NATIONAL AERONAUTICAL AND SPACE ADMINISTRATION
GRANT NGR 14-005-050

THE PHYSICAL AND CHEMICAL PROPERTIES OF HUMAN SWEAT AND FACTORS AFFECTING THE WATER BALANCE IN CONFINED SPACES

SEMI-ANNUAL STATUS REPORT, NO. 3
FOR THE PERIOD: 1 July 1966 - 31 December 1966

from the

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CONTENTS

I. PERSONNEL

Table 1.1 lists all persons who worked under this grant during the period 1 July 1966 to 31 December 1966, including several whose salaries were not paid from the grant, but by the University of Illinois.

II. RESEARCH AIMS

Three main research programs were followed during the period July 1, 1966 to December 31, 1966: 1) A study was made of the relationship between the rate of sweating and the chemical composition of the sweat. This is a classical area of research in the physiology of human sweating, and yet there is no generally agreed body of generalizations on the factors which can and do determine the chemical concentration of substances in the sweat. We changed the rate of sweating from day to day by altering the wet and dry bulb temperatures, work being constant. 2) A comparison was made of the chemical composition of sweat collected in impermeable bags on the arms, and also collected from the naked skin of the whole body where it had evaporated. Most studies of sweat are made with an impermeable collecting system, either a bag or a capsule closely applied to the skin. Very few direct comparisons have been reported between sweat so collected and sweat simultaneously produced naturally without the interposition of an impermeable capsule. Yet from a practical point of view, this is a fundamentally important comparison, because many conclusions on total dermal losses are made from arm bag sweat on the assumption that total body sweat and arm bag sweat are closely related and vary similarly under different conditions. 3) One methodological advance has been made. A simple and versatile system has been devised and proved excellent for collecting expired gas, storing it without appreciable loss of carbon dioxide, and analyzing its composition. The results can then be put into a computer program for calculating oxygen consumption.

III. METHODS AND GENERAL CONSIDERATIONS

Chemical Methods. For the most part we have continued to use chemical methods as described in Annual Report No. 1 for the year 1965-1966.

An atomic absorption spectrophotometry instrument has been purchased from Evans Electroselenium Ltd., Halstead, Essex, England. It has been used for measuring calcium and magnesium in sweat. A photomultiplier system is in process of validation for potassium and sodium.

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Measurement of Oxygen Consumption. We have now validated an improved method for measuring oxygen consumption and carbon dioxide production in man. The paper is to appear in the Journal of Applied Physiology in February 1966. The whole paper is given in Appendix A. The abstract follows.

A system is described for measuring the oxygen consumption of men at rest, during moderate work, or during heavy work. Expired air, measured and sampled from a suitable respirometer, is collected in metalized polyethylene bags. Carbon dioxide does not diffuse measurably from these in several hours. For analysis, gas is drawn successively through a drying column, a paramagnetic oxygen meter, and a thermal conductivity CO_2 meter. Alveolar air may be analyzed directly. Calculation sheets suitable for computer programs are given for respiratory exchange and the metabolic mixture.

Collection and Processing of Sweat. For arm sweat, bags are used as described in detail in the Annual Report for 1965-1966.

A system for collecting total body sweat has been standardized. If arm sweat also is to be collected, the subject shaves his arms with an electric razor on the day before the experiment. Also on the day before the experiment, all towels, clothes, and other cloth material to be used are boiled in demineralized water and air dried. In addition all plastic bags, gloves, socks, and bathtubs are rinsed three times with adequate volumes of demineralized water and air dried.

On the day of the experiment the subject takes a hot shower using Vel (Colgate-Palmolive, New York) instead of soap. He dries with a towel cleaned with demineralized water. He empties the bladder and is weighed to the nearest 5 grams. The time is noted to the nearest minute. He now moves to a cool-dry room and dons a surgical scrub suit, including cap, cotton socks, and tennis shoes, all previously cleaned with demineralized water.

He now undertakes the sweating experiment in an environmentally controlled room. We commonly use a dry heat - walking combination to induce sweating. If arm sweat is to be collected, he sweats

TABLE I.1. PERSONS ON THIS RESEARCH PROJECT FROM 1 JULY 1966 TO 31 DECEMBER 1966. (NASA GRANT NGR 14-005-050).

Name and Title	Period of Association	Percentage of Salary Paid from this Grant
R. E. Johnson Professor	1 July-31 December	0
F. Sargent II Professor	1 July-31 December	0
Mrs. Frances Robbins Biochemical Technologist	1 July-31 December	0
T. Morimoto Research Associate	1 July-31 October	100
Janet Harris Graduate Assistant	1 July-15 August	100
Diane Wakat Graduate Assistant	1 July-15 August	100
Paul Molé Graduate Assistant	1 July-31 December	100
William Kachadorian Graduate Assistant	1 July-31 August	100
Joseph Nelson Graduate Assistant	1 July-4 August	100
Mrs. Hazel Roosevelt Clerk-Typist	1 July-1 November	25
Georgiana Benner Research Assistant	1 July-10 September	100
Jackie Davis Laboratory Attendant	1 July-27 August	100
Barbara Johnson Graduate Assistant	1 September-31 December	50
Ruth Chalmers Research Assistant	1 September-31 December	50
Mrs. Helen Sandberg Graduate Assistant	16 September-31 December	100

for 10 minutes, rinses the arm, notes the time, and dons a washed pair of arm length impermeable gloves.

