FOREWORD

This report was prepared under the terms of Contract No. AF 33(616)-6763, Project No. 7222, "Biophysics of Flight," and Task No. 722204, "Human Thermal Stress." The study was initiated by the Biomedical Laboratory of the 6570th Aerospace Medical Research Laboratories, Aerospace Medical Division, Air Force Systems Command, Wright-Patterson Air Force Base, Ohio. William C. Kaufman, Major, USAF, was contract monitor for the Biothermal Section, Biophysics Branch, Biomedical Laboratory. The research was carried out in the Biotechnology Laboratory of the Department of Engineering, University of California, Los Angeles, during the period of August 1961 through November 1961. C. Martin Duke is Chairman of the Department of Engineering and P. F. O'Brien acts as his representative for research activities. John Lyman is project leader for research under the above contract.

The authors wish to thank Robert Nieman and Frank Frohman for their cooperation as experimental subjects. We would also like to acknowledge the excellent assistance rendered by John Bott and Frank Frohman during the data reduction process.

ABSTRACT

The relative contributions of local and peripheral control of sweating were investigated by subjecting the left arms of two subjects to a different environmental temperature than the rest of the body. The effect of the above conditions on the cooling power of the arm was also studied.

Arm water loss was found to be a function of the temperature of the arm's environment, as well as a function of the temperature of the body's environment. Maximum arm heat loss tends to occur when arm environment temperature equals body environment temperature, though in the cases where unusually high sweat rates for high arm environmental air temperatures were exhibited the general relationship was not reliable. Also, evidence is offered in support of the need for further experimentation in order to determine the effects of subject acclimatization and emotional sweating on the present results.

PUBLICATION REVIEW

This technical documentary report has been reviewed and is approved.

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SYMBOLS

Symbol	Definition	Units
F	Arm chamber volume air flow	$Ft.^3/min.$
q_{air}	Heat per unit time added to the air	BTU/min.
q_{arm}	Arm heat flow	BTU/min.
q_{wall}	Heat flow through arm chamber wall	BTU/min.
Q_{1-2}	Heat per pound of dry air added to the air	BTU/lb. of dry air
T_{ai}	Time average of arm chamber inlet air temperature	^oF
$\overline{T}_{ai}$	Mean T_{ac} for a group of runs	^oF
T_{ao}	Time average arm chamber outlet air temperature	^oF
T_e	Time average of tympanic membrane temperature	^oF
T_r	Time average of rectal temperature	^oF
T_{rm}	Time average of environmental room temperature	^oF
$\overline{T}_{rm}$	Mean T_{rm} for a group of runs	^oF
T_{sa}	Time average of mean left arm skin temperature	^oF
T_{sb}	Time average of mean body skin temperature	^oF
W_a	Arm water loss	gm/hr.
W_{s1}	Arm chamber inlet humidity	lbs. of H_2O/lb. of dry air
W_{s2}	Arm chamber outlet humidity	lbs. of H_2O/lb. of dry air

INTRODUCTION

The present study concerns the investigation of water and heat losses of the arm when it is subjected to an environment different from that of the rest of the body. The application of the results are twofold.

First, the experimental conditions used in this study are similar to those experienced in ventilated suit problems (Skilling, 1955; Webb, 1956) where the arms are unventilated. At high ambient temperatures the arms experience a hotter environment than the ventilated body. This condition affects the body's thermoregulatory system in ways which are still open to conjecture. Meehan and Jacobs (1957) have observed that hand cooling results in vasomotor responses which are general throughout the body and vice versa. Although their study concerns local cooling rather than local heating of the extremities, it indicates that the body's total heat mechanism is affected by local inputs. Therefore, depending on the effect of the arm's environment, it is possible that either the present type of ventilating suits, such as the MA-2 ventilating garment, provide maximum cooling power, or that by ventilating the arms, significant increases in body cooling can be effected. This extra cooling, if available, could be advantageous under conditions of high stress and heat loads where man's thermal tolerance would be reached in a dangerously short period of time.

Second, the design of this experiment allows the attainment of certain information pertaining to the nature of the body's thermoregulatory system, particularly the controversial subject of sweat control. Benzinger (1959) has concluded from the results of ice water ingestion experiments that internal and not cutaneous thermoception controls the sudomotor and vasomotor activities of the body. Also, from the results of steady state resting and working experiments, he has concluded that both sudomotor and vasomotor activities are controlled by internal body temperatures while the skin temperature has only a modifying effect on the cutaneous blood flow rate.

Belding and Hertig (1962) have recently shown through dynamic and steady state results that surface skin and deep skin temperatures and tympanic membrane temperature are all directly related to sweat rate. In an attempt to stimulate either the peripheral or central thermal control mechanism independently of the other, as suggested by Benzinger (1961), Rawson and Randall (1961) conducted experiments where the lower and upper halves of the subjects' bodies could be exposed to different temperatures. From their results, Rawson and Randall conclude that the sudomotor and vasomotor activation mechanisms can operate in man independently of head blood temperature. They were not able to indicate the relative amounts of peripheral and central control exerted, however, because the evidence of sweating was determined by the iodine-starch paper technique.

The partitional calorimetry experiment of concern here corresponds to Benzinger's requirement and gives at least some evidence of the relative effect of peripheral and central inputs to the body's thermoregulatory system.

EXPERIMENTAL DESIGN

The experimental procedure was arranged so that both steady state and transient response data could be acquired. The steady state conditions for each run were specified as nominal room air and nominal arm chamber inlet air temperatures. The room air velocity and humidity and the arm chamber inlet air volume flow and humidity were held constant for all runs.

All nine possible combinations of the two sets of variable experimental conditions, as shown in Figure 1, were run on each of two subjects.

EXPERIMENTAL APPARATUS

A. Environmental Room

The environmental room provided the environment for the body of the subject, exclusive of his left arm. The layout of the room and the position of the subject during the experimental runs are illustrated in Figure 2. The air conditioning apparatus associated with the environmental room included a blower, refrigeration unit, heaters, and a humidity-controlled steam valve. The room air flow was provided by the blower. The position of the inlet and outlet ducts were as shown in Figure 2. It should be noted that the position of the room

20/20	35/20	50/20
20/30	35/30	50/30
20/40	35/40	50/40

T_{ai} / T_{rm}

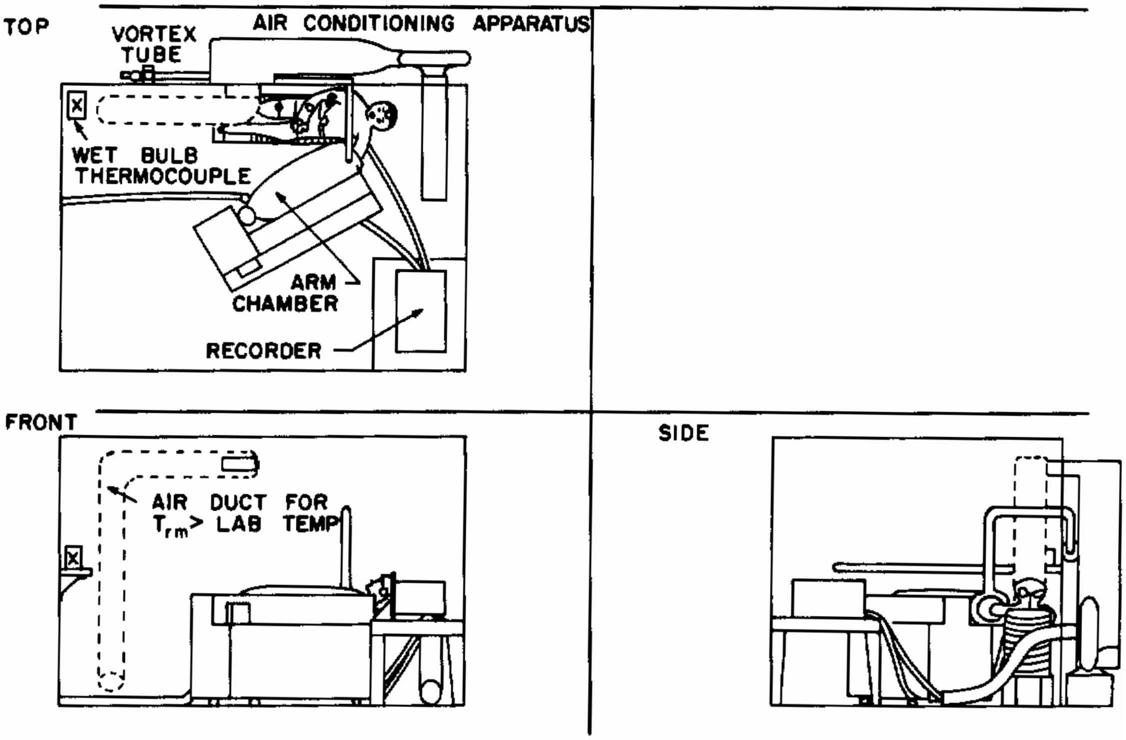
KEY

T_{ai}, ARM CHAMBER INLET AIR TEMPERATURE

T_{rm}, ENVIRONMENTAL ROOM AIR TEMPERATURE

ENVIRONMENTAL CONDITIONS

FIGURE 1



LAYOUT OF THE ENVIRONMENTAL ROOM

FIGURE 2

inlet duct was altered for the different room temperatures, being near the ceiling during runs where the room temperature was below the ambient laboratory temperature and ducted near the floor for room temperatures above the laboratory temperature. In this manner the variation of room temperature from floor to ceiling was held to within ± $1^{o}F$.

