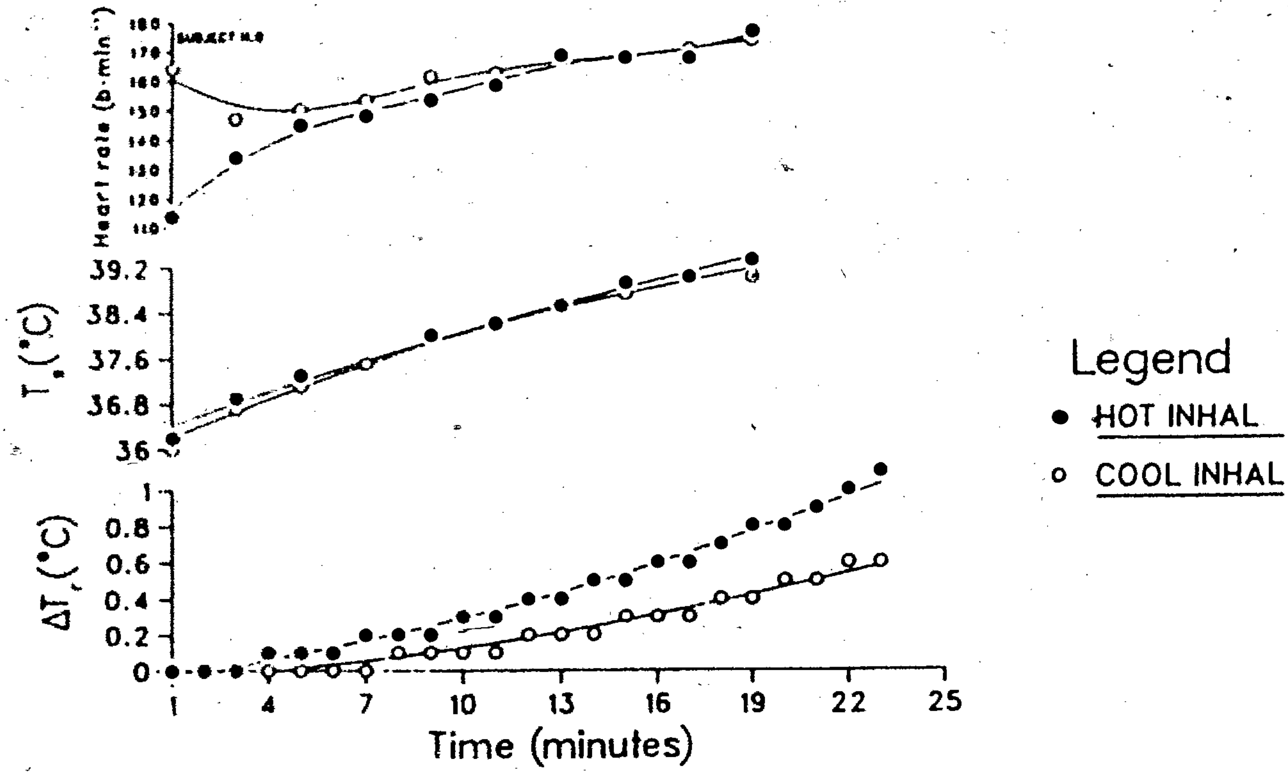

Heart rate (b·min⁻¹)
180
170
160
150
140
130
120
110
SUBJECT
T (°C)
39.2
38.4
37.6
36.8
36
ΔT (°C)
1
0.8
0.6
0.4
0.2
0
1
4
7
10
13
16
19
22
25
Time (minutes)
Legend
● HOT INHAL
○ COOL INHAL

Fig 5: **Time course of individual changes in rectal temperature, skin temperature, and heart rate during submaximal (45%-50%$\dot{V}O_2$max) exercise during inhalation of hot and cool air in the subjects G.D. (top) and L.B. (bottom).** Ambient temperature and Relative Humidity for G.D were 39.8 ° - 95% under hot inhalation and 39.6° C. - 95% under cool inhalation respectively. For L.B., they were 40.9° C. - 95% and 37.7° C.- 95% respectively. Subject's G.D. heart rate was lost.

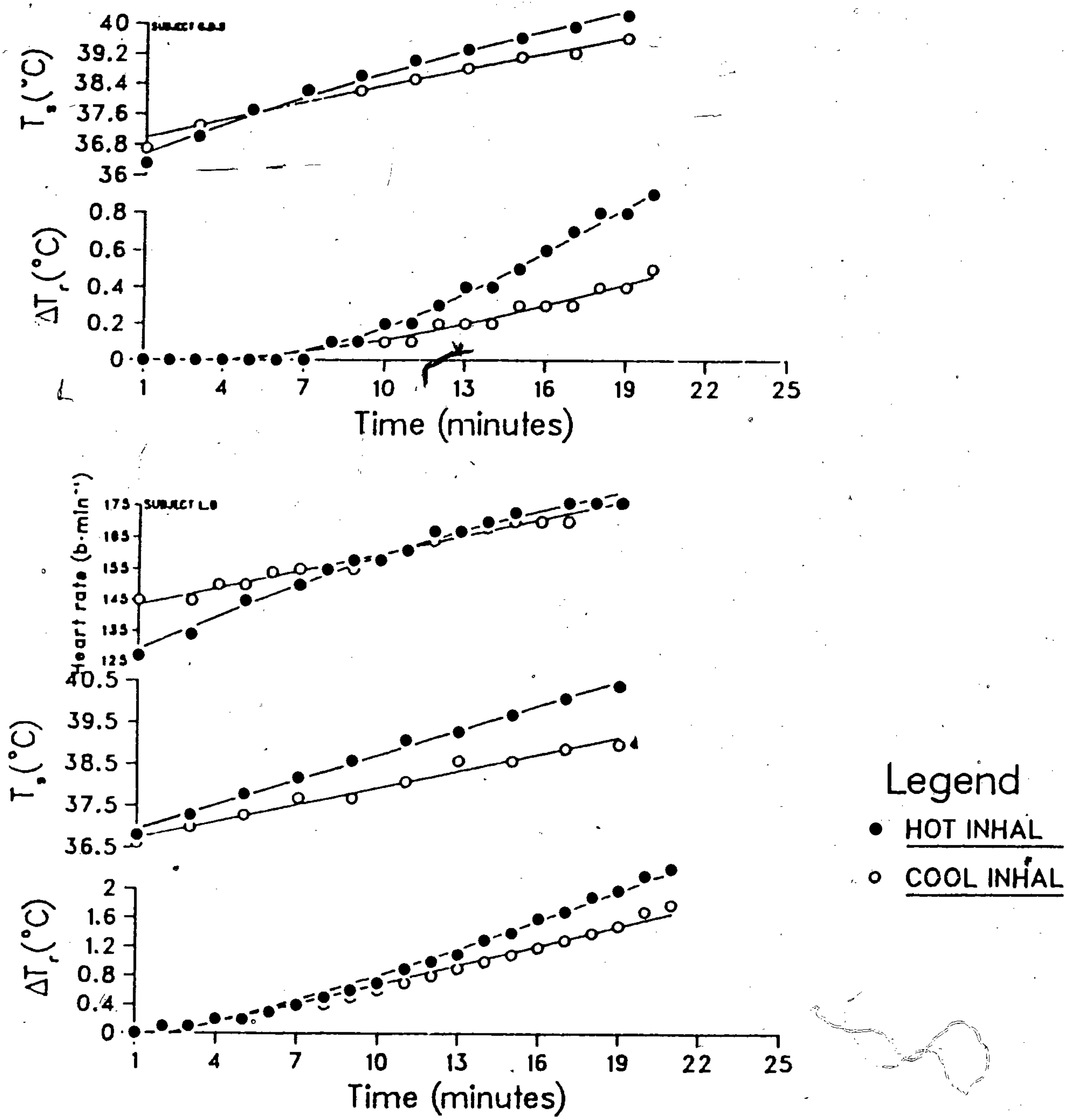
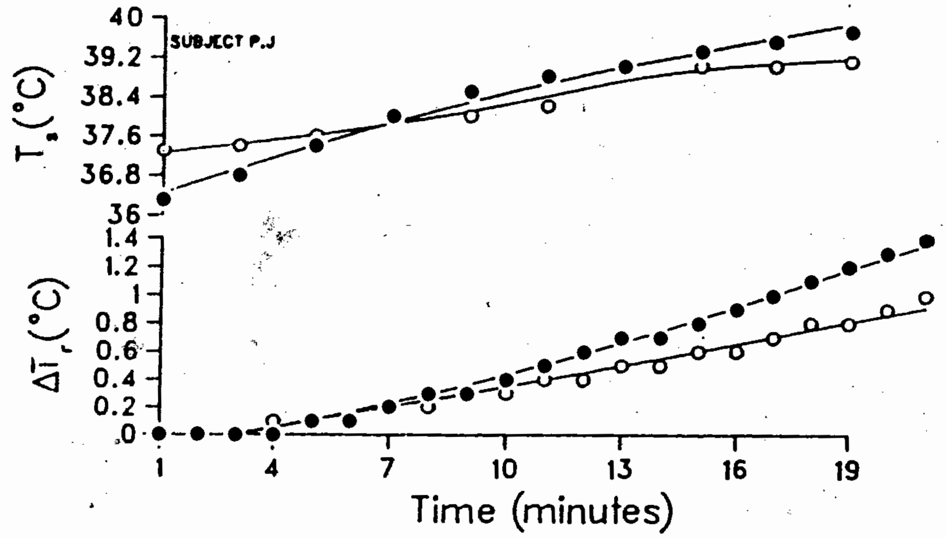
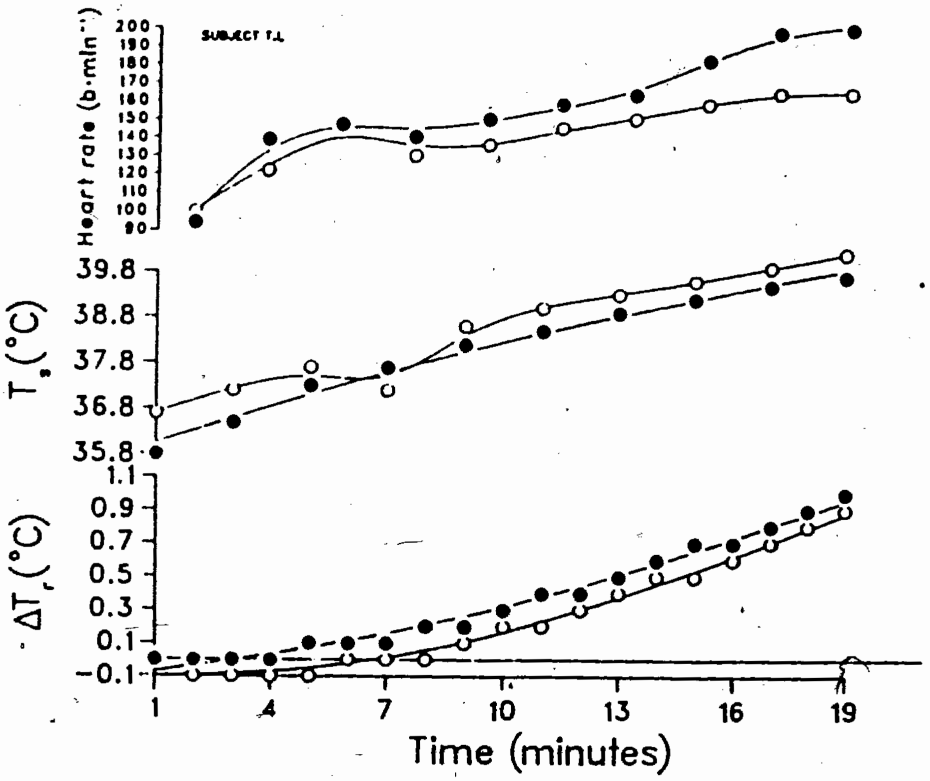

40
39.2
38.4
37.6
36.8
36
T_s (°C)
0.8
0.6
0.4
0.2
0
ΔT_r (°C)
1
4
7
10
13
16
19
22
25
Time (minutes)
SUBJECT L.B
175
165
155
145
135
125
Heart rate (b·min⁻¹)
40.5
39.5
38.5
37.5
36.5
T_s (°C)
2
1.6
1.2
0.8
0.4
0
ΔT_r (°C)
1
4
7
10
13
16
19
22
25
Time (minutes)
Legend
● HOT INHAL
○ COOL INHAL

Fig 6: **Time course of individual changes in rectal temperature, skin temperature, and heart rate during submaximal (45%-50%VO_2max) exercise during inhalation of hot and cool air in the subjects P.J (top) and T.L., (bottom).** Ambient temperature and Relative Humidity for P.J. were 38.4° C. - 95% under hot inhalation and 38.3 °C - 95% under cool respectively. For T.L., they were 37.3 °C - 95% and 40.5° C. - 95% respectively. Subject's P.J heart rate was not recorded.