At the end of the period of sweating, the subject moves back to the cool, dry room and empties the bladder. An observer wearing clean impermeable gloves removes the arm bags and measures the volume of sweat. He then removes all clothes and places them in a child's small plastic wading pool (Huey's, Urbana, Illinois). The subject now kneels nude in the tub and is washed down with successive portions of warm (37°C) distilled water, delivered from head to toe through a plastic watering can. A total of 5 liters is used for washing. He is blotted with a clean towel which is added to the wading pool. All clothes are thoroughly mixed with the water. The assumption is made that all chemicals are now evenly distributed in the sweat plus wash water. The sweat's original concentration is calculated from the following equation:

$$\text{Original concentration} = (\text{final concentration}) \frac{5 \text{ liters} + \text{glove volume} + \Delta \text{ body weight}}{\text{glove volume} + \Delta \text{ body weight}} \qquad \text{(Eq. IIIa)}$$

<u>Characteristics of Subjects</u>. Repetitive observations were made on two healthy young men. Their physical characteristics are given in Table III.1.

Height and weight were measured with a clinical scale. The surface area of the total body was calculated from the formula of Du Bois and Du Bois (1916) and Meeh (1879):

$$\underset{\text{in cm}^2}{\text{Surface Area}} = \underset{\text{in kg}}{W^{0.425}} \times \underset{\text{in cm}}{H^{0.725}} \times 71.84 \qquad \text{(Eq. IIIb)}$$

(Du Bois, D. and Du Bois, E. F.: A formula to estimate the approximate surface area if height and weight be known. Arch. Int. Med. <u>17</u>: 863-871, 1916. Meeh, K.: Oberflächenmessungen des menschlichen Körpers. Ztschr. f. Biol. <u>15</u>: 425-458, 1879.)

The surface area of the two forearms was calculated from measurements of the length and circumference of the five digits, the palm, and the forearm from wrist to elbow. The area was computed from the formula:

$$\underset{\text{in cm}^2}{\text{Area of Anatomical Unit}} = \underset{\text{in cm}}{(\text{length})} \times \underset{\text{in cm}}{(\text{mean circumference})} \qquad \text{(Eq. IIIc)}$$

The individual items of the calculations for the two subjects are given in Table III.2. The two forearms accounted for roughly 12 percent of the total surface area of the body in these two men.

TABLE III.1. CHARACTERISTICS OF SUBJECTS. SUMMER 1966. (NASA GRANT NGR 14-005-050).

DATE in 1966	HEIGHT cm	WEIGHT kg	SURFACE AREA Total Body m^2	SURFACE AREA Forearms m^2
Kachadorian, William, male, age 23 yr., graduate student, daily running and swimming.				
29 June	179.7	75.7	1.95	
6 July	-	75.7	1.95	
13 July	179.7	75.3	1.95	
20 July	178.7	74.6	1.93	0.220
27 July	179.7	74.7	1.94	
3 Aug	179.1	74.7	1.94	
Nelson, Joseph, male, age 20 yr., graduate student, daily walking, intermittent tennis, swimming and bowling.				
30 June	178.4	61.8	1.78	
7 July	-	61.7	1.78	
14 July	177.8	61.6	1.78	
21 July	178.6	62.5	1.79	0.222
28 July	179.1	62.2	1.79	
4 Aug	178.6	61.9	1.78	

General Protocol. For each week's experiment, the subject came to the metabolic unit late in the afternoon of the day before the experiment. He ate a supper at 6 p.m., a regular kind of meal for him. No food was taken thereafter until the end of the experiment next day, but the subject was urged to keep up his water balance.

The next morning the experiment was carried out as shown in Table III.3. Class and work schedules required that the men be about 4 hours out of phase with each other. Specimens were collected as required for the metabolic questions under study. Physiological measurements were made of the body temperature, the pulse rate, and the blood pressure as a check on the subject's fitness to continue the experiment to the planned end.

Environmental Conditions. The outdoor temperatures and the barometric pressures for 45 days of the summer are given in Table III.4. It was a typical summer for Champaign County, Illinois. The barometer was fairly constant around 740 mm Hg. The mean daily temperatures were from 20 to 30°C with only one day below that range, and two days above it. There were two heat waves in July, when the maximum was 35°C or over.