The room humidity was controlled by first cooling the recirculating room air to a temperature below that of the wet bulb temperature corresponding to the desired humidity, then adjusting the humidity by injecting controlled amounts of steam into the inlet air duct. The desired room temperature was set by adding enough energy to the air with electrical resistance heaters to raise the air temperature to the desired level.

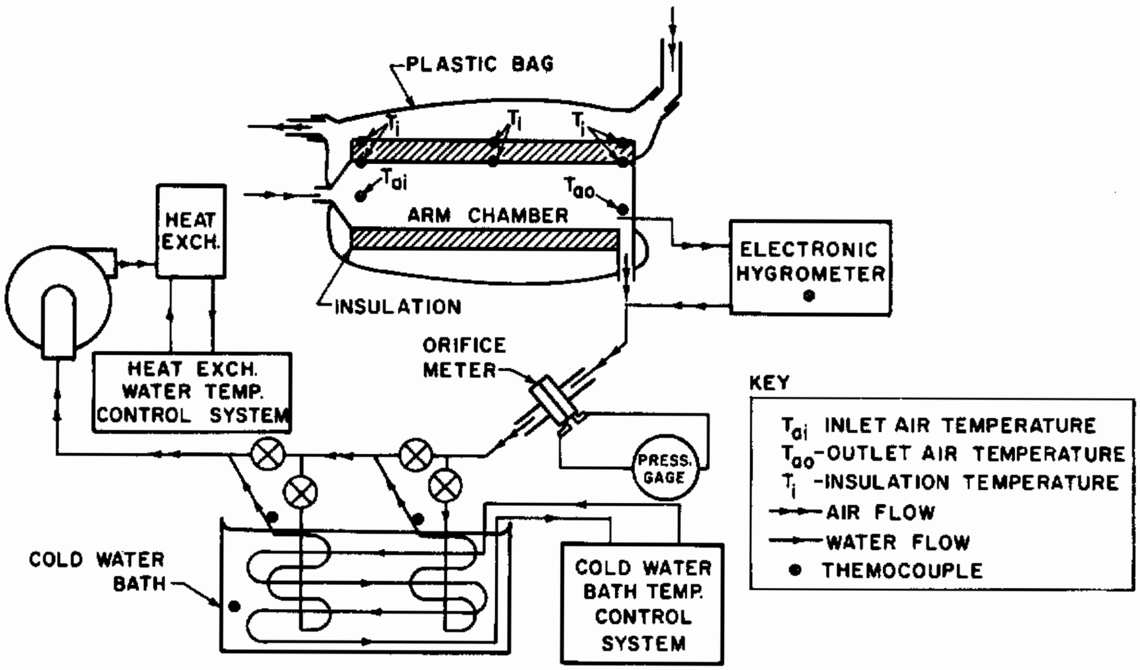
Two deficiencies were encountered in the above temperature and humidity control system. During the cold runs (room temperature $69^{o}F$.) the steam valve control system operated erratically, usually resulting in a somewhat lower room humidity than the set design constant (10 mm Hg.). During the hot runs (room temperature $104^{o}F$) the cooling power of the refrigeration unit was not great enough to completely remove the excess water vapor above 10 mm Hg. vapor pressure. This resulted in a higher humidity than was desired.

B. Arm Chamber and Associated Apparatus

The arm chamber provided the environment for the left arm of the subject. The layout of the arm chamber and associated apparatus are schematically illustrated in Figure 3. The design and function of the arm chamber is essentially the same as described by Hale (1960) with the following alterations:

1. Heat exchanger

This unit, used to control the temperature of the arm chamber inlet air, was converted from a variable flow-constant temperature control system, to a constant flow-variable temperature system. A cooling cycle was also added in order that arm chamber air temperatures below the room ambient temperature could be run.



ARM CHAMBER AND ASSOCIATED APPARATUS

FIGURE 3

2. Air-flow measurement

A calibrated orifice meter and pressure gage were substituted for the original calibrated velocity chamber and velocity probe, thus allowing a direct measurement of the air volume flow to be made.

3. Arm chamber

In order to reduce the heat flow through the arm chamber wall it was insulated with styrofoam. For the first seven runs a 4-inch thickness of styrofoam was used. For the remainder of the runs the insulation thickness was reduced and the arm chamber was enveloped with a plastic bag through which air, at the temperature of the arm chamber air, was passed. The temperature of this air was controlled with the aid of a vortex tube attached to a high-pressure line located outside the environmental room. The air entered the room and plastic bag through plastic hoses and was exhausted outside the room in the same manner.

4. Humidity measurement

Connections were installed in the arm chamber air circuit, as illustrated in Figure 3, so that an electronic hygrometer (Anonymous, 1950) could be hooked in parallel with the air circuit. The hygrometer gave an instantaneous measure of the arm chamber outlet humidity by maintaining a mirror surface at the dew point temperature of the air passing through the apparatus. The mirror temperature was measured with a copper-constantan thermocouple. Since the inlet humidity was held constant, the hygrometer indirectly measured instantaneous arm water loss.

EXPERIMENTAL MEASUREMENTS

A. Arm Water Loss

The arm water loss was measured in the manner described by Hale, 1960. Through various chamber calibrations the collection error was found to be ± .125 grams per hour.

B. Arm Heat Flow

In order to determine the heat flow from the subject's left arm it was necessary to know the arm chamber air flow, the inlet and outlet air temperatures and humidities, the temperature of the arm, and the temperature profile of the arm chamber wall insulation. The air flow was measured with a calibrated orifice meter and pressure gage. The total error of this system was found to be ± .03 ft^3 per minute. The air temperatures, arm temperatures, and insulation temperature profile were measured with iron-constantan thermocouples and recorded by a Brown automatic recording potentiometer with an accuracy of ± .5°F. The placement of the thermocouples is shown in Figure 3. Inlet humidity was a set design constant. Outlet humidity was calculated from the total arm water loss measurement.

C. Physiological Measurements

Physiological measurements included ear (tympanic membrane) and rectal temperatures and body skin temperatures. The ear temperature was measured in the manner described by Benzinger (1959) using a copper-constantan thermocouple. The probability of contact between the ear thermocouple and tympanic membrane was ascertained by pain sensation and the length to which the thermocouple was inserted into the ear. The rectal temperature was measured with a copper-constantan thermocouple inserted to a depth of 10 cm. The thermocouple potentials were measured with a Leeds and Northrup K-2 potentiometer. The accuracy of this system was ± .5μv or ± .02^{O}F.

The skin temperature measurements consisted of the hand and forearm temperatures of the left arm in the arm chamber, and skin temperatures of seven local areas of the body (Hale, et al, 1960). The temperatures were recorded on a Brown recorder.

D. Experimental Conditions

The room temperature was measured with an iron-constantan thermocouple placed about a foot above the subject's thighs and a foot away from his chest. One thermocouple was felt adequate for this measurement because of the small temperature gradient (± 1^{O}F) existing from the floor to the ceiling. The room humidity was measured with a wet bulb iron-constantan thermocouple positioned as shown in Figure 2. The measurements were recorded on a Brown recorder.

The arm chamber inlet air temperature was measured as described in (B) of this section. The inlet humidity was set and controlled at the design constant of 10 mm. Hg.

SUBJECTS AND EXPERIMENTAL PROCEDURE

A. Subjects

The two subjects were healthy male college students. Both received physical examinations before undergoing experimentation. Data relevant to the subjects appears in Table 1.

TABLE 1
SUBJECT DATA

Subject	Age(yrs.)	Height (ft.)	Weight(lbs.)	Arm Chamber Air Velocity ft./min.	De Bois Body Surface Area (ft.)	Approx. Exposed Arm Surface Area (ft^2)	Approx. Hand Area (ft^2)
FF	20	5.8	140	6.3 ± .2	19.1	.94	.49
RN	21	6	160	6.3 ± .2	20.6	1.08	.45

B. Preliminary Procedure

The subjects reported to the laboratory at either 8:00 a.m. or 1:00 p.m. During the first few runs the subjects entered the chamber to undress, don the body thermocouple harness, and insert the rectal probe and ear thermocouple. For later runs an outside dressing room was provided so that the subject could be instrumented before entering the room, thus allowing some transient response data to be collected.

C. Experimental Period

Upon entering the chamber, the subject was seated in a reclining position as illustrated in Figure 2. The arm thermocouples were placed on his left arm and the arm inserted in the arm chamber. After this a waiting period of one hour ensued in which the subject was allowed to come to thermal equilibrium. During the second hour arm water loss was collected.

During the experimental period the ear and rectal temperatures were measured every 1 to 5 minutes. The time increment was constant for a run but variable from run to run.

The air flow of the arm chamber was monitored by the experimenter and kept constant at the required experimental value during the run.