Legend

● HOT INHAL

○ COOL INHAL

Fig 7: Time course of individual changes in rectal temperature, skin temperature, and heart rate during submaximal (45%–50%$\dot{V}O_2max$) exercise during inhalation of hot and cool air in the subjects A.L (top) and D.V., (bottom). Ambient temperature and Relative Humidity for A.L were 37.4° - 95% under hot inhalation and 36.9° C. - 95% under cool inhalation respectively. For D.V., they were 36.0° C. - 95% and 35.2 °C. - 95% respectively.

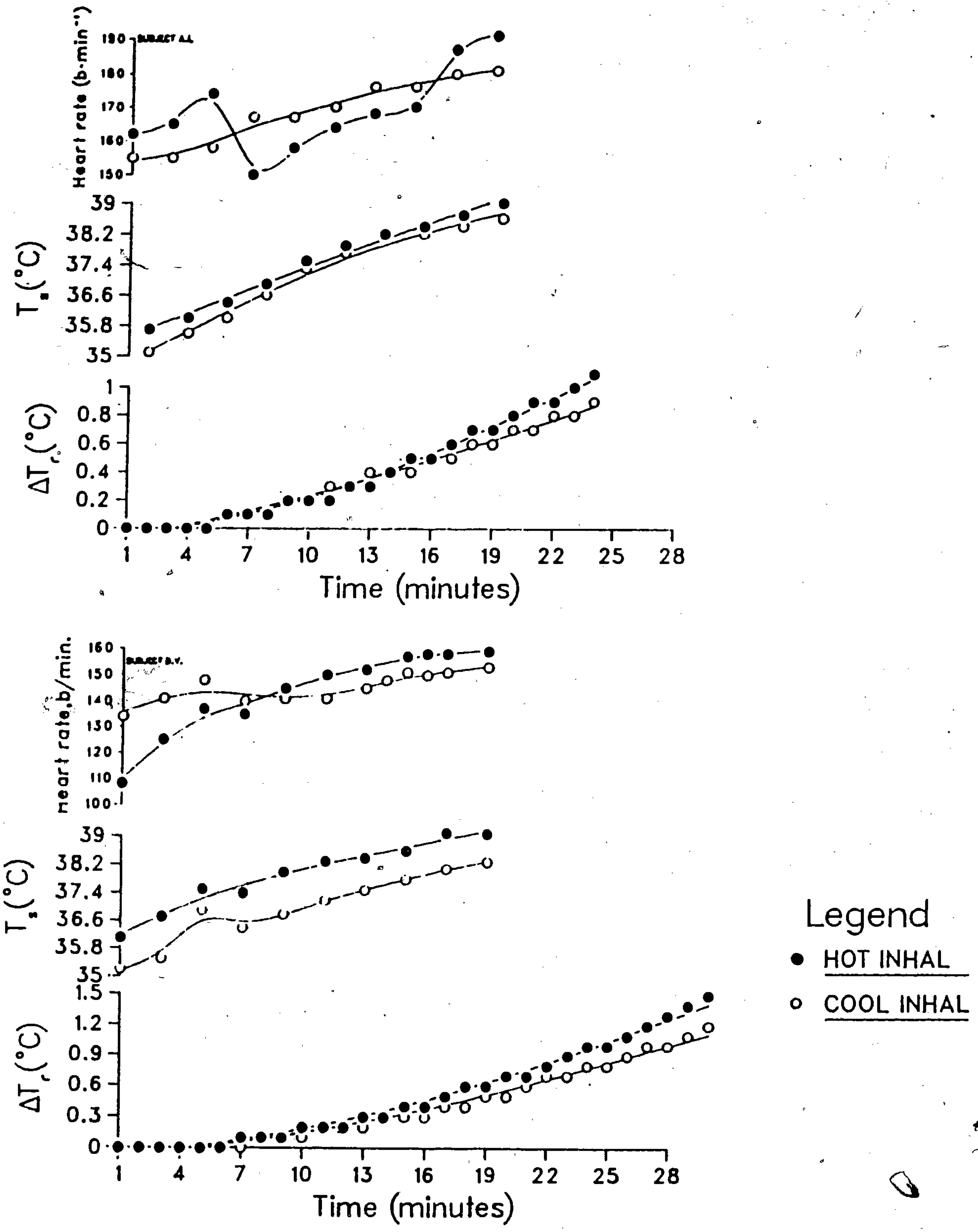
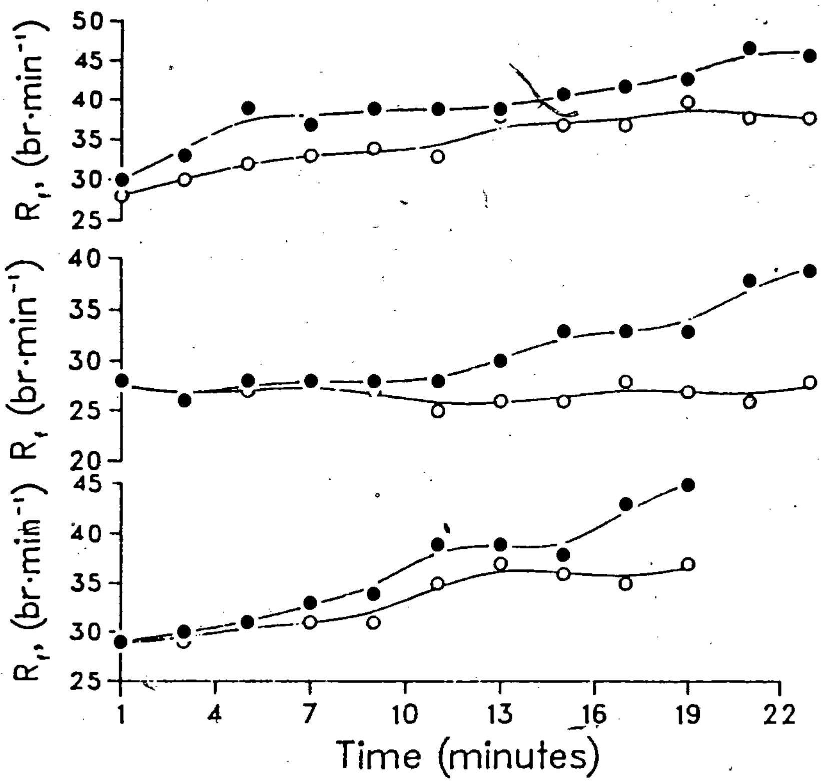
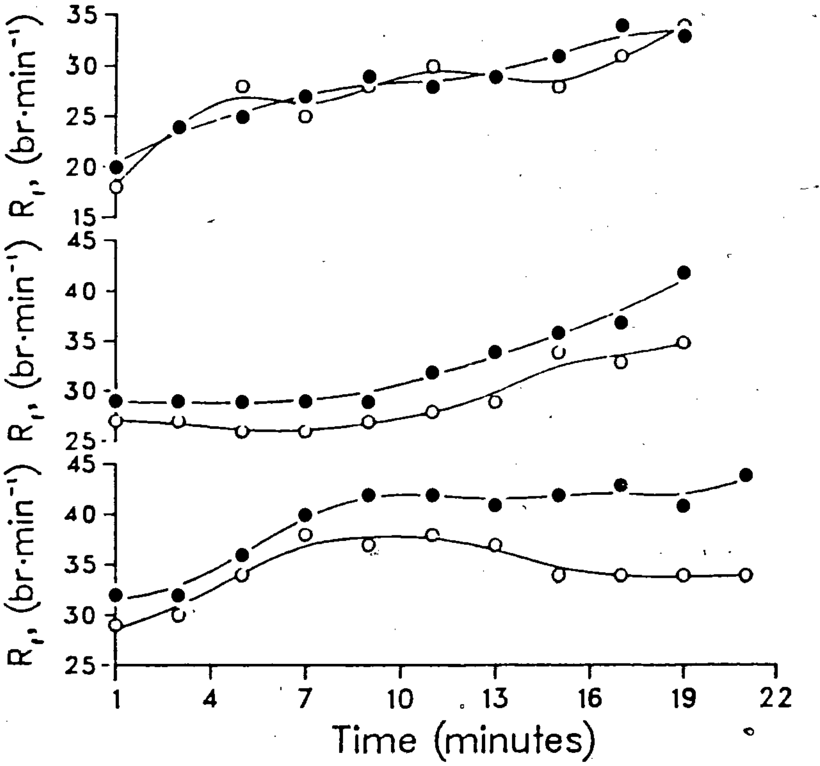

SUBJECT A.L.
Heart rate (b·min⁻¹)
150
160
170
180
190
T_s (°C)
35
35.8
36.6
37.4
38.2
39
ΔT_{re} (°C)
0
0.2
0.4
0.6
0.8
1
1
4
7
10
13
16
19
22
25
28
Time (minutes)
SUBJECT D.V.
heart rate, b/min.
100
110
120
130
140
150
160
T_s (°C)
35
35.8
36.6
37.4
38.2
39
ΔT_r (°C)
0
0.3
0.6
0.9
1.2
1.5
1
4
7
10
13
16
19
22
25
28
Time (minutes)
Legend
● HOT INHAL
○ COOL INHAL

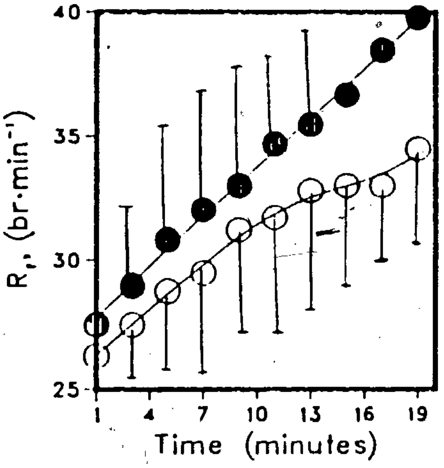
Table 3:Changes in respiratory frequency in 6 healthy exercising subjects induced by breathing hot and cool air under heat stress.•p≤0.004

Subject/	TIME (min)											
	1	3	5	7	9	11	13	15	17	19	21	23
Condition	FREQUENCY (cycles·min⁻¹)											
N.A./Hot	**30**	**33**	**39**	**37**	**39**	**39**	**39**	**41**	**42**	**43**	**47**	**46**
N.A./Cool	28	30	32	33	34	33	38	37	37	40	38	38
N.G./Hot	**28**	**26**	**28**	**28**	**28**	**28**	**30**	**33**	**33**	**33**	**38**	**39**
N.G./Cool	28	26	27	28	27	25	26	26	28	27	26	28
L.B./Hot	**29**	**29**	**29**	**29**	**29**	**32**	**34**	**36**	**37**	**42**		
L.B./Cool	27	27	26	26	27	28	29	34	33	35		
G.D./Hot	**20**	**24**	**25**	**27**	**29**	**28**	**29**	**31**	**34**	**33**		
G.D./Cool	18	24	28	25	28	30	29	28	31	35		
T.L./Hot	**29**	**30**	**31**	**33**	**34**	**39**	**39**	**38**	**43**	**45**		
T.L./Cool	29	29	31	31	35	37	37	36	35	37		
A.L./Hot	**32**	**32**	**36**	**40**	**42**	**42**	**41**	**42**	**43**	**41**	**44**	
A.L./Cool	29	30	34	38	37	38	37	34	34	34	34	
Mean/Hot	**28**	**29**	**31.3**	**32.3**	**33.5**	**34.7**	**35.3**	**36.8**	**38.7**	**39.5•**		
S.D ±	**4.1**	**3.5**	**5.2**	**5.3**	**5.9**	**6.1**	**5.1**	**4.3**	**5.2**	**5.2**		
Mean/Cool	26.5	28.2	29.7	30.2	31.3	31.8	32.7	32.5	33	34.7•		
S.D ±	4.2	1.7	3.1	4.9	4.5	5.1	5.2	4.5	3.2	4.3		

Fig 8: **The time course of individual differences in Respiratory frequency during submaximal exercise (45%–50%** $\dot{V}O_2$*max*) induced by inhalation of hot and cool respired air in six subjects, N.A., N.G., T.L., G.D., L.B., A.L., (from the top to the bottom). The insert shows changes in group mean values during the same period.







Legend

● HOT INHAL

◎ COOL INHAL

Table 4: *Changes in total accumulated Respiratory Heat Exchange, pulmonary ventilation, inspired and expired temperature during exercise under heat stress in eight subjects breathing hot and cool air.*

Subjects'	HOT INHALATION				COOL INHALATION				TIME
Initials	$\dot{V}_E$ l·min^{-1}	T_{in} °C	T_{ex} °C	R H E kcal	$\dot{V}_E$ l·min^{-1}	T_{in} °C	T_{ex} °C	R H E kcal	min.
N.A.	54.5	37.1	38.3	-2.68	47.7	-11.3	9.9	-10.95	24
N.G.	46.2	38.8	38.3	+1.18	43.3	4.0	16.11	-4.79	23
P.J.	43.6	38.2	37.4	+0.91	40.0	2.2	22.5	-4.79	21
T.L.	53.7	36.6	37.7	-1.80	48.8	6.2	20.5	-7.86	19
G.D.	49.3	39.0	38.2	+1.74	44.7	5.3	20.5	-6.62	20
L.B.	48.7	39.6	39.1	+1.52	46.8	5.7	21.6	-7.13	21
A.L.	59.8	36.6	38.5	-5.95	57.8	7.8	27.9	-17.97	24
D.V.	54.9	36.0	37.5	-5.90	79.3	9.0	28.7	-31.36	30
Mean	51.3	37.7	38.1	-1.37	51.0	3.6	20.2	-11.44	22.7
S.D.±	5.3	1.33	0.57	3.23	12.5	6.4	6.5	9.12	4.77

Table 5: Body heat storage and mean body temperature using the caloric equivalant of Oxygen , Hardy and DuBois' (1937) and Kakitsuba Mekjavic's (1986)(ΔS), equations which are based on core - skin temperature and adiposity respectively. ΔT_r and ΔT_s represent the differences between initial and final rectal and skin temperatures respectively.