DATA REDUCTION

A. Arm Heat Flow

The arm heat flow was calculated assuming the system illustrated in Figure 4 and using the heat balance equation,

$$q_{arm} = q_{air} - q_{wall} \qquad (1)$$

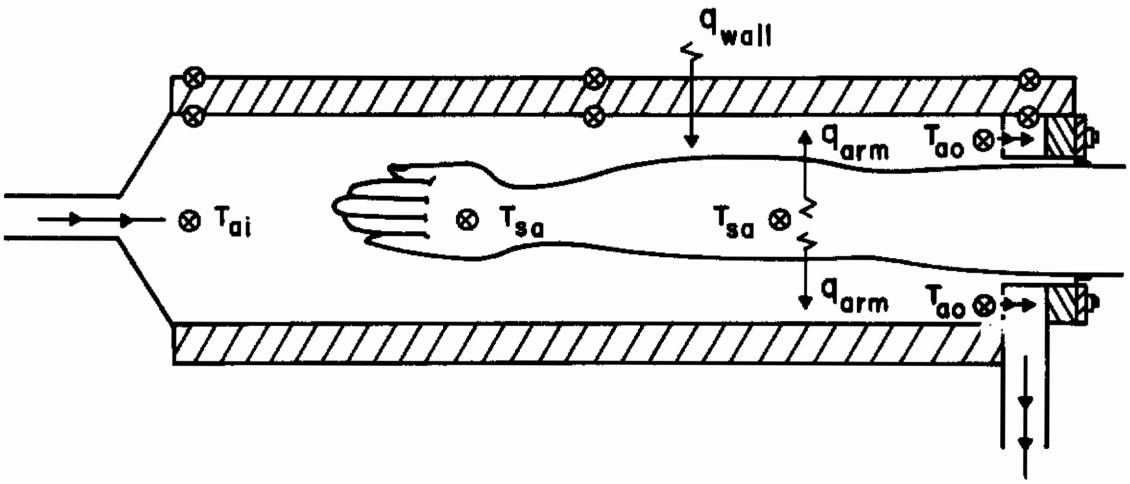
where the positive direction of q_{arm} and q_{wall} are indicated by the arrows in Figure 4 and q_{air} is positive for an increase in enthalpy. q_{air} is computed using the relation,

$$q_{air} = \gamma F Q_{1-2} \qquad (2)$$

where F is the arm chamber air volume flow, γ is the air density, and Q_{1-2} is the heat per pound of dry air added to the air. Q_{1-2} is given by the relationship,

$$Q_{1-2} = (0.24 + .45W_{s1})(T_{ao}-T_{ai}) + (W_{s2}-W_{s1})(1092.5-T_{sa}+0.45\ T_{ao}) \qquad (3)$$

(Jennings, 1958, pp. 69).*



HEAT FLOWS AND THERMOCOUPLE LOCATIONS

FIGURE 4

q_{wall} was determined by multiplying the average wall temperature gradient by a constant determined after several chamber calibrations. This constant was actually found to be somewhat variable and could not be determined any closer than ± 25%. However, since the term does not have a very large effect on the total heat balance, the error was not regarded as serious enough to invalidate the results.

B. Physiological Measurements

No reduction other than time averages was performed on the ear and rectal thermocouple voltages. The mean body skin temperatures were obtained

*Jennings' notation has been changed to conform with the nomenclature in this report.

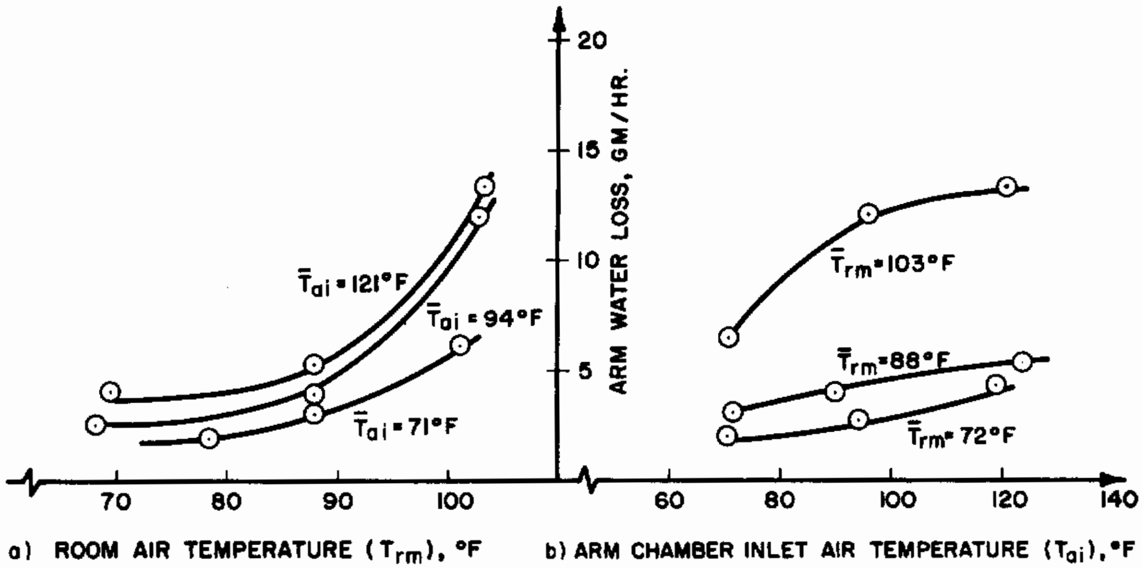
numerically from the seven locally measured temperatures. The mean left arm skin temperature was obtained from the two locally measured temperatures. In some of the runs either the hand thermocouple or the forearm thermocouple gave erroneous values, because of poor contact. Such values were excluded from the averages.

RESULTS AND DISCUSSION

A. Arm Water Loss

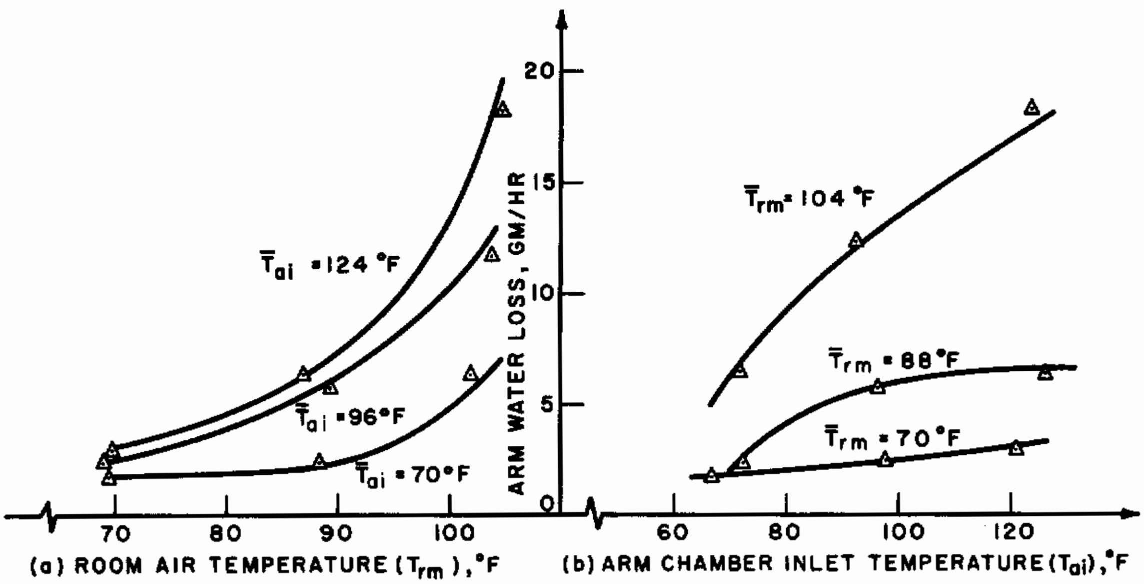
In Figures 5 and 6, the average arm water loss is plotted as a function of both average room air temperature and average arm chamber inlet air temperature. The average was taken over the one-hour collection period. The relationship between the variables in Figures 5(a) and 6(a) indicates that arm water loss over the range studied increases at an increasing rate with an increasing room air temperature. This was true even when the arm chamber inlet air temperature was maintained at a constant value. Thus the above results imply that some sort of central sweat control is in effect.

Figures 5(b) and 6(b) illustrate the manner in which arm water loss was found to increase with an increasing arm chamber inlet air temperature, holding the room air temperature constant. The results appear to indicate either that local sweat control is in effect, or that the conditions applied to the arm are indirectly affecting a central sweat control mechanism. The latter supposition is not supported by Figures 7, 8, 9 and 10, however. In these figures, water loss has been plotted as a function of average ear (tympanic membrane) temperature and average rectal temperature. In these graphs, the effect of the arm chamber inlet air temperature as a parameter is illustrated. From the graphs it may be noted that for a constant rectal or ear temperature, sweat rate increases with an increasing arm chamber inlet air temperature. This result indicates that sweat rate is not strictly a function of deep body temperatures, but is also a function of the temperature of the air around the arm. It may also be noted in Figures 11 and 12 that the ear and rectal temperatures are relatively unaffected by changes in the arm chamber temperature. Thus the arm conditions are seen as having a minimal



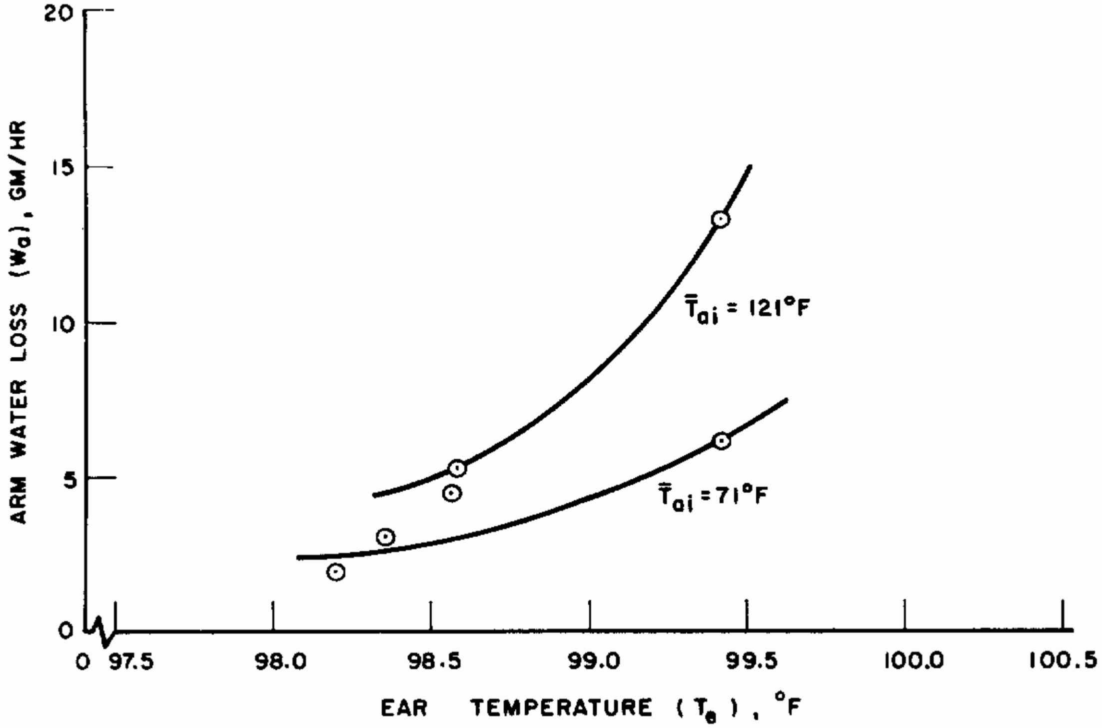
ARM WATER LOSS AS FUNCTION OF ROOM AIR TEMPERATURE AND ARM CHAMBER INLET AIR TEMPERATURE - SUBJECT FF

FIGURE 5



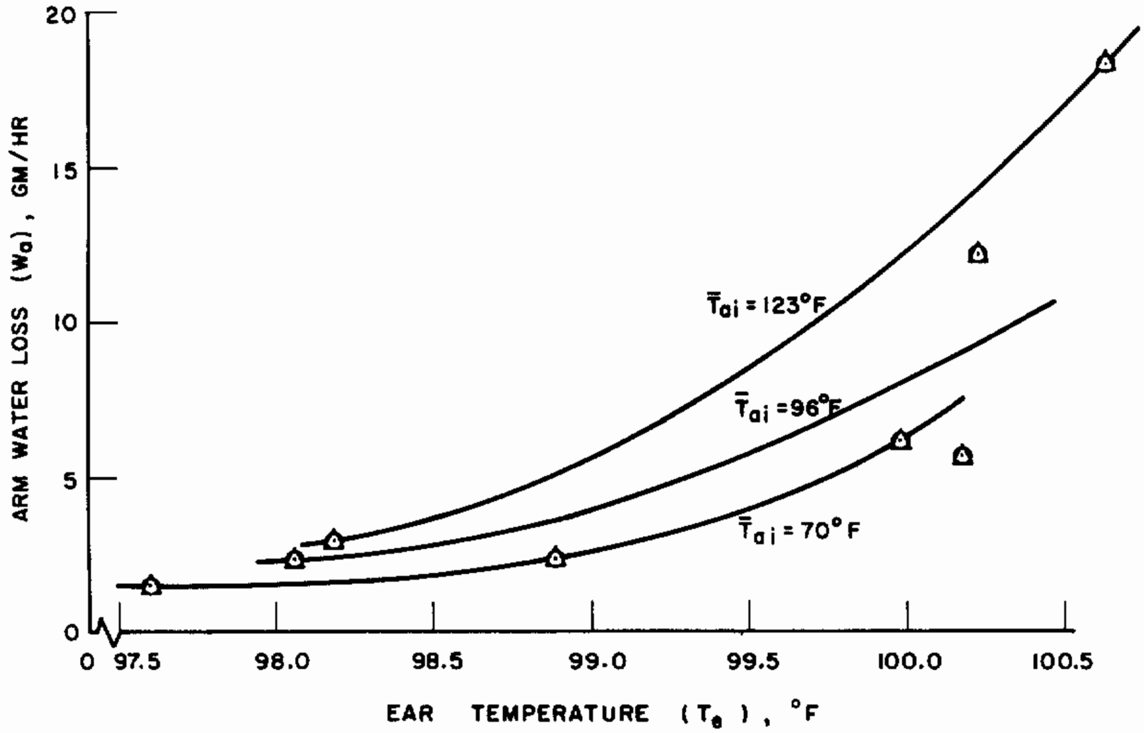
ARM WATER LOSS AS A FUNCTION OF ROOM AIR AND ARM CHAMBER INLET AIR TEMPERATURE - SUBJECT RN