Subjects/ Condition	$\dot{V}O2$ l/min	Calorific kcal/°C	ΔTrectal °C	ΔTskin °C	Hardy's °C	Adiposity %	ΔS kcal
N.A/Hot	**2.14**	**166.9/2.94**	**1.8**	**4.0**	**2.90**	**20.4**	**195.60**
N.A/Cool	2.00	134.9/2.46	1.4	3.5	2.45	20.4	147.40
N.G/Hot	**1.78**	**158.0/2.67**	**1.1**	**3.5**	**2.30**	**28.0**	**154.05**
N.G/Cool	1.58	129.0/2.18	0.6	3.5	2.05	28.0	093.93
T.L/Hot	**2.39**	**150.8/2.51**	**1.0**	**3.9**	**2.45**	**19.8**	**132.96**
T.L/Cool	2.00	140.0/2.33	0.9	3.5	2.20	19.8	119.60
G.D/Hot	**1.94**	**152.2/2.27**	**0.9**	**4.1**	**2.50**	**20.1**	**139.58**
G.D/Cool	1.70	125.5/1.86	0.5	3.1	1.80	20.1	083.34
L.B/Hot	**1.90**	**161.2/3.16**	**2.3**	**3.8**	**3.05**	**21.6**	**224.90**
L.B/Cool	1.70	120.0/2.35	1.8	2.7	2.25	21.6	175.08
A.L/Hot	**2.33**	**178.1/2.48**	**1.1**	**3.8**	**2.45**	**31.7**	**208.62**
A.L/Cool	2.50	182.1/2.50	0.9	4.0	2.45	31.7	171.30
Mean/Hot	**2.08**	**161.2/2.68**	**1.4**	**3.8**	**2.61**	**23.6**	**175.95**
±S.D/Hot	**0.25**	**010.2/0.32**	**0.6**	**0.21**	**0.30**	**5.0**	**38.73**
Mean/Cool	1.91	138.0/2.28	1.0	3.38	2.20	23.6	131.84
±S.D/Cool	0.33	022.4/0.23	0.5	0.44	0.25	5.0	39.09

Table 6: *Changes in accumulated Respiratory Heat Exchange, Convection, Radiation, Evaporation and Weight loss during exercise under heat stress in six subjects breathing hot and cool air. Number of subjects in body weight changes is equal to eight.*

Subjects	HOT INHALATION				COOL INHALATION					
Initials	R H E Kcal	C kcal	R kcal	E kcal	WEIGHT kg	R H E kcal	C kcal	R kcal	E kcal	WEIGHT kg
N.A.	-2.68	-3.36	-2.33	-22.6	-1.03	-10.95	-3.78	-2.18	-28.22	-1.11
N.G.	+1.18	+2.49	+1:40	-1.44	-0.95	-4.79	-0.69	-0.45	-1.31	-1.20
T.L.	-1.80	-2.45	-1.67	-13.6	-1.53	-7.86	+5.03	+3.15	00.00	-1.53
G.D.	+1.74	+3.67	+2.17	-0.90	-0.80	-6.62	+3.14	+1.59	00.00	-0.92
L.B.	+1.52	+6.06	+4.06	00.00	-1.00	-7.13	-0.90	-0.81	-5.95	-1.05
A.L.	-5.95	-1.72	-1.12	-22.7	-0.89	-17.97	-2.36	-1.58	-21.00	-1.06
P.J.					0.84					-0.97
D.V.					1.00					-2.80
Mean	-1.37	0.78	0.42	-10.20	-1.00	-11.44	0.07	0.00	-9.4	-1.33
S.D.±	3.23	3.8	2.5	10.8	0.23	9.12	3.35	2.01	12:2	0.62

Fig. 9: Enhanced changes of rectal temperature during thirty minutes of recovery on six occasions in thermally stressed subjects at rest after ceasing exercise while surrounded by neutral environment. The inset figure at the right shows an enlargement of the lowest line of the main figure.

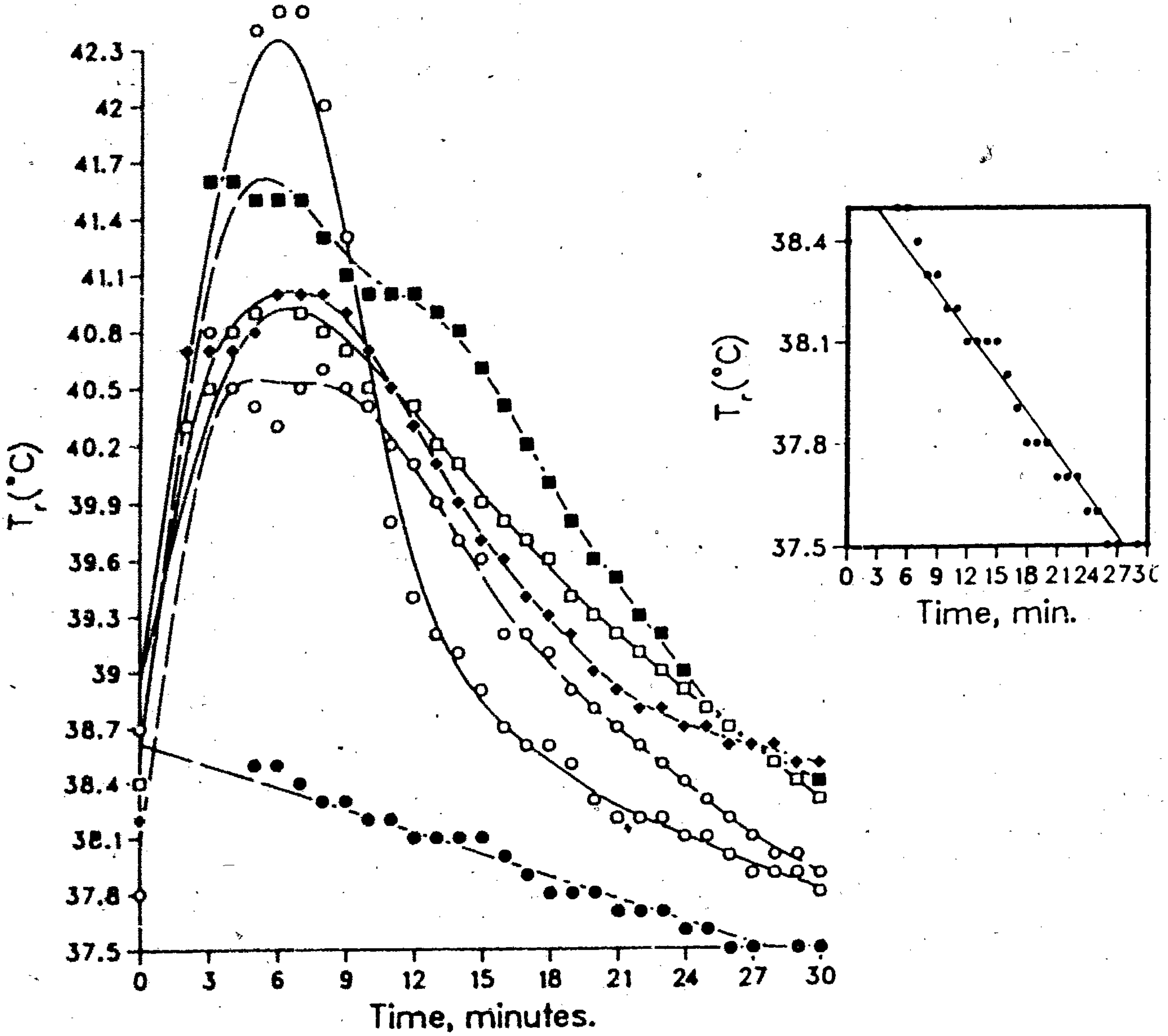
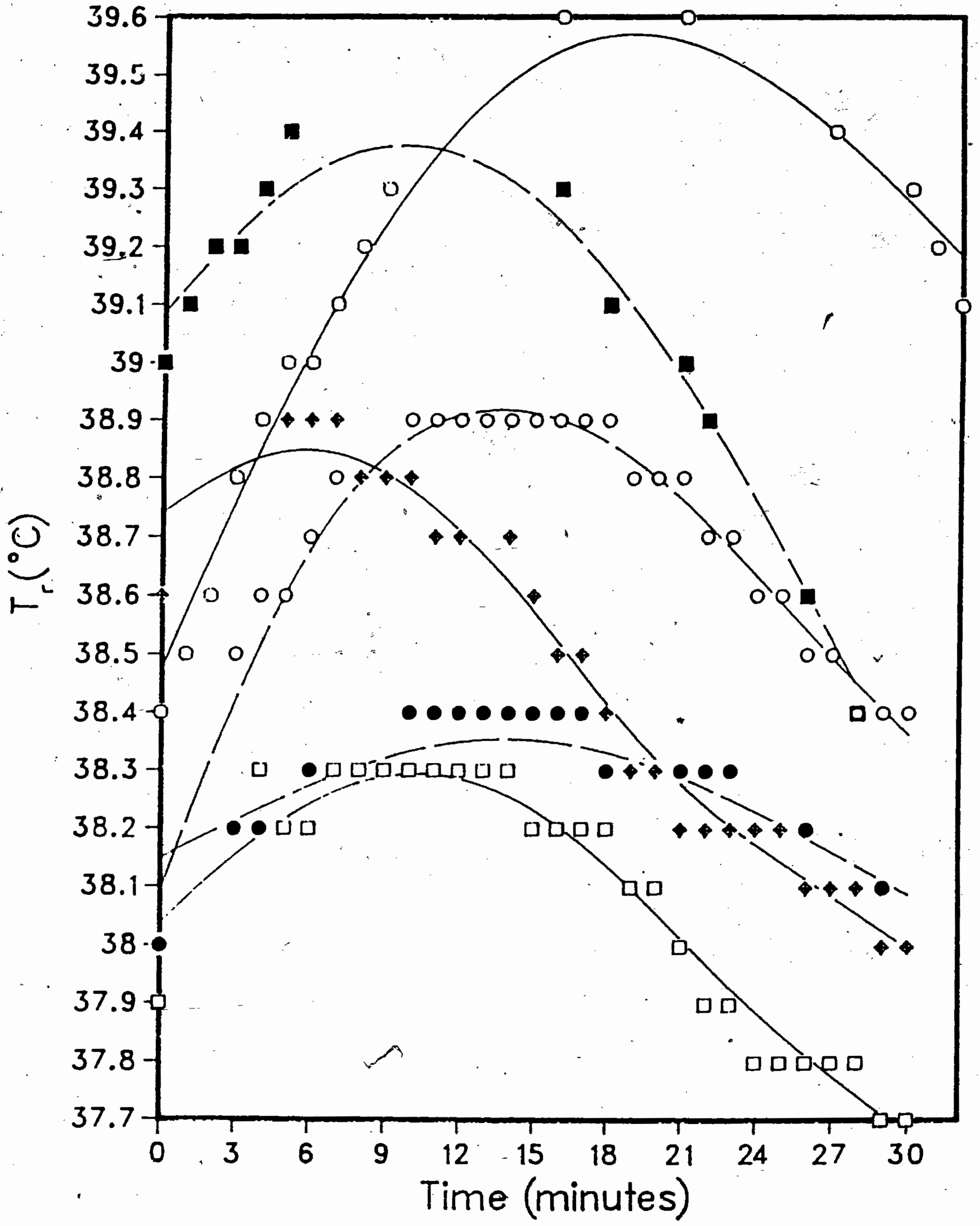

T_r(°C)
42.3
42
41.7
41.4
41.1
40.8
40.5
40.2
39.9
39.6
39.3
39
38.7
38.4
38.1
37.8
37.5
0
3
6
9
12
15
18
21
24
27
30
Time, minutes.
T_r(°C)
38.4
38.1
37.8
37.5
0 3 6 9 12 15 18 21 24 27 30
Time, min.