FIGURE 6



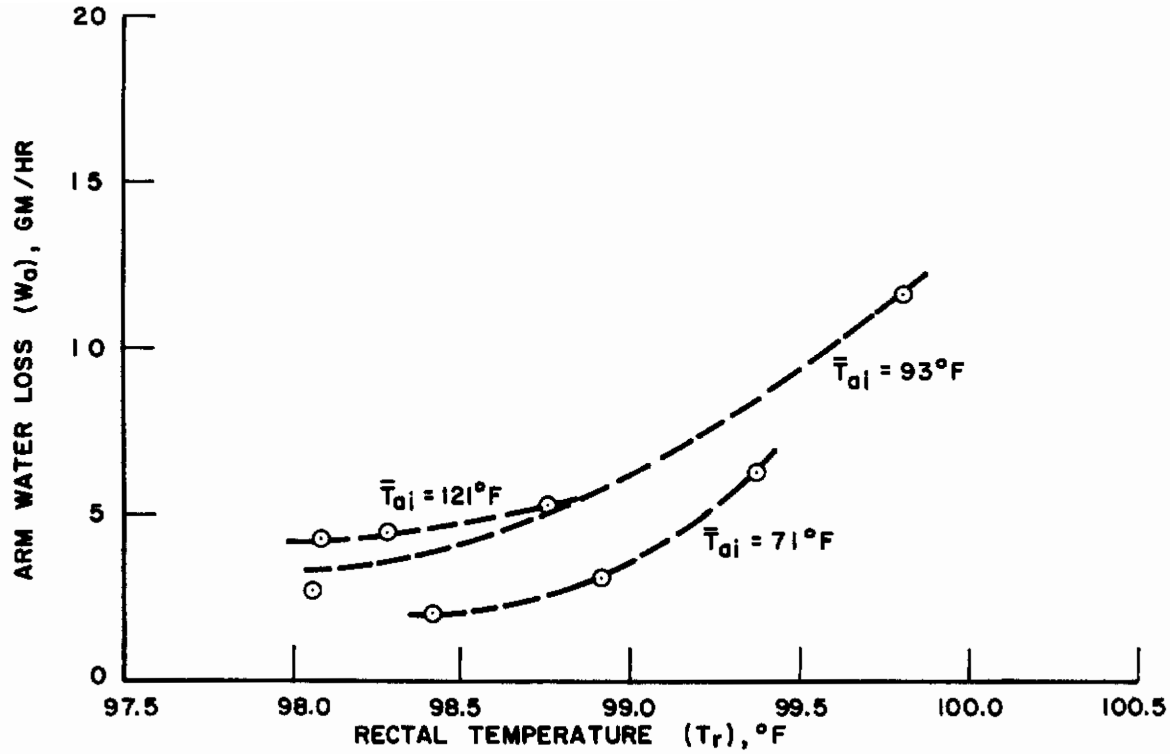
ARM WATER LOSS AS A FUNCTION OF EAR TEMPERATURE FOR SUBJECT FF

FIGURE 7



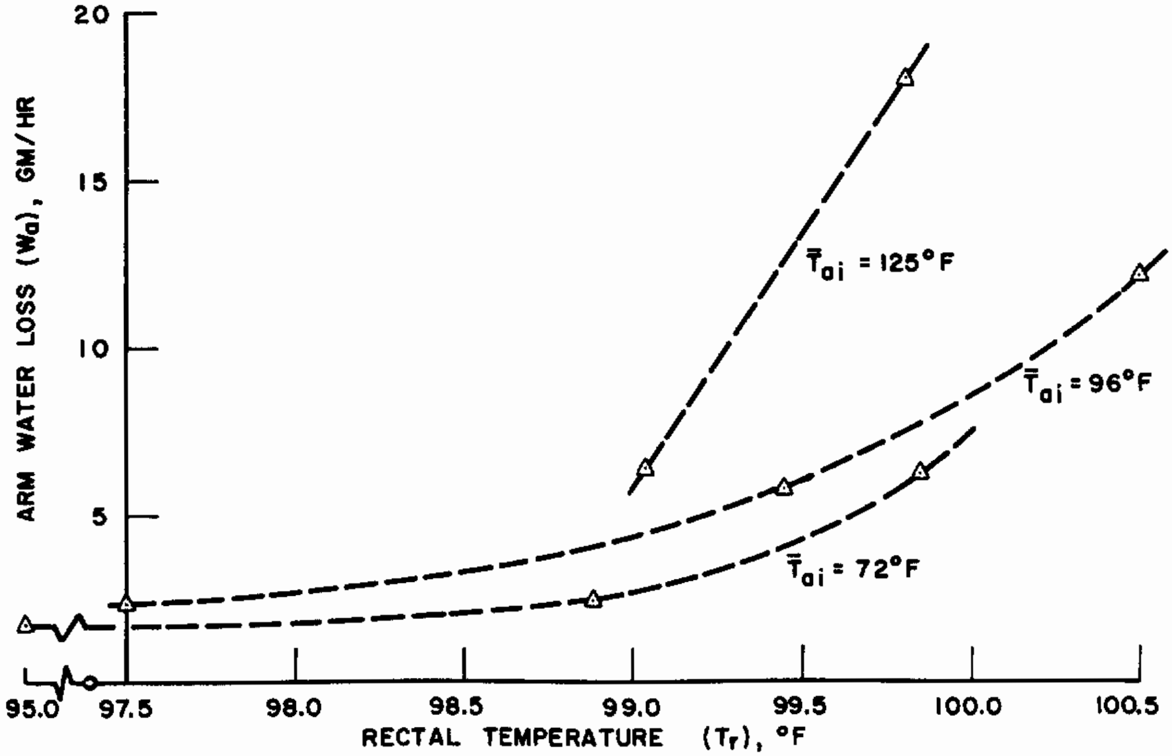
ARM WATER LOSS AS A FUNCTION OF EAR TEMPERATURE FOR SUBJECT RN

FIGURE 8



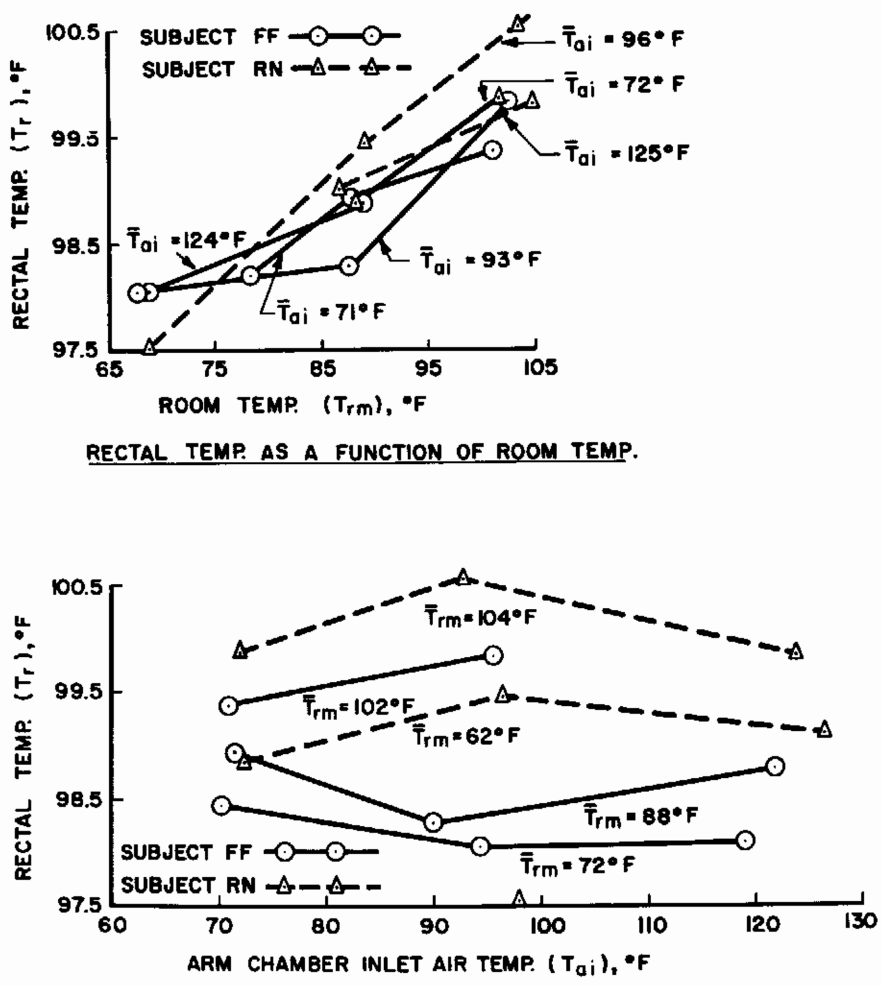
ARM WATER LOSS AS A FUNCTION OF RECTAL TEMPERATURE FOR SUBJECT FF

FIGURE 9



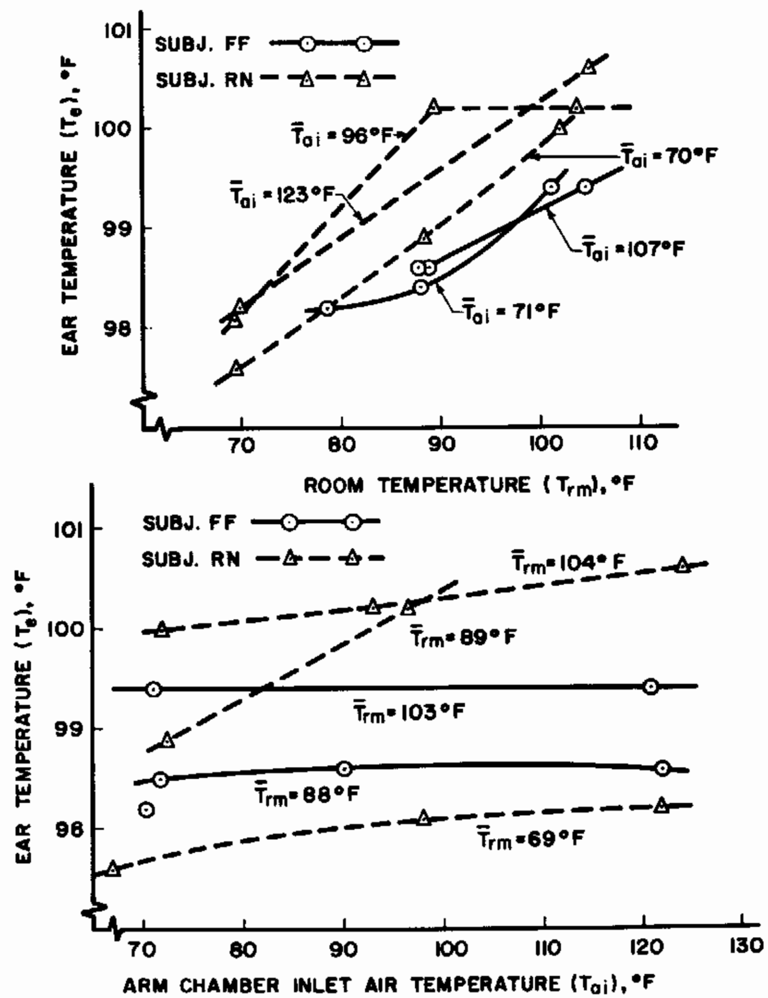
ARM WATER LOSS AS A FUNCTION OF RECTAL TEMPERATURE FOR SUBJECT RN

FIGURE 10



RECTAL TEMPERATURE AS A FUNCTION OF ROOM TEMPERATURE AND ARM CHAMBER INLET AIR TEMPERATURE

FIGURE 12



EAR TEMPERATURE AS A FUNCTION OF ROOM TEMPERATURE AND ARM CHAMBER INLET AIR TEMPERATURE

FIGURE 11

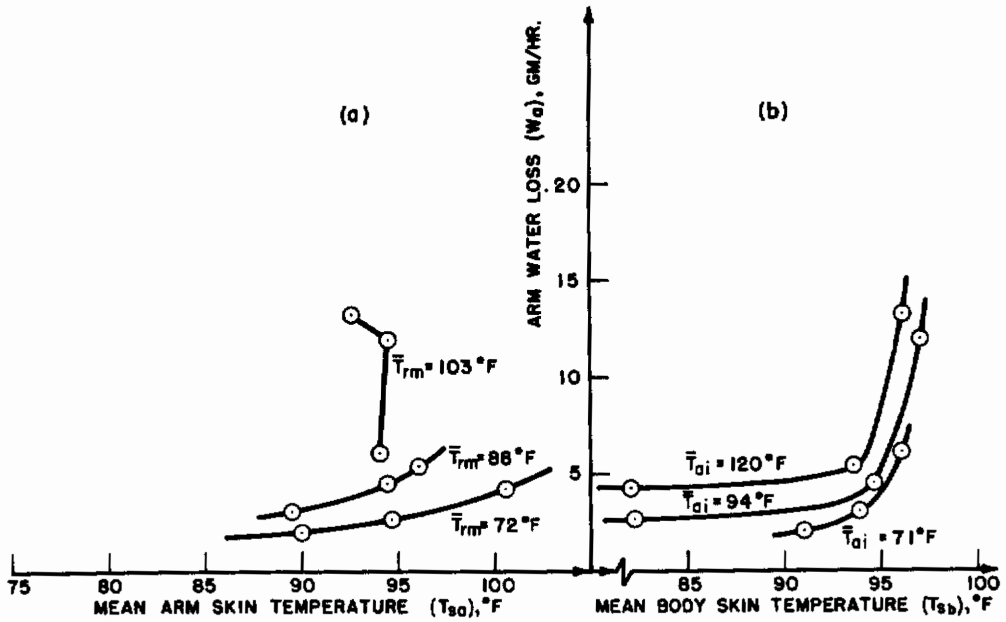
effect on the deep body temperatures.

In Figures 13 and 14, arm water loss is related to both arm skin temperature and body skin temperature. The data are tabulated in Table 2. The relationship between arm skin temperature and water loss is not apparent for either subject. The relationship between body skin temperature and arm water loss for subject FF (Figure 13(b)) is similar to the relation reported by Benzinger (1959) between total body skin temperature and water loss. Figures 13 and 14 also show the effect of arm chamber inlet air temperature as a parameter, higher air temperatures corresponding to higher water losses.

The relationship between body skin temperature and arm water loss (Figure 14(b)) for subject RN is similar to that for FF except for the paradoxically low skin temperatures exhibited during runs 11 and 17. The low temperatures were probably brought about by the interaction of the effects of different arm and body environments and are related in some way to the relatively high arm water losses subject RN exhibited at high arm chamber air temperatures.

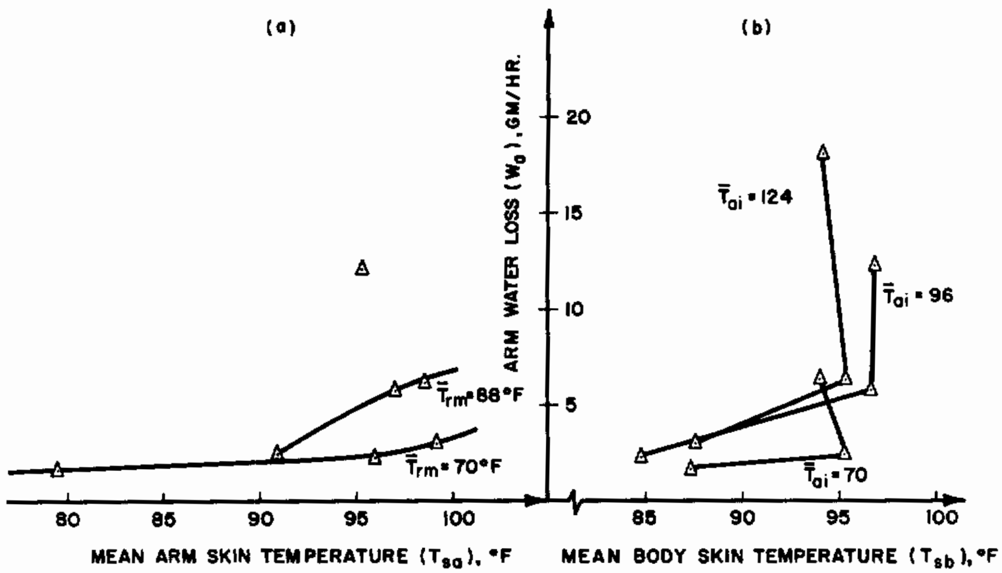
Mean arm skin temperature is graphed as a function of average arm chamber inlet air temperature in Figure 15. The effect of room air temperature is also illustrated. For subject FF (Figure 15), arm skin temperature is noted to decrease with increasing room temperatures at $\overline{T}_{ai} \cong 120^{o}F$. This is caused by the increase in evaporative heat loss as increased room temperatures produce more sweating.

It has been observed that changes in arm chamber inlet air temperature for a constant room temperature do not significantly affect deep body temperatures, but have a pronounced effect on arm skin temperature and water loss. From this evidence it follows that peripheral control of sweating is probably a significant factor in the body's thermoregulatory system. However, due to the inverse relationship between surface skin temperature and surrounding air for certain conditions (as shown in Figure 15) and also reported by Benzinger (1959), it seems unlikely that superficial surface skin temperature controls arm sweating to any degree. It is more likely that sweating is in



ARM WATER LOSS AS A FUNCTION OF ARM SKIN AND BODY SKIN TEMPERATURES - SUBJECT FF

FIGURE 13



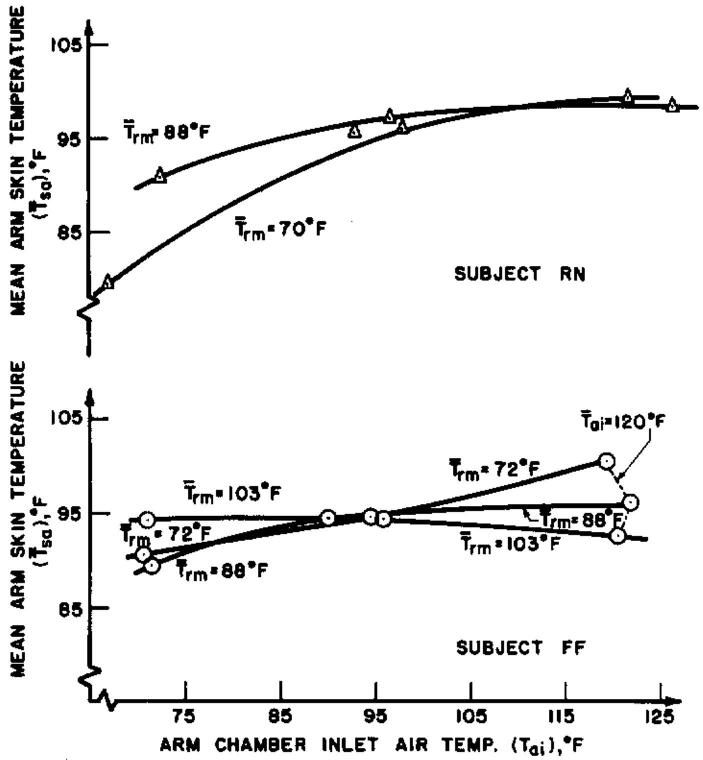
ARM WATER LOSS AS A FUNCTION OF ARM SKIN AND BODY SKIN TEMPERATURES - SUBJECT RN

FIGURE 14

TABLE 2

EXPERIMENTAL CONDITIONS, BODY TEMPERATURE AND WATER LOSS

Run # Subject	Date Time of Day	Nominal Conditions T_{ai}/T_{rm} ^oC	T_{rm} ^oF	Room Humidity (mm of Hg)	T_{ai} ^oF	T_{ao} ^oF	W_a gm/hr	T_e ^oF	T_r ^oF	T_{sb} ^oF	T_{sa} ^oF
1/FF	8/14/61/AM	35/30	88.0	13.3	90.0	92.5	4.5	98.57	98.28	95.0	94.5
2/RN	8/14/61/PM	35/30	89.5	17.0	96.5	95.0	5.7	100.17	99.45	96.5	97.0
4/RN	8/18/61/AM	35/40	103.5	13.3	93.0	96.0	12.2	100.23	100.53	97.0	95.5
5/FF	8/18/61/PM	35/40	102.5	16.6	95.5	96.0	12.1		99.82	97.0	94.5
6/FF	8/21/61/PM	20/20	78.5	11.1	70.5	86.0	2.1	98.21	98.43	91.0	90.5
7/RN	8/25/61/PM	20/20	69.5	8.8	70.0	-	1.7	97.60	94.97	87.5	79.5
8/FF	8/30/61/AM	20/30	88.0	8.7	71.5	79.5	3.1	98.36	98.93	94.0	89.5
9/RN	8/30/61/PM	20/30	88.5	10.2	72.5	80.5	2.4	98.88	98.89	95.5	91.0
10/FF	9/1 /61/AM	20/40	101.0	12.6	71.0	77.0	6.2	99.43	99.37	96.0	94.0
11/RN	9/1 /61/PM	20/40	102.0	15.5	72.0	79.0	6.3	99.97	99.86	94.0	-
12/RN	9/6 /61/AM	35/20	69.0	7.4	98.0	97.5	2.4	98.05	97.52	85.0	96.0
14/FF	9/8 /61/AM	50/30	89.0	13.3	122.0	106.5	5.3	98.59	98.77	93.5	96.0
16/RN	9/11/61/PM	50/20	70.0	8.4	121.5	106.5	3.0	98.18	-	87.5	99.0
17/RN	9/13/61/PM	50/40	105.0	15.7	124.0	107.0	18.1	100.65	99.81	94.0	-
18/FF	9/15/61/AM	50/40	104.5	18.8	120.5	107.0	13.3	99.42	-	96.0	92.5
19/RN	9/15/61/PM	50/30	87.0	10.4	126.5	108.5	6.3	-	99.04	95.5	98.5
20/FF	10/13/61/PM	50/20	69.0	10.0	119.0	108.0	4.3	-	98.09	82.0	100.5
21/FF	11/13/61/PM	35/20	68.0	10.0	94.5	96.5	2.7	-	98.06	82.0	94.5



MEAN ARM SKIN TEMPERATURES AS A FUNCTION OF
ARM CHAMBER INLET AIR TEMPERATURE

FIGURE 15

part a direct function of deep skin temperatures as reported by Belding and Hertig (1962), with the possibility of a direct effect of temperature level on the sweat glands.