Fig. 10: Diminished changes of rectal temperature during thirty minutes of recovery on six occasions in thermally stressed subjects at rest after ceasing exercise surrounded by a thermally neutral environment


39.6
39.5
39.4
39.3
39.2
39.1
39
38.9
38.8
38.7
38.6
38.5
38.4
38.3
38.2
38.1
38
37.9
37.8
37.7
T_r(°C)
0
3
6
9
12
15
18
21
24
27
30
Time (minutes)

6. DISCUSSION

6.1 Rectal temperature

The present study supports the hypothesis that cool air inhalation under heat stress reduces the rectal temperature and this is in agreement with Lind's findings (1955). The mean group value of rectal temperature was significantly diminished by cool air respiration under hot humid ambient conditions. The rectal temperature difference between hot and cool gas inhalation was significant ($p \leq 0.002$), from the fourth minute of exercise onwards and was greatest (+0.4 °C) during the last minute of the work task (Fig.1). Subject T.L., Fig. 7, attained a final rectal temperature difference of 0.1 °C. breathing cool gas even though the ambient temperature under hot inhalation was 3.2 °C. higher than under cool inhalation. Curiously during cool inhalation this subject's rectal temperature showed an initial decrease of -0.1 °C. This decrease is supported by previous research, (Aikas et al, 1962; Baker and Chapman, 1977) and has been attributed to an acute heat redistribution from the core to the periphery. Probably for similar reasons the rectal temperature remained at a plateau for the first 2-7 minutes of exercise in all the subjects. Exercise induced diversion of blood flow from the viscera coupled with the facts that the structures of the pelvis have a great heat capacity, are efficiently insulated and have relatively poor circulation could explain such delays. Murray-Smith, et al. (1984) criticized the use of rectal temperature during steady-state exercise as an indicator of change in core temperature since conductance is not homogenous throughout human tissue.

6.2 Respiratory Heat Exchange (RHE)

The respiratory system does not play a prominant role in overall heat exchange in humans. Its minor role is indicated by the fact that a RHE mediated heat gain is almost impossible even in hot environments. This is shown in table 4, for subjects N.A, T.L., A.L., D.V., where core temperature rose above ambient temperature during steady state work elevating expired air temperature and initiating a heat loss. In the present study, during cool air inhalation the expired air was only around 50% saturated thus conserving thermal energy. This finding is in agreement with the work of Ferrus et al. (1984) and suggests that a number of studies which assume that the expired air is fully saturated even during cold air inspiration, (Deal et al, 1979; Hoke et al, 1976) should be reinterpreted more carefully. The ability of the respiratory system to protect itself from excessive heat gain or loss complies with the principle of regulated morphogenesis whereby the formation of structural elements of the body is regulated to satisfy, but not to exceed, the requirements of the functional system (symmorphosis), Taylor and Weibel (1981).

Although RHE during cool air inhalation evoked an 8 fold increase in heat loss, the decrease of rectal temperature under these conditions is not totally attributable to these losses. The average 10.1 kcal difference in RHE between hot and cool inhalation is only equivalant to a 0.165 °C rectal reduction breathing cool air compared with the actual temperature of 0.36 °C during the period of exposure as shown in table 5.

6.3 Oxygen consumption and Respiratory frequency

Table 5 shows that oxygen uptake was slightly, but insignificantly ($p \leq 0.10$), decreased, (−0.170 l·min^{-1}) during cool air inhalation. Some speculation on this may be appropriate since only a 100 ml·min^{-1} decrease in oxygen uptake is needed to explain the discrepancy observed between respiratory heat loss and rectal temperature difference between cool and hot air respiration. Such a small decrease in oxygen uptake however might imply a remarkable thermogenic reduction. Specifically, the equivalent core temperature decrease of this oxygen uptake decrement is 0.22 °C for the period of exposure.

It is known that ambient temperatures above the thermoneutral zone exert a definite thermogenic effect in mammals at rest, (Fellows et al, 1984; Johnson and Elizondo, 1974). An upward oxygen uptake "drift" during prolonged exercise at a constant workrate has also been noted at normal temperatures by Saltin and Stenberg (1964) and under heat stress by MacDougall et al. (1975) and Rowell et al. (1969). Furthermore, Happ et al. (1949) showed that oxygen requirements for a given amount of work may be reduced by applying abdominal cold packs during exercise. It is possible that the decreased stress and metabolic heat production observed in the present study under cool inhalant gas breathing could have been caused by reduced respiratory muscle work as evidenced by the significantly lower respiratory frequency, during cool gas breathing ($p \leq 0.004$) shown in Table 3 and figure 9, as Kruk et al. (1985) also found.

See (1983) and See (1976) also demonstrated the ability of a non-specific hypothalamic site responsible for temperature regulation to deliver sufficient input to the respiratory rhythm generator in the absence of all chemical afferent stimuli. Moreover, Philips and Jennings (1973) induced panting in conscious dogs by increasing ambient temperature or directly by increasing the temperature of the anterior hypothalamus. Almost identical results were also recently reported by Kaminski et al. (1985) in ponies which thermally are a similar species to the human. These authors found that respiratory frequency was about 300% above normal in response to elevation in ambient temperature.

Jennings et al. (1973) pointed out that oxygen uptake is diminished at a lower tidal volume in resting awake dogs. Moreover Hales and Dampney (1975) showed that in exercising dogs only 0.8% of the cardiac output perfused the leg skin whereas that going to the nasobuccal area and to respiratory muscles was 3% and 17% of the total respectively. Additionally in hypeventilating dogs, Baile et al., 1985 found that airway blood flow could approach the value of 7% of the whole circulatory volume.

In humans, an increase in core temperature is accompanied by an increase in minute ventilation, Hanson (1974), Walker et al. (1961), and Cotes (1955). In resting man passive elevation of body core temperature leads to rapid, shallow breathing, (Peterson and Vejby-Christensen, 1977; Hey et al, 1966)

During prolonged exercise, at a constant pulmonary ventilation, respiratory frequency increased as core temperature increased (Martin et al. 1979). Moreover, Totel (1974) during examination of the physiological response to heat of a sweating-impaired resting man, found that body temperature and panting were linearly correlated. Oxygen uptake was also remarkably increased.

At rest about 2% of the oxygen uptake is required for respiratory work. During hard exercise, however, 20% of the oxygen uptake is directed for respiratory work, Shepard (1966), and Schmidt and Thews (1983). Some researchers have reported that oxygen consumption of the respiratory muscles is so high during exercise that it reduces the efficency of the work by some 7%-10%, (Whittow and Findlay, 1968; Campbell _et_ _al_., 1959; Fritts _et_ _all_., 1959; McKerrow and Otis 1956). Consequently, panting may, under some circumstances, contribute to the enhancment of heat stress in man, (Totel 1974). In summary, therefore, cool air inhalation may indirectly affect oxygen uptake by reducing hypothalamic temperature which, in turn, inhibits input to respiratory centers and produces a decreased respiratory rate.

It should be emphasized that this proposed schema is relatively simplistic. Body cooling is associated with a lower lactacidemia (Kruk _et_ _al_., 1985), and an attenuated tachypnoea and hyperpnoea which all affect chemical control of respiration. Interaction between chemical and thermal drives to respiration during heat stress has been thoroughly reviewed by See (1984), Leigh (1984), Strange-Petersen and Vejby-Christensen (1977), and Jackson (1971). The thermoregulatory and chemical drive to ventilation thus may be said to compete for the use of the respiratory system according to the urgency of their specific requirments. Experimental findings show:

1. Hypercapnia and hypoxia inhibit thermal panting while hypocapnia enhances panting.
2. Chemosensory afferents do not completely override a hypothalamic drive on respiration under, heat stress.

A recent report complicating the mechanism of respiratory control proposed above, has demonstrated a bradypnea induced by cooling the blood in the pulmonary arteries causing speculation on the existence of localized tone receptors being susceptible to temperature changes, (Ledsome _et_ _al_., 1985).

6.4 Individual differences in respiratory frequency

The similarity of variations in respiratory frequency in all subjects during work in hot, humid ambient conditions breathing either hot or cool air shows that the stimulus causing the respiratory response is identical but of different intensity, (see for example subjects L.B., T.L., Fig. 9).

In subjects N.G., T.L., and A.L. respiratory frequency remained unchanged during the first 5–10 minutes. Such a lag in the onset of any divergence in the time course of respiratory frequency between the hot and cool inhalant gas breathing conditions may be due to hypothalamic delay in appreciating temperature changes occuring in the rectum, Baker (1982). Moreover, Nakayama et al. (1963) pointed out that hypothalamic heating produces an increased neural excitatory frequency in the preoptic region which is not followed by an immediate change in respiratory rate. Subject G.D. presented a puzzling feature because his breathing rate was almost identical under both experimental treatments although his core temperature underwent a sharp reduction during cool air inhalation. Finch and Robertshaw (1979) and Baker, (1984) reported that excess dehydration may reduce water loss from sweating but increase the rate of panting, in order to keep the brain cool despite a concominant core temperature rise. In the present study, cool air inhalation resulted in greater fluid losses in all the subjects. However, G.D. was not exceptionally dehydrated. Thus, the latter results are either due to experimental error or temperature is not the single factor determining respiratory behaviour under heat stress. In fact, Iscoe et al.. (1983) and Jennings et al. (1973) found that not all the dogs acutely exposed to heat stress will change from a non-panting to a panting respiratory pattern.

6.5 Heart rate

In no instance did any subject reach a steady-state in heart rate under either method of working despite the submaximal nature of the work task, (Fig. 4-8). Pooling of a large portion of the blood flow in the skin tissue necessary for heat dissipation combined with a large hyperaemia of the exercising muscles probably induced a decreased stroke volume. Thus, heart rate continued rising in order to compensate for this stroke volume decrement and maintain cardiac output constant (MacDougall et al., 1974; Rowell et al., 1966). The final group mean heart rate attained under cool air inhalation was significantly lower, ($p \leq 0.05$), than under hot air inhalation. It reached a maximum slope of 22.5 beat $\cdot min^{-1} \cdot {}^{\circ}C^{-1}$. An increased body temperature decreases the duration of heart action potentials pontentially introducing a rise in heart rate, Schmidt and Thews (1983). However, changes in body temperature seem to have an even more drastic effect on the heart rate after complete autonomic blockade, (intrinsic heart rate). Jose et al. (1970) found a direct linear relationship between the intrinsic heart rate and the mixed venous blood temperature over the range from 35 °C to 40 °C during exercise (gradient 7.1 beat$\cdot min^{-1} \cdot {}^{\circ}C^{-1}$). It has also been reported that a rise in temperature elevates atrial pacemakers activity and weakens the contraction of the heart muscle (Blinks and Koch-Weser, 1963). The reduced rise in final heart rate during cool air inspiration could also be attributed to diminished pulmonary ventilation. When an increase in pulmonary ventilation is pronounced, heart rate usually accelerates (Berne and Levy, 1981).

During whole body cooling the heart rate response is exactly the opposite. It has been well established that hypothermia suppresses the positive chronotropia of catecholamines on the heart and enhances contractility (Chiba et al., 1976; Nayler and Wright, 1963). On the contrary, in the present study, heart rate was higher during the first 4–10 minutes of cool air inhalation than during the same period under hot air inspiration. It is likely however, that breathing cool air contributed to concomitant enhancement of heart rate and contractility of the myocardium. Aikas et al. (1962) found an initial decrease of esophageal temperature below 37 °C at the onset of exercise in hot environment, breathing ambient air. In the current investigation, esophageal temperature may have been drastically decreased at the onset of exercise by the additive effect of cool air inhalation. Thus, it may be suspected that coronary arteriole constriction and/or changes in collateral blood flow distribution occur. This may lead to a transient myocardium hypoxia which according to Jose and Stitt (1967) results in increases of both the intrinsic heart rate and myocardial contractility.

6.6 Losses of Body Fluids

As shown in table 4, subjects lost a remarkable amount of fluid during 23 minutes of exercise. These losses occurred through sweat gland activity and respiratory evaporation. Evaporation via sweating was almost impossible due to high, (95%), surrounding ambient humidity. Thus sweat glands were not effective in temperature regulation.

The maximum amount of water which may be lost via respiration in a favorable dry environment fluctuates about the value of 5 $g \cdot min^{-1}$, (Fanger 1972). Thus, weight reduction mainly occurred through direct water loss from sweat. In the present study, only a total of 6.4 g of water was lost through respiration during cool air inhalation. The former value is not in agreement with the prediction equation given by Mitchell et al. (1972). However, their work did not encompass any cool air breathing, during which conservation of heat becomes profound and they also did not take into account the respiratory frequency which varies inversely with water loss, (Ferrus et al. 1984).

During cool air inhalation 300 grams more water were lost which is not easy to explain, especially since only 1.15 grams could be directly attributed to enhanced respiratory loss, and the core temperature was reduced. Sato (1973) and Terada (1966) pointed out that adrenergic input increases total sweat output. It is possible that the excess water loss during cool air inhalation is caused by an elevated amount of norepinephrine, (unpresented data). The proposed etiology would parallel Ladell's (1964) conclusion that temperate-climate man readapts in tropical conditions by induction of a highly reactive endocrine system initially producing uneconomical sweat rates. Shephard (1982), stated that if the radiant heating was avoided, the hot dry climate of a desert would be tolerated much better than the hot wet climate of a jungle. The accuracy of the latter statement may be judged by comparing the 1 kg of water losses of the present experiment lasted 23 minutes with the 1 kg of water losses of another study executed under quite similar but dry condition which lasted 60 minutes (Fortney and Vorman, 1985).

6.7 Body Heat Storage

Since 1780, when Lavoiser introduced direct calorimetry (Lavoiser and Laplace 1892), many thermometric methods for determining body heat content have been established. In the present thesis an indirect calorific method to determine body heat content (BHC) during various phases of heat exposure has been compared with Hardy and DuBois (1937), and Kakitsuba and Mekjavic (1986). However, all of the above methods are subject to criticism due to many underlying assumptions.

For instance, the caloric equivalent of oxygen ignores the participation of anaerobic mechanism during heat generation attended by an inevitable redistribution of circulation, (Mitchell 1977). Hardy and DuBois (1937) oversimplified the heat storage concept when they considered that the human body consisted of two cylinders. Their model fails to incorporate the dynamic physiology by determining various coefficients of the equation only at rest. Nor does it account for individual differences. It is known that small subjects carry 58% of their body mass close to the periphery while obese ones carry less than 50% of their bulk within 2.5 cm of the epidermis. Kakitsuba-Mekjavic's (1986) concept of body heat content seems to be the most comprehensive because it allows for individual differences by incorporating measures of body adiposity into the predictive BHC equation. However, this model overlooks individual differences in terms of cardiovascular fitness. There are also problems attendant upon the accurate estimation of body surface area. Though more than ten equations for estimating surface area have been developed since DuBois and DuBois first worked out the problem in 1915 they are all flawed. The most commonly used, DuBois and DuBois (1916), is inadequate due to the extremely small number of subjects from whom the equation was derived. In the present study two recent methods were used to calculate body surface area, (Haycock et al. 1978, and Jones et al. 1985). The first one, based on height and weight, has been criticized for over-estimating the surface area of obese people and it does not take into account the thigh trunk distortion, (Jones et al. 1985). Thus only values derived by the Jones' equation have been reported in the current thesis. Although they used exclusively female subjects their average values of body surface area are similar to those of Haycock et al. (1978) . Nevertheless there are significant individual differences. For example subject's N.G. body surface area was variously estimated to be 1.92 m^2 (Haycock et al.) and 2.04 m^2 (Jones et al.). Using the first value in the Kakitsuba- Mekjavic equation, results in 143.27 kcal of heat storage while the second value results in 154.05 kcal. This difference is equivalant to a difference in the core temperature of 0.25 °C.

6.8 Effect of cool air inhalation treatment on performance

Increase in body temperature is one important limiting factor of physical performance, (Adams et al., 1975; MacDougall et al., 1974; Saltin et al., 1970). Other investigators managed to prolong exercise by maintaining diminshed elevation of body temperature, (Schmict and Bruck, 1981; Bruck et al., 1980; Bruck et al., 1978). Extrapolation of the above investigations implies that cool air inhalation could increase both total work output and endurance time. Indeed, most of the subjects stated that they felt that cool air respiration was beneficial and they would have been able to cycle longer. Their subjective impression was verified when two subjects cycled 15% longer during cool air inhalation at the investigator's request.

6.9 Rectal temperature during recovery

During the initial stages of body cooling from hyperthermia there was a continued accumulation of core heat shown as an after-rise in temperature, (Fig. 10 and 11). To the author's knowledge this phenomenon has not been reported previously. Although Baker (1982) and Aikas et al. (1962) show in various figures of their individual papers a tendency for rectal temperature to rise after withdrawing heat and exercise stimuli neither comment on the phenomenon. In the present study a rise in temperature (41°C - 44°C) subsequent to the end of the experiments was recorded in various subjects. Such a rise is a paradox.

Accompanying an increased body temperature a large proportion of cardiac output is directed to the skin (Rowell 1974). However, the rate of increase in heat loss from the hand is reduced by increasing the intensity of exercise (Hirata <u>et</u> <u>al</u>., 1983) due to supressed vasodilation (Hirata <u>et</u> <u>al</u>. 1984). Nielsen <u>et</u> <u>al</u>. (1984) found attenuation in forearm blood flow above 38°C in core temperature. Therefore, at the end of exercise most probably there was a shift of blood flow to the body core insulating the center from the periphery thus trapping metabolic heat. Skin cooling of previously heated subjects causes further veno-constriction at a time when tissue temperatures are still very high (Rowell 1974), resulting in excessive return of hot blood to the core. This explanation is challenged by a recent controversial study which shows that during passive heating a further pronounced increase in flow occurred in both hands (Henriksen <u>et</u> <u>al</u>. 1984). An alternative theory analogous to Savard's <u>et</u> <u>al</u>. (1985) explanation of after-drop in hypothermia is that the core gains heat via conduction from the intermediate hottest muscular tissue. Regardless of the exact mechanism however high elevation of rectal temperature may be a life threatening factor impairing liver function and inducing chemical changes in the blood. The degree of possible danger and the aetiology of this needs further research in order to develop, if possible, an alternative cooling method after ceasing exercise in hot environments.

7. REFERENCES

Adams WC, Fox RA, Frey AJ, McDonald IC (1975) Thermoregulation during marathon running in cool moderate and hot environments. J Appl Physiol 38:1030-37

Aikas E, Karvonen MJ, Phronen P, Ruosteenoja R (1962) Intramuscular, rectal and oesophageal temperature during exercise. Acta Physiol Scand 54:366-370

American Thoracic Society (1962) Defination and classification of chronic bronchitis, asthma and pulmonary enphysema. Am Rev Resp Dis 85:762-68

Baile EM, Dahlby RW, Wiggs BR, PD Paré (1985) Role of tracheal and bronchial circulation in respiratory heat exchange. J Appl Physiol 58(1): 217-222

Baker MA (1982) Brain cooling in endotherms in heat and exercise. Am Rev Physiol 44:85-96

Baker MA (1984) Influence of dehydration on thermoregulation in panting mammals. In Thermal Physiology (ed) Hales JRS. Raven Press, N.Y.

Baker MA, Chapman L (1977) Rapid brain cooling in exercising dogs. Science 195:781-783

Baltrop D (1954) The relation between body temperature and respiration. J Physiol (London) 125:19-20

Berne RM, Levy MN (1981) Cardiovascular Physiology. Fourth edition. CV Mosby Company

Blinks JR, Koch-Weser J (1963) Physical factors in the analysis of the actions of drugs on myocardial contractility. Pharmacological Reviews 15:531-599

BMDP (1981). Statistical software UCLA, California, 90024

Braithwaite W (1972) The calculation of minimum safe inspired gas temperature limits for diving. Report 12-72, U.S Navy Expiremental Unit, Wash D.C.

Brebbia D, Golman R, Buskirk E (1957) Water vapor loss from the respiratory tract during outdoor exercise in the cold. J Appl Physiol. 11(2):219-222

Bruck K, Bahner E, Kranning B, Neuman G (1978) Aerobic work capacity in relation to mean body temperature and thermoregulatory effort, (abstract). Pfluegers Arch 377:R31

Bruck K, Bahner E, Kranning B, Neuman G (1980) Exercise preformance and adaptive modifications in the thermoregulation system. In: The proceedings of the 8th International Biometeorogical Congress (Israel, 1979). Netherlands:Snets and Zeitlinger

Burton A (1935) Human calorimetry - II. The average temperature of the tissues of the body. J of Nutrition 9(3):261-280

Campbell EJM, Westlake E, Cherniack R (1959) The oxygen consumption and efficiency of respiratory muscles of young males subjects. Clin Scin 18:55-65

Chiba S, Simmons TW, Levy MN. (1976) Effects of temperature on norepinephrine induced sinus accelaration and overdrive suppression in the isolated dog atrium. Japanese Heart Journal, 17:656-662,

Cole P (1953) Further observations on the conditioning of respiratory air. J Laryngol Otol 67:669-81

Cole P (1954) Recordings of respiratory air temperature. J Laryng and Otol 68:295

Cotes JE (1955) The role of body temperature in controlling ventilation during exercise in one normal subject breathing oxygen. J Physiol (London) 129:554-563

Costill D (1977) Fluids for athletic performance. In the new runners diet. Mountain view. Cal. World publ

Davies C (1979) The effect of different levels of heat production induced by diathermy and eccentric work on thermoregulation during exercise at given skin temperature. Eur J Appl Physiol 40:171-180

Deal E,jr, McFadden E,jr, Ingram R,jr, Jaeger J (1979) Esophageal temperature during exercise in asthmatic and nonasthmatic subjects. J Appl Physiol 46:484-90

Deal E,jr, McFadden E,jr, Ingram R,jr, Strauss R, Jaeger J (1979) Role of respiratory heat exchange in production of exercise produced asthma. J Appl Physiol. 46(3):467-475

Deal E,jr, McFadden E,jr, Ingram R,jr, Jaeger J (1979) Hyperpnea and heat flux:initial reaction sequence in exercise induced asthma. J Appl Physiol 46(3):476-484

DuBois D and DuBois EF (1915) The measurement of the surface area of man. Archs Intern Med 15:868-881

DuBois D and DuBois EF (1916) Clinical Calorimeter. A formula to estimate the approximate surface area if height and weight be known. Archs Intern Med 17(Part II) :863-871

Drinkwater DT (1984) An anatomical derived method for the anthropometric estimation of human body composition. Ph.D thesis Simon Fraser University

Falls B (1969) Circulatory response to cold showers: effect of varied time lapses before exercise. Res Quart 40:45-49

Fanger P (1972) Thermal comfort - Analysis and applications in environmental engineering. McGraw-Hill book Comp

Faulkner J, White T, Markley J (in press) The 1979 Canadian ski marathon: A natural experiment in hypothermia. In Balke Symposium Proceedings.Nagle F.C. Thomas, Springfield

Fellows I, Bennet T, Macdonald I (1984) Influence of environmental temperature on the thermoregulatory responses to ethanol. In Thermal Physiology (ed) by Hales JRS, Raven Press, N.Y.

Ferrus L, Commenges D, Gire J, Varene P (1984) Respiratory heat loss as a function of ventilatory or environmental factors. Resp Physiol 56:11-20

Ferrus L, Guenard H, Vardon G, Verene P (1980) Respiratory water loss. Resp Physiol 39:367-81

Finch V, Robertshaw D (1979) Effect of dehydration on thermoregulation in elend and hartbeest. Am J Physiol 237:R192-R196

Flyn E, Vorosmart J, Modell H (1974) Temperature requirements for the maintenance of the thermal balance. Navy Experimental Unit, Washington D.C..

Fortney S, Vroman N (1985) Exercise, Performance and Temperature Control: Temperature regulation during exercise and implications for sports performance and training. Sports Medicine 2:8-20

Fritts H, Filler jr. J, Fishman A, Cournand A (1959) The efficency of ventilation during voluntary hyperpnea: studies in normal subjects and in dyspneic patients with either chronic pulmonary emphysema or obesity. J Clin Invest 38:1339-1348

Gagge P, Hardy J, Rapp G (1969) Proposed standard system for thermal physiology. J Appl Physiol 27:439-446

Gorlin R (1966) Physiology of the coronary circulation. In: The heat (ed) Hurst J, Logan R McGraw Hill N.Y 653-58

Guleria J, Talwar J, Malhotra O, Pande J (1969) Effect of breathing cold air on pulmonary mechanisms in normal man. J Appl Physiol 27(3):320-22,

Hales JRS, Dampney A (1975) The redistribution of cardiac ouput in the dog during heat stress. J Therm Biol 1:29-34

Hanson G (1974) Respiratory heat loss at increase core temperature. J Appl Physiol 37(1):103-107

Happ P, Tuttle W, Wilson M (1949) The physiologic effect of abdominal cold packs. Res Quart 20:153-159

Hardy J (1939) The radiatory power of human skin. Am J Physiol, 127:454-62

Hardy J, DuBois E (1937) Basal metabolism, radiation, convection and vaporization at temperatures of 22 to 35 °C J of Nutrition 15(5):477-479

Hartung H, Myhre L, Nunnely S (1980) Physiological effects of cold inhalation during exercise. Aviat Space Envir Medicine 1(6):591-594

Haycock GB, Schwartz GJ, Witosky DH (1978) Geometric method of measuring body surface area: A height-weight formula validated in infants, children and adults. J Paediatr 93:62-66

Henriksen O, Bulow J, Kristensen JK, and Lassen N.A (1984) Local tissue temperature: An important factor for regulation of blood flow in peripheral tissues during indirectly induced hyperthermia. In Thermal Physiology (ed) by Hales JRS Raven press N.Y.

Hey EN, Lloyd BB, Cunningaham DJ, Jukes NG, and Bolton DP (1966) Effects of various respiratory stimuli on the depth and frequency of breathing in man. Resp Physiol 1:193-205

Hirata K, Nagasaka T, Hirai A, Hirashita M, and Takahata T (1984) Suppression of finger vasodilator response during exercise in proportion to its intensity. In Thermal Physiology (ed) by Hales JRS Raven press N.Y.