B. Arm Heat Loss

On the whole, the arm heat flow results were not as consistent or meaningful as the water loss results. This was largely due to the error in the q_{wall} term of the heat balance (Equation (1)). The design of the arm chamber was originally intended to limit the wall heat flow so that this term would be negligible, but in the experiments the equipment did not meet this requirement. In Table 3 the arm heat flows and their respective theoretical maximum possible errors are tabulated for each run. (Equipment failure resulted in the loss of the arm chamber outlet temperature record for run 7 so that heat flow could not be computed.) The data for computing the q_{wall} term of the heat balance for run 1 were not recorded, but since the conditions

TABLE 3

ARM HEAT FLOW

Run # Subject	Total Arm Heat Flow (q arm), BTU/min	Max. Possible Error in q arm BTU/min	Convective Arm Heat Flow $(q\ arm)_c$ BTU/min	Max. Possible Error in $(q\ arm)_c$ BTU/min	Evaporative Arm Heat Flow $(q\ arm)_e$ BTU/min	Max. Possible Error in $(q\ arm)_e$ BTU/min
1/FF	.24	.01	.07	.01	.17	.00
2/RN	.25	.03	+.03	.03	.22	.00
4/RN	.39	.05	-.09	.04	.47	.00
5/FF	.35	.04	-.11	.04	.46	.00
6/FF	.35	.04	+.29	.03	.08	.00
7/RN	-	-	-	-	-	-
8/FF	.19	.03	.07	.10	.12	.00
9/RN	.18	.03	.08	.03	.09	.00
10/FF	.20	.04	-.07	.04	.24	.00
11/RN	.19	.05	-.06	.04	.24	.00
12/RN	.22	.04	+.13	.04	.09	.00
14/FF	.11	.04	-.08	.04	.20	.00
16/RN	.03	.04	-.08	.04	.12	.00
17/RN	.47	.03	-.23	.02	.70	.00
18/FF	.29	.02	-.22	.03	.51	.00
19/RN	.13	.04	-.11	.04	.24	.00
20/FF	.09	.04	-.07	.03	.16	.00
21/FF	.01	.03	+.08	.03	.10	.00

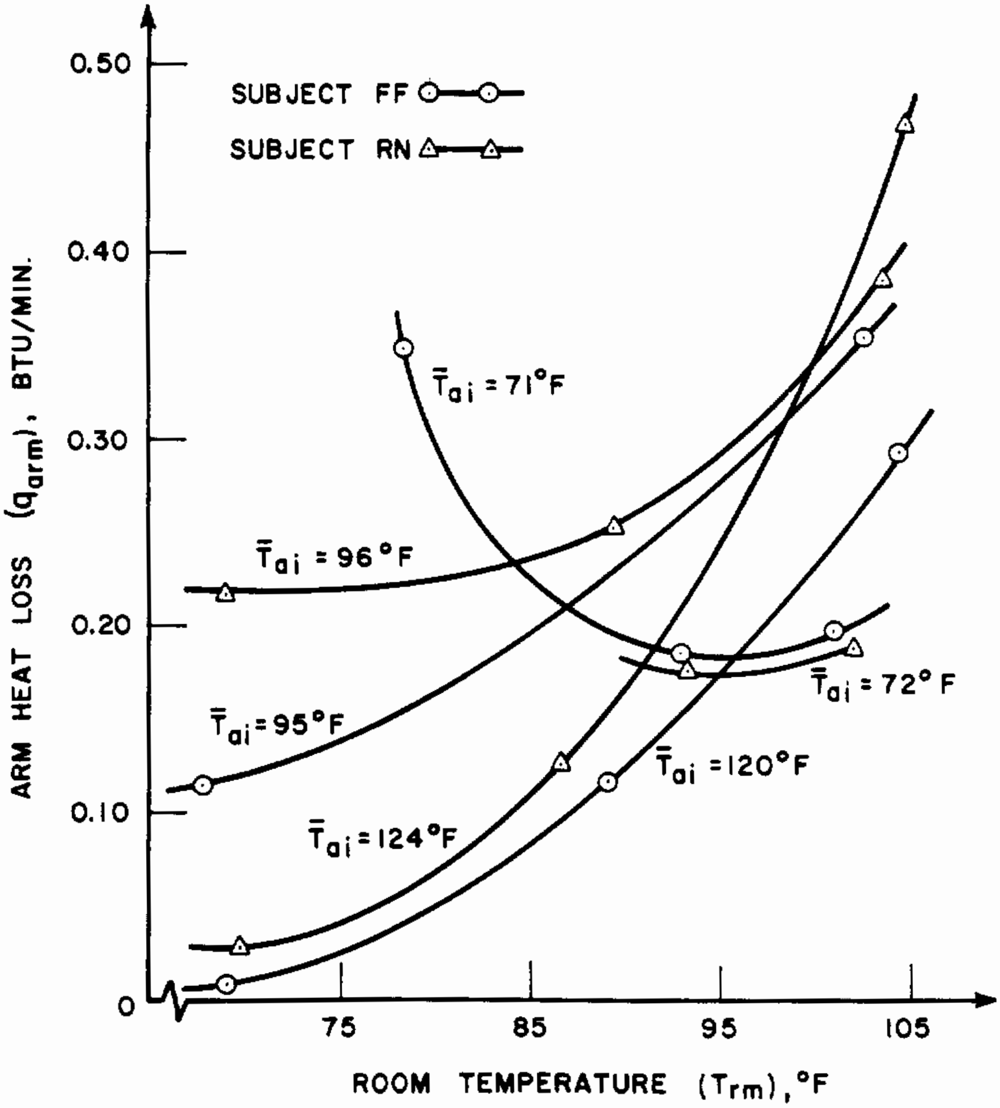
for this run were similar to those of run 2, and in that case q_{wall} was relatively small, it was possible to make a reasonable approximation for the term in question.

In Figure 16 arm heat loss is shown as a function of room temperature. In this figure the effect of convective heat loss suppression, due to high arm chamber temperatures, is noted at low room temperatures. The sweat rates produced by high room temperatures seem to offset the heat suppression somewhat. The arm heat loss for run 6 appears to be erroneous, considering that low room and arm chamber air temperatures were involved. In Table 2 it is noted that the arm chamber outlet temperature for this run was $5^{o}F$ higher than the other low arm chamber inlet temperature runs. No other explanation than experimental error from an unknown source can be offered for this inconsistent result.

In Figure 17, where arm heat loss is plotted as a function of the arm chamber inlet temperature, the effect of arm heat flow suppression at high arm chamber temperatures is more clearly apparent. In the one case where this suppression does not occur (run 17, subject RN) a relatively high sweat rate is noted. It appears to offset the negative convective loss.

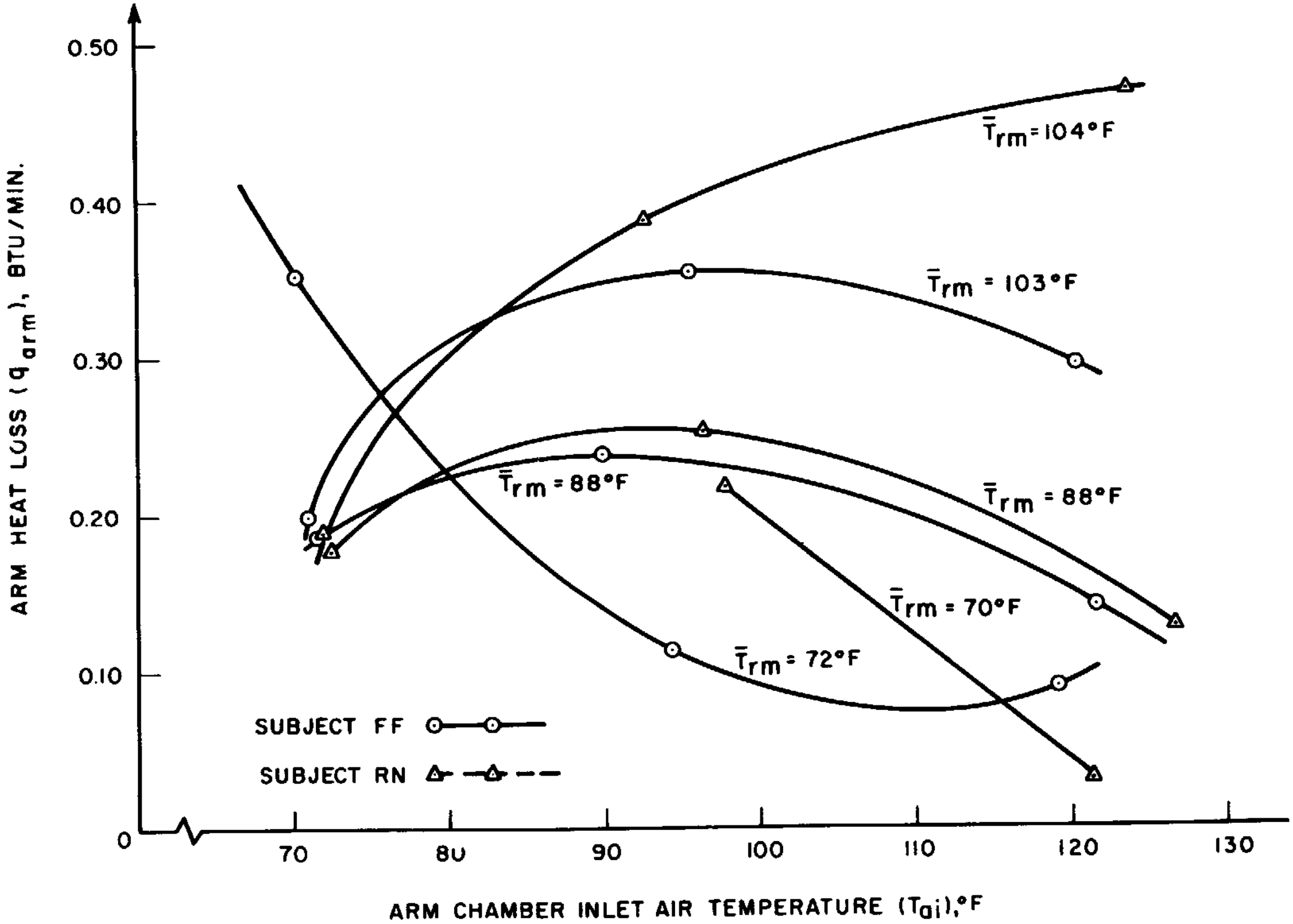
There is an inconsistency in Table 3 among the convective heat flows. For runs 10 and 11, where the arm chamber inlet air temperature was approximately $70^{o}F$ the convective heat flow term is negative, apparently indicating the arm is taking in heat. These results again must be attributed to an unknown experimental error. The evaporative heat flows were directly proportional to the corresponding water losses and are not illustrated. The error in the convective heat flows was too large in most cases, and therefore convective heat flow is not separately graphed. Heat flow as a function of ear and rectal temperature was investigated but no functional relationships were apparent on the basis of the available data.