Hirata K, Nagasaka T, Hirai A, Hirashita M, and Takahata T (1983) Peripheral vascular tone during heat load is modified by exercise. Eur J Appl Physiol

Hodgman C (1965) Handbook of Chemistry and Physics Cleveland Chemical Rubber Co.

Hoke B, Jackson D, Alexaner J, Flyn E (1976) Respiratory heat loss and pulmonary functions during cold gas breathing at high pressures. In Underwater Physiology (ed) Lambertsen C. Bethesda FAESB

Holman J (1976) Heat transfer. McGraw Hill 4th edition pp 503

Hsieh V, Frayser R, Ross J (1968)The effect of cold air inhalation on ventilation in normal subjects and in patients with obstructive pulmonary diseases. Am Rev Resp Dis 98:613-22

Ingelstedt S (1956) Studies on the conditioning of air in the respiratory tract. Acta Oto-Laryngol Supl 131:1-74

Iscoe S, Young R, Jennigs D (1983) Control of respiratory pattern in conscious dogs: effect of heat and CO_2. J Appl Physiol 54:623-631

Jackson D (1971) The effect of temperature on ventilation in the turtle, Pseudemys scripta elegans. Resp Physiol 12:131-140

Jaeger J, Deal E,jr, Roberts D, Ingram R,jr, McFadden E, jr, (1980) Cold air inhalation and esophageal temperature in exercising humans. Med and Sci in Sports and Exer 12(5):365-69

Jennigs DB, Chen C, Philips H, Sparling J (1973) Respiration and metabolism in panting and non panting. J Appl Physiol 35:490-496

Jennings D, Phillips H, Chen C, and Sparling J (1973) Cardiovascular function in panting and nonpanting resting conscious dogs. Am J Physiol 225:700-705

Johnson GS, Elizondo RS (1974) Eccrine sweat gland in macaca mullata:physiology, histochemistry and distribution. J Appl Physiol 37(6):814-820

Jones PRM, Wilkinson S, Davies PSW (1985) A revision of body surface area estimation. Eur J Appl Physiol 53:376-379

Jose AD, Stitt F (1967) Cardiac function after combined beta adrenergic and cholinergic blockade: relationship of intrinsic rate to contractile force of the heart in dogs. Circ Res 20 and 21 (Suppl. III):231,

Jose AD, Stitt F, Collison D (1970) The effects of exercise and changes in body temperature on the intrinsic heart rate in man. Am Heart J 79(4):4488-498

Kakitsuba N, Mekjavic IB (1986) Determination of the rate of storage of body heat incorporating body composition.(in press)

Kaminski R, Rorster H, Bisgard G, Pan L, Dorsey S (1985) Effect of altered ambient temperature on breathing in ponies. J Appl Physiol 58(5):1585-1591

Kerslake D (1972) The stress of hot environments. Cambridge University Press

Kruk B, Kaciuba - Uscilko H, Nazar K, Greenleaf J, Kozlowski S (1985) Hypothalamic, rectal, and muscle temperatures in exercing dogs: effect of cooling. J Appl Physiol 58(5):1444-1448

Ladell W (1964) Terrestrial animals in humid heat: man. In Adaption to the environment (ed) Dill D section 4:541-550. American Physiological Society Washington D.C.

Lavoisier AL, Laplace PS (1892) Abhandlung uber die Warme, (first published 1780). In Rosental L (ed) Zwei Abhandlungen uber die Warme Leipzig. Wilhelm Engelmann

Ledsome JR, Kan WO, Bolter CP (1981) Respiratory and cardiovascular response to temperature changes in the perfused pulmonary arteries of the dog. Can J Physiol Pharmacol 59:439-499

Leigh J (1984) Dynamic mathematical models of the interaction between the thermoregulatory system and the chemical respiratory control in mammals. In Thermal Physiology (ed) Hales JRS Raven Press N.Y.

Lind R (1955) The influence of inspired air temperature on tolerance to work in the heat. Br J Ind Med 12:126-130

Martin BJ, Morgan EJ, Zwillich CW Weil JV (1979) Influence of exercise hyperthermia on exercise breathing pattern. J Appl Physiol 47(5):1039-1042

McCutchan J, Taylor C (1951) Respiratory heat exchange with varying temperature and humidity of inspired air. J Appl Physiol 31:121-135

McDougall JD, Reddan WG, Layton CR, Dempsey JA (1974) Effects of metabolic hyperthermia on performance during heavy prolonged exercise. J Appl Physiol 36(5):538-544

McKerrow C, Otis A (1956) Oxygen cost of hyperventilation. J Appl Physiol 9:375-379

McFadden ER, Pichurko BM, Bowman HF, Ingenito E, Burns S, Douling N, Solway J (1985) Thermal mapping of the airways in humans. J Appl Physiol 58(2):564-570

Millar J, Nairn J, Unkles R, McNeill R (1965) Cold air and ventilatory function. Br J Dis Chest 59:23-27

Mitchell D (1977) Physical basis of thermoregulation. In Environmental Physiology II. International review of Physiology vol 15 (ed) Robertshaw D University Park press

Mitchell HH, Hamilton TS, Steggerda F, Bean H (1945) The chemical composition of the adult human body and its bearing on the biochemistry of growth. J Biological Chem 158(2):625-537

Mitchell J (1977) Energy exchange during exercise: Problems with temperature regulation during exercise, p. 11-26 (ed) Nadel E. Academic Press Inc

Mitchell J (1970) Measurements of the thermal emissivity of human skin in vivo. Physiological and Behavioral Temperature Regulation. (ed) Hardy JD, Gagge A, Stolwijk J, chap. 3, p. 25-33. Charles Thomas, Springfield Ill

Mitchell J, Nadel E, Stolwijk J (1972) Respiratory weight losses during exerise.J Appl Physiol 32(4):474-76

Moritz R, Weisiger R (1945) Effects of cold air on the air passages and lungs. Arch Int Med 75:233

Murray-Smith A, Stewart J, Cohen M (1984) Dependence of human physiological conductance on metabolic rate. In Thermal Physiology (ed) Hales JRS, Haven press N.Y.

Nakayama T, Hammel H, Hardy JD, Eisenman J (1963) Thermal stimulation of electical activity of single units of the preoptic region. Am J Physiol 204:1122

Nayler WG, and Wright JE. (1963) Effect of epinephrine on the mechanical and phosphorylase activity of normo- and hypothermic hearts. Circulation Research 13:199-206

Nielsen B (1969) Thermoregulation in rest and exercise. Acta Physiol Scand (suppl) 323:1-74

Nielsen B, Rowell L and Bonde-Petersen F (1984) Cardiovascular responses to heat stress and blood volume displayments during exercise in man. Eur J Appl Physiol 52:370-374

Nishi Y, Gagge A (1970) Direct evalution of convective heat transfer coefficient by naphthaline sublimation. J Appl Physiol 29(6):830-38

O' Cain C, Dowling N, Slutsky A, Hensley M, Strohl K, McFadden Ejr, Ingram Rjr (1980) Airway effect of respiratory heat loss in normal subjects.J Appl Physiol 49(5)875-880

Olesen BW (1984) How many sites are necessary to estimate a mean skin temperature?. Thermal Physiology, (ed) Hales JRS Raven Press N.Y.

Olesen BW, Fanger PO (1973) The skin temperature distibution for resting man in comfort. Arch Sci Physiol 27:A385-393

Peterson ES, and Vejby-Chistensen (1977) Effects of body temperature on ventilatory response to hypoxia and breathing pattern in man. J Appl Physiol 42:492-500

Pugh L (1967) Rectal temperatures, weight losses and sweat rates in marathon running. J Appl Physiol 23:347-72

Philips H Jennigs D (1973) Cardiorespiratory effect of hypothalmic heating in conscious dogs. Am J Physiol 225:700-705

Ramanathan N (1964) A new weighting system for mean surface temperature of the human body. J Appl Physiol 19(3):531-533

Ramson J (1977)Time course of bronchoconstrictive response in asthmatic subjects to reduced temperature. Thorax 32:26-28

Rapp G (1970) Convective mass transfer and the coefficient of evaporative heat loss from human skin. In Physiological and Behavioral Temperature Regulation (ed) Hardy JP, Gagge AP, Stolwijk AJ. Chap 6 Charles Thomas Ill

Rowell LB (1974) Human cardiovascular adjustments to exercise and thermal stress. Physiol Rev 54(1):75-159

Rowell LB, Marx B, Bruce R, Conn R, Kusumi F (1966) Reduction of cardiac output, arterial blood volume and stroke volume with thermal stress in normal men during exercise. J Clin Invest 45:1801-1816

Rowell LB, Brengelmann GL, Murray JA, Kranging II KK, Kusumi F (1969) Human metabolic response to hyperthermia during mild and maximal exercise. J Appl Physiol 26:395-402

Saltin B, Harmansen L (1966) Esophageal, rectal and muscle temperature during exercise. J Appl Physiol 21:1757

Saltin B, Stenberg J (1964) Circulatory responses to prolonged severe exercise. J Appl Physiol 28:538-544

Saltin B, Gagge A, Stolwijk A (1970) Body temperature and sweating during thermal transients caused by exercise. J Appl Physiol 28:318-327

Sato K (1973) Sweat induction from an isolated eccrine sweat gland. Amer J Physiol 225:1147-1151

Savard GK, Cooper KE, Veale WL, Malkinson TJ (1985) Peripheral blood during rewarming from mild hypothermia in humans. J Appl Physiol 58(1):4-13

Schmidt V, Bruck K (1981) Effect of a precooling maneuver on body temperature and exercise performance. J Appl Physiol 50(4) 772-778

Schmidt RF, Thews G (1983) Human Physiology. Springer-Verlag, Berlin-Heidelberg-N.Y.

See W (1976) Respiratory drive in hyperthermia, interaction with central chemosensitivity. In : Acid base homeostasis of the brain extracellular fluid and the respiratory control system (ed) Loeschcke H, p.p.122-129 Thieme Stuttgardt

See WR, Schlaefke ME and Loeschke HH (1983) Role of chemical afferents in the maintance of rhythmic respiratory movements. J Appl Physiol 54(2):453-459

See WR (1984) Interactions between chemical and thermal drives to respiration during heat stress. In Thermal Physiology, (ed) Hales JRS. Raven Press N.Y.

Seely L (1940) Study of changes in the temperature and water vapor content of respired air in the nasal cavity. Heating Piping and Air Conditioning 12:377

Shephard R (1966) The oxygen cost of breathing during vigorous exercise. Quart J Exp Physiol 51:336-350

Shephard R (1982) Physiology and Biochemistry of Exercise. Praeger publishers N.Y.

Sohal R, Sun S, Colcolough H, Burch G (1968) Heat stroke: an electron microscopic study of endotheliac cell and dissiminated intravascular coagulation. Arch Intern Med 122:43-47

Spitler D, Horath S, Koboyashi K, Wagner J (1980) Work performance breathing normoxic Nitrogen or Helium mixtures. Eur J Appl Physiol 43:157-166

Strange-Petersen E, Vejby-Christensen H (1977) Effects of body temperature on ventilatory response to hypoxia and breathing pattern in man. J Appl Physiol 42:492-500

Taylor CR and Weibel ER (1981) Design of the mammalian respiratory system. I.

Problems and strategy. Resp Physiol 44:1-10

Terada E (1966) Effects of adrenaline on human sweating. J Physiol Society (Japan), 28:176-184

Totel G (1974) Physiological responses to heat of resting man with impaired sweating capacity. J Appl Physiol 37(3):346-352

Walker J, Wells R, Merrill E (1961) Heat and water exchange in the respiratory tract. Amer J of Med Feb:259-67

Weast R. (1976) Handbook of Chemistry and Physics by CRC press

Webb P (1955) Heat loss from the respiratory tract in cold. Arctic Aeromedical Laboratory Alaska

Wells R jr, Walker J, Hickler R (1960) Effects of cold air on respiratory airflow resistance in patients with respiratory tract disease. N Engl J Med 263:268-73

Whittow G, Findlay J (1968) Oxygen cost of thermal panting. Am J Physiol 214:94-99

8. APPENDIX 1

8.1 Raw Data

Raw data for eight healthy subjects exercising in hot-humid environment breathing cool and hot air. Treat, Tski, Tamb, Tcor, VO2, H.R., W represent type of treatment, skin temperature, ambient temperature, rectal temperature, oxygen consumption, heart rate, and weight respectively. Treatment 1 corresponds to hot air inhalation and treatment 2 corresponds to cool air inhalation. Subjects are listed in the following order: 100 - N.G, 101 - N.A. 102 - D.V., 103 - P.J., 104 - A.L., 105 - L.B., 106 - G.D., 107 - T.L.

Subj	Treat	Time	Tsk	Tamb	Tcor	VO2	H.R	W
100	1	01	36.2	38.9	36.9		114	73.15
100	1	03	36.0	39.0	36.9	1.9	134	
100	1	05	37.3	38.4	37.0	1.8	145	
100	1	07	37.7	38.8	37.1	1.8	148	
100	1	09	38.0	38.6	37.1	1.9	153	
100	1	11	38.2	38.8	37.2	1.8	158	
100	1	13	38.5	39.1	37.3	1.9	168	
100	1	15	38.9	39.0	37.4	1.9	167	
100	1	17	39.0	39.1	37.5	1.9	167	
100	1	19	39.3	39.2	37.7	1.9	176	
100	1	21	39.5	39.3	37.8	2.0	172	
100	1	23	39.7	39.4	38.0	1.8	182	72.20
100	2	01	36.0	37.5	37.2	1.6	164	73.55
100	2	03	36.7	37.7	37.2	1.7	147	
100	2	05	37.1	37.9	37.2	1.6	150	
100	2	07	37.5	37.9	37.2	1.6	153	
100	2	09	38.0	37.8	37.3	1.6	161	
100	2	11	38.3	37.7	37.3	1.6	162	
100	2	13	38.5	37.9	37.4	1.6	167	
100	2	15	38.7	38.4	37.5	1.6		
100	2	17	38.9	38.5	37.5	1.6	170	
100	2	19	39.0	38.9	37.6	1.6	173	
100	2	21	39.3	38.9	37.7	1.6		
100	2	23	39.5	38.4	37.8	1.6		72.35
101	1	01	36.2	37.4	37.2	2.2	141	70.15
101	1	03	36.9	37.5	37.3	2.2	148	
101	1	05	37.5	37.4	37.4	2.6	158	
101	1	07	37.9	37.7	37.5	2.4	161	
101	1	09	38.3	37.5	37.7	2.1	167	
101	1	11	38.6	37.6	37.8	2.1	173	
101	1	13	38.6	37.6	38.0	2.0	173	
101	1	15	39.1	37.7	38.2		173	
101	1	17	39.3	37.8	38.4	2.3	176	

101	1	19	39.6	37.8	38.6	2.3	178	
101	1	21	39.8	37.9	38.7	2.4	180	
101	1	23	40.0	37.9	38.9	2.1	180	
101	1	24	40.1	38.0	39.0	2.0	180	69.12
101	2	01	36.1	37.2	37.1	2.0		69.60
101	2	03		37.1	37.1		145	
101	2	05	37.5	37.2	37.1	2.0	148	
101	2	07		36.9	37.2		150	
101	2	09	38.0	36.9	37.3	2.0	161	
101	2	11		36.7	37.4		161	
101	2	13		37.1	37.5	2.0	167	
101	2	15	38.6	37.4	37.7		170	
101	2	17		37.4	37.8	2.0	167	
101	2	19	39.1	37.7	38.0		170	
101	2	21		37.8	38.2	2.0	173	
101	2	23		38.1	38.4			
101	2	24	39.7	38.2	38.5	2.0	176	68.49
102	1	01	35.2	36.0	37.1	1.9	108	65.80
102	1	03	35.5	35.7	37.1	1.9	125	
102	1	05	35.9	35.9	37.1	2.1	137	
102	1	07	36.4	35.8	37.2	1.6	135	
102	1	09	36.8	35.9	37.2	2.0	145	
102	1	11	37.2	35.8	37.3	2.0	150	
102	1	13	37.5	36.1	37.4	2.1	152	
102	1	15	37.8	36.1	37.5	2.1	157	
102	1	17	38.1	36.1	37.6	2.1	158	
102	1	19	38.3	36.4	37.7	2.0	155	
102	1	21	38.5	36.5	37.8	1.9	158	
102	1	23	38.8	36.5	38.0	2.2	160	
102	1	25	39.1	36.6	38.1	2.2	168	
102	1	27	39.3	36.6	38.3	2.2	171	
102	1	29	39.4	36.5	38.5	2.2	170	
102	1	30	39.6	36.7	38.6	2.1	167	64.80
102	2	01	35.0	35.2	37.3			66.80
102	2	03	35.2	35.0	37.3			
102	2	05	35.9	35.3	37.3		138	
102	2	07		35.4	37.3		140	
102	2	09	36.7	35.1	37.4		141	
102	2	11	36.9	35.2	37.5	3.6	141	
102	2	13		35.5	37.6	3.8	145	
102	2	15	37.8	35.0	37.6	3.6	151	
102	2	17		35.3	37.7	3.6	151	
102	2	19	38.1	35.2	37.8	3.6	153	
102	2	21	38.4	35.6	37.9	3.7	153	
102	2	23		34.9	38.0	3.6	155	
102	2	25	38.7	35.2	38.1	3.8	158	
102	2	27		35.3	38.3	3.6		
102	2	29	39.1	35.2	38.4	3.6	161	
102	2	30	39.3	35.1	38.5	3.7	161	64.00
103	1	01	36.3	38.3	37.2	1.2		77.40
103	1	03	36.8	38.4	37.2	1.5	148	
103	1	05	37.4	38.5	37.3	1.6	158	
103	1	07	38.0	38.8	37.4	1.6	167	

103	1	09	38.5	38.4	37.5	1.7	176	
103	1	11	38.8	38.4	37.7	1.8	176	
103	1	13		38.2	37.9	1.7	176	
103	1	15	39.3	38.3	38.0	1.8	187	
103	1	17	39.5	38.1	38.2	1.8		
103	1	19		38.2	38.4	1.9	192	
103	1	21	39.9	38.3	38.6	2.0	195	76.56
103	2	01	37.3	38.1	37.2			76.67
103	2	03	37.4	37.8	37.2			
103	2	05	37.6	37.6	37.3			
103	2	07	37.9	37.5	37.4			
103	2	09	38.0	37.6	37.5			
103	2	11	38.2	38.3	37.6			
103	2	13		38.7	37.7			
103	2	15	39.0	38.9	37.8			
103	2	17		38.9	37.9			
103	2	19	39.1	39.2	38.1			
103	2	21	38.3	39.0	38.2			75.70
104	1	01	35.7	36.9	37.3	2.0		88.45
104	1	03	36.0	37.6	37.3	2.2		
104	1	05	36.4	37.5	37.3	2.2		
104	1	07	36.9	37.6	37.4	2.2		
104	1	09	37.5	37.4	37.5	2.6		
104	1	11	37.9	37.5	37.5	2.6		
104	1	13	38.2	37.3	37.6	2.6		
104	1	15	38.4	37.2	37.8	2.5		
104	1	17	38.7	37.4	37.9	2.5		
104	1	19	39.0	37.6	38.0	2.5		
104	1	21	39.2	37.6	38.2	2.6	187	
104	1	23	39.4	37.7	38.3	2.4	191	
104	1	24	39.5	37.7	38.4	2.6	191	87.56
104	2	01	35.1	36.6	36.9	2.1		89.05
104	2	03	35.6	36.8	36.9	2.5		
104	2	05	36.0	36.5	36.9	2.4	155	
104	2	07	36.6	36.7	37.0	2.7		
104	2	09	37.3	37.0	37.1	2.6	158	
104	2	11	37.7	37.1	37.2	2.6	167	
104	2	13	38.1	36.9	37.3	2.3	167	
104	2	15	38.2	37.4	37.3	2.5		
104	2	17	38.4	37.2	37.4	2.6	176	
104	2	19	38.6	37.1	37.6	2.6	176	
104	2	21	38.8	37.1	37.6	2.7	180	
104	2	23	39.0	37.0	37.7	2.7	182	
104	2	24	39.1	37.0	37.8	2.7	184	87.99
105	1	01	36.8	41.7	36.4	1.4	127	63.80
105	1	03	37.3	40.7	36.5	1.6	134	
105	1	05	37.8	40.6	36.6	1.9	145	
105	1	07	38.2	40.2	36.8	1.7	150	
105	1	09	38.6	40.5	37.0	2.0	158	
105	1	11	39.1	40.7	37.4	1.8	161	
105	1	13	39.3	40.4	37.5	1.9	167	
105	1	15	39.7	41.3	37.8	2.0	173	
105	1	17	40.1	41.3	38.1	1.9	176	

105	1	19	40.4	41.4	38.4	2.0	176	
105	1	21	40.6	40.6	38.7	1.9	176	62.80
105	2	01	36.6	37.5	36.5	1.4	145	63.75
105	2	03		37.6	36.6	1.6	145	
105	2	05	37.3	37.4	36.7	1.7	150	
105	2	07		37.8	36.9	1.6	155	
105	2	09	37.7	37.5	37.0	1.6	155	
105	2	11	38.1	37.6	37.2	1.6	161	
105	2	13		37.9	37.4	1.7	167	
105	2	15	38.6	38.0	37.6	1.6	170	
105	2	17		37.8	37.8	1.6	170	
105	2	19	39.0	38.0	38.0	1.6	178	
105	2	21	39.3	38.2	38.3	1.7	176	62.70
106	1	01	36.3	39.4	36.9	1.2		83.92
106	1	03	37.0	39.4	36.9	1.9		
106	1	05	37.7	39.6	36.9	1.8		
106	1	07	38.2	39.8	36.9	1.9		
106	1	09	38.6	39.8	37.0	2.0		
106	1	11	39.0	40.2	37.1	2.0	194	
106	1	13	39.3	39.8	37.3	2.0	195	
106	1	15	39.6	39.7	37.4	2.0	204	
106	1	17	39.9	40.0	37.6	2.1	204	
106	1	19	40.2	40.0	37.7	2.1	208	
106	1	20	40.4	39.9	37.8	2.2	206	83.12
106	2	01	36.7	39.1	37.4	1.3		83.45
106	2	03	37.3	39.5	37.4	1.7		
106	2	05	37.8	39.5	37.4	1.8		
106	2	07	38.1	39.3	37.4	1.9		
106	2	09	38.2	39.2	37.5	1.9		
106	2	11	38.5	39.6	37.5	2.0		
106	2	13	38.8	39.7	37.6	2.0		
106	2	15	39.1	39.8	37.7	1.9		
106	2	17	39.2	39.8	37.7	1.4		
106	2	19	39.6	40.3	37.8	1.3		
106	2	20	39.8	40.3	37.9	1.3		82.53
107	1	01	35.8	36.6	37.1	2.1	94	76.05
107	1	03	36.5	36.4	37.1	2.4		
107	1	05	37.3	36.3	37.2	2.4	147	
107	1	07	37.7	36.7	37.2	2.3	140	
107	1	09	38.2	37.4	37.3	2.3	150	
107	1	11	38.5	37.8	37.5	2.5	158	
107	1	13	38.9	38.2	37.6	2.4	163	
107	1	15	39.2	38.0	37.8	2.6	182	
107	1	17	39.5	38.1	37.9	2.5	197	
107	1	19	39.7	37.9	38.1	2.4	199	74.52
107	2	01	36.7	39.9	37.3	1.7	100	74.75
107	2	03	37.2	40.0	37.2	1.9	122	
107	2	05	37.7	40.1	37.2	1.9		
107	2	07	37.2	40.4	37.3	1.9	130	
107	2	09	38.6	40.3	37.4	2.0	136	
107	2	11	39.0	40.6	37.5	2.0	145	
107	2	13	39.3	40.5	37.7	2.1	150	
107	2	15	39.6	40.8	37.8	2.1	158	

107	2	17	39.9	41.0	38.0	2.1	164	
107	2	19	40.2	41.0	38.2	2.2	164	73.22

8.2 Rectal Temperature during recovery

Raw data of rectal temperature in 7 subjects on 12 different occasions resting in thermally neutral environment either after hot air inhalation (H) or after cool air (C) inhalation.