For three cases (subject FF: $T_{rm} = 88^{o}F$ and $103^{o}F$; subject RN: $T_{rm} = 88^{o}F$) in Figure 19 maximum arm heat flow occurs at a temperature



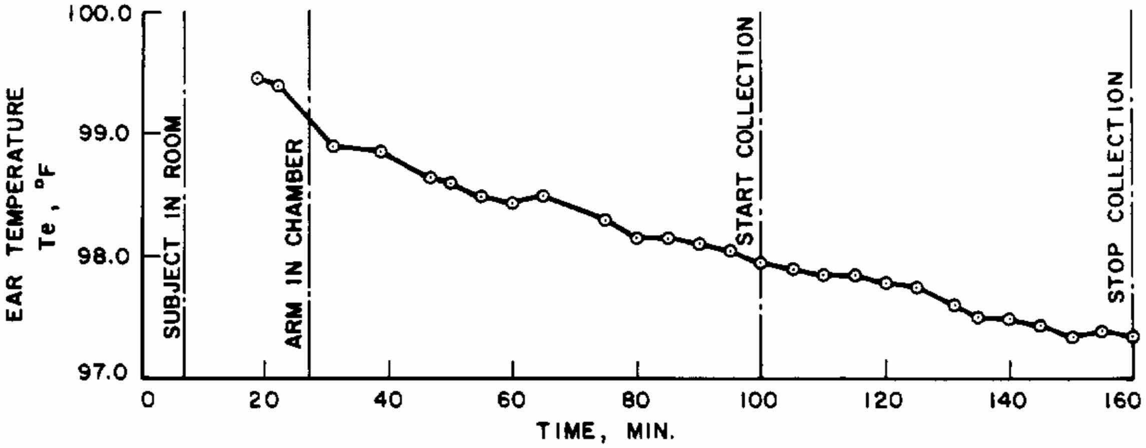
ARM HEAT LOSS AS A FUNCTION OF ROOM AIR TEMPERATURE

FIGURE 16



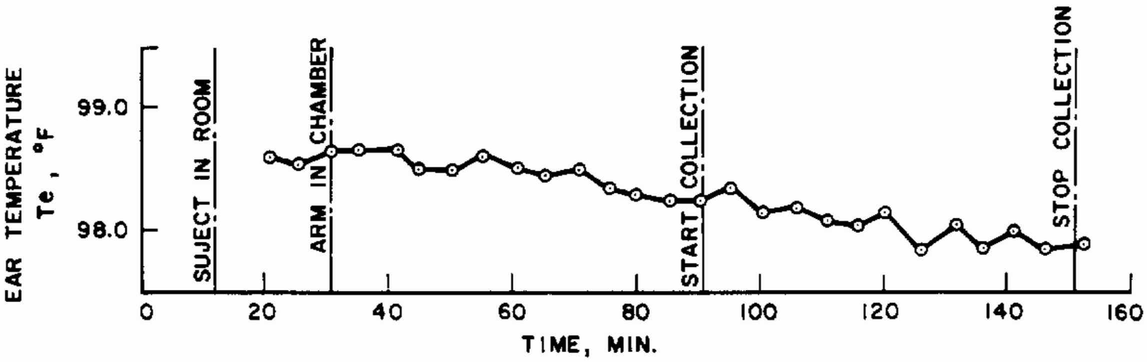
ARM HEAT LOSS AS A FUNCTION OF ARM CHAMBER INLET AIR TEMPERATURE

FIGURE 17



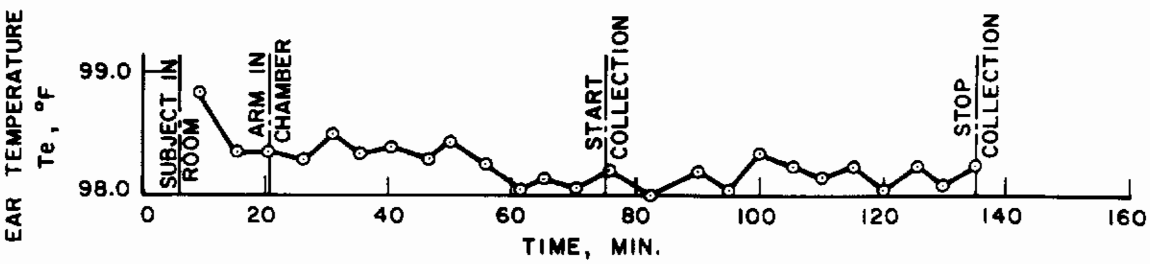
DYNAMIC RESPONSE OF TYMPANIC MEMBRANE TEMPERATURE (T_e) FOR SUBJECT RN, RUN NO. 12

FIGURE 18



DYNAMIC RESPONSE OF TYMPANIC MEMBRANE TEMPERATURE (T_e) FOR SUBJECT RN, RUN NO. 16

FIGURE 19



DYNAMIC RESPONSE OF TYMPANIC MEMBRANE TEMPERATURE (T_e) FOR SUBJECT RN, RUN NO. 7

FIGURE 20

approximately equal to that of room temperature. For this condition, Hertzman et al (1951) have determined the relative cooling power of different parts of the body for air temperatures between 24^{o} and 37^{o}C. At 37^{o}C the highest total heat loss was recorded, and heat loss at this point was still increasing with air temperature increases. At this point total arm minus hand heat loss amounted to 7.1% of total body heat loss, or about 8.5% of the heat loss from that portion of the body that is ventilated with present ventilating garments.

From the point of view of subject variability, run 17, subject RN is interesting. As pointed out above, the sweat rate of RN in run 17 caused an unusually high arm heat loss. In a previous series of unpublished runs, another subject was noted to have unusually high sweat rates during high arm chamber air temperature runs, even though room temperature was low. In this case it was learned that the subject was conditioned to cold climates from having served two winters in the Army in Korea. Subject RN of the present series could offer no comparable explanation, however. Meehan and Jacobs (1957) noted significant subject variability with respect to vasoconstrictor response. The available evidence seems to indicate that the body's heat loss mechanisms are significantly variable from individual to individual and that the arms of some individuals may exhibit greater cooling power, especially at higher ventilation air temperatures, than others. It is also possible that the heat loss mechanisms of a person may be provoked into increased activity by proper acclimatization.

It should be noted that the results presented in this report are not entirely applicable to the ventilated suit problem because the roles of the three heat loss mechanisms, evaporation, convection and radiation, are not identical between nude exposures and ventilated suit experiments. Skilling, et al (1955) noted that in the latter case a larger proportion of unevaporated perspiration occurs than with corresponding nude exposures.

C. Time Plots

A characteristic of the biothermal regulatory system is suggested in Figures 18 and 19 (subject RN). In these figures when T_e dropped to a level of approximately 98.0°F the temperature began to oscillate with an amplitude of $\frac{1}{4}$°F and a period of 15 minutes. However, during run 7 (Figure 20, subject RN) T_e dropped to 97.78°F and leveled out, exhibiting no oscillations. No oscillations were observed during any of the runs involving subject FF. An adequate explanation for the observed results does not appear to be possible without additional experimentation.

It was hoped at the outset of this experiment that similar cycling, if manifested by the body's sweat control mechanism, would show up in the hygrometer records. However, during run 2 we noted that the record was dominated by variations in sweat rate due to what apparently was emotional sweating stimulated by equipment and other noises and movements of the experimenters. It was not feasible, during this series of runs, to eliminate these stimuli.

Although nothing of quantitative value could be extracted from the data in regards to possible emotional sweating, the above evidence does seem to point toward an area of study in need of investigation since the significance of this response as a heat loss mechanism, or interaction of this response with thermoregulatory sweating, is not known.

CONCLUSIONS

1. From the available evidence, peripheral sweat control appears to be a significant factor in the human body's thermoregulatory system.
2. It appears unlikely that superficial skin temperature controls peripheral sweating to any degree, but rather that the thermal condition of the sweat glands themselves may be involved.
3. Arm heating and cooling, in the range of conditions studied in this experiment, have minimal effects on deep body temperatures (T_e and T_r).
4. Maximum arm heat loss tends to occur when the arm experiences the same environmental temperature as the rest of the body; however, subject variability with respect to sweating response offsets this result somewhat.
5. More experimentation is needed to determine the cooling power of the arm for subjects with different levels of acclimatization.

6. Additional experimentation is needed to quantitatively relate emotional sweat response to psychological stress in the presence of thermoregulatory sweating.

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