"A.L.-H"
0,38.4 1,38.5 2,38.6 3,38.8 4,38.9 5,39.0 6,39.0

07,39.1 8,39.2 09,39.3 16,39.6 21,39.6 27,39.4
30,39.3 31,39.2 32,39.1
"P.J-H"
0,38.6 4,38.9 5,38.9 6,38.9 7,38.9 8,38.8 9,38.8 10,38.8
11,38.7 12,38.7 14,38.7 15,38.6 16,38.5 17,38.5 18,38.4
19,38.3 20,38.3 21,38.2 22,38.2 23,38.2 24,38.2 25,38.2
26,38.1 27,38.1 28,38.1 29,38.0 30,38.0
"N.G-C"
0,37.9 4,38.3 5,38.2 6,38.2 7,38.3 8,38.3 9,38.3
10,38.3 11,38.3 12,38.3 13,38.3 14,38.3 15,38.2 16,38.2
17,38.2 18,38.2 19,38.1 20,38.1 21,38.0 22,37.9 23,37.9
24,37.8 25,37.8 26,37.8 27,37.8 28,37.8 29,37.7 30,37.7
"N.G-H"
0,38 3,38.2 4,38.2 5,38.2 6,38.3 7,38.3 8,38.3 9,38.3
10,38.4 11,38.4 12,38.4 13,38.4 14,38.4 15,38.4 16,38.4
17,38.4 18,38.3 19,38.3 20,38.3 21,38.3 22,38.3 23,38.3
24,38.2 25,38.2 26,38.2 27,38.1 28,38.1 29,38.1 30,38.0
"G.D-C"
0,37.9 3,38.5 4,38.6 5,38.6 6,38.7 7,38.8 8,38.8 9,38.8
10,38.9 11,38.9 12,38.9 13,38.9 14,38.9 15,38.9 16,38.9
17,38.9 18,38.9 19,38.8 20,38.8 21,38.8 22,38.7 23,38.7
24,38.6 25,38.6 26,38.5 27,38.5 28,38.4 29,38.4 30,38.4
"T.L-H"
0,39 1,39.1 2,39.2 3,39.2 4,39.3 5,39.4 16,39.3
18,39.1 21,39.0 22,38.9 26,38.6 28,38.4
"L.B-H"
0,38.7 5,42.4 6,42.5 7,42.5 8,42.0 9,41.3 10,40.4 11,39.8
12,39.4 13,39.2 14,39.1 15,38.9 16,38.7
17,38.6 18,38.6 19,38.5 20,38.3 21,38.2 22,38.2 23,38.2
24,38.1 25,38.1 26,38.0 27,37.9 28,37.9 29,37.9 30,37.8
"P.J-C"
0,38.2 2,40.7 3,40.7 4,40.7 5,40.8 6,41 7,41 8,41
09,40.9 10,40.7 11,40.5 12,40.3 13,40.1 14,39.9 15,39.7
16,39.6 17,39.4 18,39.3 19,39.2 20,39.0 21,38.9 22,38.8
23,38.8 24,38.7 25,38.7 26,38.6 27,38.6 28,38.6 29,38.5
30,38.5
"T.L-C"
0,38.4 2,40.3 3,40.5 4,40.8 5,40.9 6,41.0 7,40.9 8,40.8 9,40.7
10,40.5 11,40.5 12,40.4 13,40.2 14,40.1 15,39.9 16,39.8
17,39.7 18,39.6 19,39.4 20,39.3 21,39.2 22,39.1 23,39.0
24,38.9 25,38.8 26,38.7 27,38.6 28,38.5 29,38.4 30,38.3

```
"T.L-H"
 0,38.2  3,41.6  4,41.6  5,41.5  6,41.5  7,41.5  8,41.3  9,41.1
10,41.0  11,41.0  12,41.0  13,40.9  14,40.8  15,40.6  16,40.4
17,40.2  18,40.0  19,39.8  20,39.6  21,39.5  22,39.3  23,39.2
24,39.0  25,38.8  26,38.7  27,38.6  28,38.5  29,38.5  30,38.4
"L.B-C"
 0,38.4  5,38.5  6,38.5  7,38.4  8,38.3  9,38.3  10,38.2  11,38.2
12,38.1  13,38.1  14,38.1  15,38.1  16,38.0  17,37.9  18,37.8
19,37.8  20,37.8  21,37.7  22,37.7  23,37.7  24,37.6  25,37.6
26,37.5  27,37.5  29,37.5  30,37.5
"G.D-H"
 0,37.8  3,40.8  4,40.5  5,40.4  6,40.3  7,40.5  8,40.6  9,40.5
10,40.4  11,40.2  12,40.1  13,39.9  14,39.7  15,39.6  16,39.2
17,39.2  18,39.1  19,38.9  20,38.8  21,38.7  22,38.6  23,38.5
24,38.4  25,38.3  26,38.2  27,38.1  28,38.0  29,38.0  30,37.9
```

9. APPENDIX 2

9.1 Body heat content calculations

9.1.1 Calorific method

An example of calculation of body heat content for subject N.A. during exercise under heat stress while breathing hot air.

HEAT GENERATED VIA METABOLISM (M)

1 litre of O2 = 5 kcal (RQ=1)
2.14 l/min x 24min x 5 kcal/l'min = 256.4 kcal of work produced during 24 minutes of exercise.
mechanical efficiency = 0.25 (Fanger, 1972)
useful work = 64.1 kcal during 24 minutes of exercise
accumulated heat generated(256.4−64.1)= 192.3 kcal heat during 24 minutes of exercise

HEAT DISSIPATED

Convective heat loss (C)

$$C = h_c \times BSA \times (T_s - T_a)$$

Based on equation (3) in the text (p. 18) and assuming that hc=7.2 W/m²°C (Nishi and Gagge 1970) and effective BSA=0.8BSA (Flyn 1974) convective heat loss for the first minute of exercise is equal to −12.79 Watts. (Ts=36.2 °C, Ta=37.4 °C, BSA=1.85m²; 1 Watt=0.01433 kcal/min)

TOTAL CONVECTIVE HEAT LOSS = 3.36 kcal
during 24 minutes of exercise

Radiative heat loss (R)

$$R = \epsilon \times \sigma \times (T_s^4 - MRT^4) \times f_c \times BSA$$

According to equation (4) in the text (p. 19) and assuming that $\epsilon=1$ (Hardy 1939), fc=0.7 (Fanger 1972); Ts=36.2 °C, MRT=37.4 °C, BSA=1.85 m², 1 Watt=0.01433 kcal/min .

TOTAL RADIATIVE HEAT LOSS = 2.33 kcal
during 24 minutes of exercise
(for σ values see Kerslake 1972 pp53 appendix 5)

Evaporative heat loss (E)

$$E = h_D\{\phi s(C_s - C_a)\}\lambda \times BSA$$

According to eq. (6) in the text (p. 20)

$h_D = 0.3734$ m/min;

($\rho = 1.13$ kg/m³, $c = 0.242$ kcal/kg°C $= 1013$ J/kg°C)

According to eq. (7) in the text (p. 20)

$\phi s = 1.0$ ($\Delta T = 1$ °C, $Ts \leq Ta$)

C_s, C_a derived according to Weast, 1976 and Ta, Ts measured

Thus, based on eq. (5) of the text (p. 20)

TOTAL EVAPORATIVE HEAT LOSS = 22.6 kcal
during 24 minutes of exercise

Respiratory Heat Exchange (RHE)

$$RHE = \dot{V}_E \{H_c(T_{in} - T_{ex}) + \lambda (P_{wi} - P_{we})\}$$

According to eq (1) in the text (p. 17) and Appendix 3 (p.84)

TOTAL RHE = −2.68 kcal
during 24 minutes of exercise

Body heat Storage (S)

$$S = M \pm RHE \pm C \pm R - E$$

According to eq. (2) in the text p. (18)

S = 161.3 kcal during 24 min. of exercise

Mean body temperature (MBT)

$$MBT = S/(c) \times (W);$$

Where c = specific heat of tissue, BW = bodyweight,

c = 0.8 kcal/kg°C, BW = 68.5 kg. (Weast 1976)

Thus:

$$MBT = (161.3/0.8 \times 68.5) = \underline{2.94\ ^{\circ}C}$$

9.1.2 Thermic method

The following equation was used: (Burton 1935, Hardy and DuBois, 1937)

$$\mathrm{MBT} = (0.5 \times \Delta Tr) + (0.05 \times \Delta Ts)$$
$$\mathrm{MBT} = (0.5 \times 1.8) + (0.5 \times 4.0) = \underline{2.9\ ^{\circ}C}$$

9.1.3 Body Heat Storage

$$S = 0.84 \times BW \times (X \times \Delta T_r + Y \times \Delta T_s)$$

BHS was calculated according to equation (8) p. 21 in the text. The fraction of adipocity for N.A was equal to 0.204, X=0.905, Y=0.0535; see above calculations for subjects' weight, body surface area and Δ in skin and rectal temperature.

S = 186.8 kcal during 24 minutes of exercise.

10. APPENDIX 3

10.1 Calculations of Respiratory Heat Exchange

An interactive microcumputer program written in BASIC which calculated Respiratory Heat Exchange is attached below. The program starts with insertion of values in mv which was the analog output of inspired and expired temperature.

```
  5 DIM V(40),I(40),D(8),E(40)
  9 DIM P(30),F(30),K(30),W(30)
 13 DIM C(30),G(30),N(30),S(30)
 17 DIM O(30),R(30),Y(30),T(30)
 21 DIM X(30)
 25 FOR K=1 TO 8
 29 READ D(K)
 33 NEXT K
 37 DATA .10086091,25727.94369,-
    767345.8295,78025595.81
 41 DATA -9247486589,69768800000
    0,-2.66192E13,3.94078E14
 45 PRINT
 49 DISP "TEMP IN MV"
 53 PRINT
 57 PRINT "*** INSP-VOLT ***"
 61 PRINT
 65 FOR J=1 TO 25
 69 INPUT V(J)
 73 PRINT "V(";J;")=";V(J)
 77 V(J)=V(J)/1000
 81 NEXT J
 85 PRINT
 89 PRINT "***  INSP-TEMP IN DEG
    REES ***"
 93 PRINT
 97 FOR H=1 TO 25
101 I(H)=D(1)
105 FOR J=1 TO 7
109 K=J+1
113 I(H)=I(H)+D(K)*V(H)^J
117 I(H)=.001*IP(1000*I(H))
121 NEXT J
125 PRINT "POINT";H;"Ti  :";I(H)
129 NEXT H
133 DISP "EXP-TEMP IN MV"
137 PRINT
141 PRINT "*** EXP-VOLT ***"
145 PRINT
149 FOR H=1 TO 25
153 INPUT V(H)
157 PRINT "V(";H;")=";V(H)
161 V(H)=V(H)/1000
165 NEXT H
169 PRINT
173 PRINT "*** EXP-TEMP IN DEGRE
    ES ***"
177 PRINT
181 FOR H=1 TO 25
```

```
185 E(H)=D(1)
189 FOR J=1 TO 7
193 K=J+1
197 E(H)=E(H)+D(K)*V(H)^J
201 NEXT J
205 E(H)=.001*IP(1000*E(H))
209 PRINT "POINT";H;"Te \";E(H)
213 NEXT H
217 PRINT
221 PRINT
225 PRINT "*** DIFF-TEMP ***"
229 PRINT
233 FOR H=1 TO 25
237 F(H)=I(H)-E(H)
241 F(H)=.001*IP(1000*F(H))
245 PRINT "POINT";H;"Ti-Te";F(H)
249 NEXT H
253 PRINT
257 DISP "AIR DENSITY"
261 PRINT "*PAEKNOTES OF AIR*"
265 PRINT
269 FOR H=1 TO 25
273 INPUT P(H)
277 PRINT "P(";H;")";P(H)
281 NEXT H
285 S=.00024
289 PRINT "SPECIFIC AIR HEAT";S
293 PRINT
297 PRINT "***HEAT CAPACITY***"
301 PRINT
305 FOR H=1 TO 25
308 G(H)=S*P(H)
313 PRINT "MINUTE";H;G(H)
317 NEXT H
318 PRINT
321 PRINT "*CONDUCTION'S FACT*"
325 PRINT
329 FOR H=1 TO 25
333 C(H)=F(H)*G(H)
337 PRINT "MINUTE";H;C(H)
341 NEXT H
345 PRINT
349 DISP "INSPIRED WATER VAPOR
       CONTENT"
353 PRINT "**INSPIRED WATER VAPO
    R CONTENT**"
357 PRINT
361 FOR H=1 TO 25
365 INPUT W(H)
369 PRINT "W(";H;")";W(H)
373 NEXT H
377 PRINT
381 DISP "EXPIRED WATER VAPOR
         CONTENT"
385 PRINT "*EXPIRED WATER VAPOR
    CONTENT**"
389 PRINT
393 FOR H=1 TO 25
397 INPUT N(H)
401 PRINT "N(";H;")";N(H)
405 NEXT H
```

```
409 PRINT
413 PRINT "*WATER VAPOR DIFFEREN
    CES**"
417 PRINT
421 FOR H=1 TO 25
425 K(H)=W(H)-N(H)
429 PRINT "K(";H;")";K(H)
433 NEXT H
437 PRINT
441 L=.58
445 PRINT "LATENT HEAT OF AIR";L
449 PRINT
453 PRINT "**EVAPORATION'S FACTU
    R**"
457 PRINT
461 FOR H=1 TO 25
465 S(H)=L*K(H)
469 PRINT "POINT";H;S(H)
473 NEXT H
477 PRINT
481 DISP "MINUTE VENTILATION"
482 PRINT
485 PRINT "MINUTE VENTILATION"
486 PRINT
489 FOR H=1 TO 25
493 INPUT O(H)
497 PRINT "POINT";H;O(H)
498 NEXT H
502 PRINT
503 PRINT "@@@@ C.R.H.E.@@@@"
504 PRINT
505 FOR H=1 TO 25
509 R(H)=O(H)*C(H)
517 PRINT "MINUTE";H;R(H)
521 NEXT H
522 PRINT
523 PRINT "**** E.R.H.E.****"
524 PRINT
525 FOR H=1 TO 25
529 Y(H)=O(H)*S(H)
541 PRINT "MINUTE";H;Y(H)
545 NEXT H
546 PRINT
547 PRINT "@@@@ R. H. E. @@@@"
548 PRINT
549 FOR H=1 TO 25
553 T(H)=R(H)+Y(H)
554 PRINT "MINUTE";H;T(H)
555 NEXT H
569 PRINT
570 PRINT "### TOTAL R.H.E.# "
573 X=0
577 FOR H=1 TO 25
581 X=X+T(H)
586 NEXT H
587 PRINT X
589 END
```