One chief aim of the experiments was to alter the ambient conditions between actual experimental exposures so that three different rates of sweating would be sustained on each of two occasions. In addition, total body sweat was to be studied. Therefore the ambient water vapor tension was to be kept as low as feasible. Both objectives were achieved, as Table III.5 shows. The index called by its inventors the "Predicted Four Hour Sweat Rate" (abbreviated P4SR; see McArdle, B., Dunham, W., Holling, H.E., Ladell, W. S. S., Scott, J. W., Thomson, M. L., and Weiner, J. S.: The prediction of the physiological effects of warm and hot environments. Med. Res. Council Royal Naval Personnel Res. Committee, RNP 47/391, H.S. 194, October 1947) is a useful predictor of the total thermal stress of the environment. It includes the factors dry bulb temperature, wet bulb temperature, water vapor tension, wind velocity, and metabolic heat production. For our conditions it is given in the last column of Table III.5. A stepwise increment was in fact achieved between experiments, as was desired.

Physiological Responses. Measurements of the pulse, blood pressure, oral temperature, and skin temperature (measured on the medial aspect of the left upper arm) are given in Tables III.6A and III.6B for both subjects at rest in a cool room, and after 15, 35, and 55 minutes of walking at 5.8 km per hr on the level in the hot room. The combined stresses of work and heat raised the pulse rate and body temperature, but not to values high enough to indicate any distress. There was no evidence of increased acclimatization during

TABLE III.2. SURFACE AREA OF FOREARMS OF SUBJECTS. SUMMER 1966. (NASA GRANT NGR 14-005-050).

AREA	KACH		NELS	
	Left	Right	Left	Right
Elbow to wrist, cm	27.0	29.0	29.0	29.0
Elbow circumference, cm	27.0	28.0	26.0	26.0
Wrist circumference, cm	17.5	17.0	17.5	17.0
Forearm, surface area, cm^2	600.8	652.5	630.8	623.5
Palm length, cm	10.5	10.0	9.0	9.0
Palm circumference, cm	21.8	22.5	22.0	21.5
Hand area, cm^2	228.9	225.0	198.0	193.5
Little finger - length, cm	6.0	6.0	7.0	7.0
- circumference, cm	5.5	6.0	6.0	6.0
- area, cm^2	33.0	36.0	42.0	42.0
Ring finger - length, cm	7.5	7.5	9.0	9.0
- circumference, cm	6.5	7.0	6.5	5.5
- area, cm^2	48.8	52.5	58.5	49.5
Middle finger - length, cm	8.5	8.5	10.0	9.5
- circumference, cm	7.0	7.5	7.0	6.0
- area, cm^2	59.5	63.8	70.0	57.0
Forefinger - length, cm	7.0	7.5	9.5	9.0
- circumference, cm	6.5	7.0	7.0	6.5
- area, cm^2	45.5	52.5	65.5	58.5
Thumb - length, cm	7.5	7.5	10.0	8.5
- circumference, cm	7.0	7.0	7.5	7.0
- area, cm^2	52.5	52.5	75.0	59.5
Hand and forearm, total area, cm^2	1069.0	1134.8	1139.8	1083.5
Sum of 2 forearms, area, cm^2	2203.8		2223.3	

TABLE III.3. SCHEDULE OF EXPERIMENTS. SUMMER 1966.
(NASA GRANT NGR 14-005-050).

SUBJECT: KACH TIME OF DAY:	1100	1300	1310	1315	1320	1325	1330	1335	1340	1345	1350	1355	1400	1405	1410	1415	1420	1425	1430	1435	1440	1450	1500
SUBJECT: NELS TIME OF DAY:	0700	0800	0810	0815	0820	0825	0830	0835	0840	0845	0850	0855	0900	0905	0910	0915	0920	0925	0930	0935	0940	0950	1000
ACTIVITY OF SUBJECT																							
1. Rises	X																						
2. Showers		X																					
3. Walks					X	X	X		X	X	X		X	X	X		X	X	X				
4. Dress, soak arms								X															
5. Rest												X				X				X			
6. H_2O consumed		X																					
SPECIMENS																							
1. Urine				X																		X	
2. Sweat, arm												X				X				X			
3. Sweat, body																							X
4. Blood																							X
5. Respiratory Gas		X	X							X	X						X	X					
MEASUREMENTS																							
1. Body Weight		X																				X	
2. Body Height				X																			
3. Temperature, oral, skin				X								X											X
4. Pulse rate				X								X											X
5. Blood pressure				X																			X

TABLE III.4. OUTDOOR TEMPERATURES AND BAROMETRIC PRESSURE. SUMMER 1966. (NASA GRANT NGR 14-005-050).

DAY	DATE	TEMPERATURE Max ^0C	TEMPERATURE Min ^0C	TEMPERATURE Mean ^0C	BAROMETRIC PRESSURE mm Hg
JUNE					
T	28	30	20	25	742
W	29	30	19	25	760
Th	30	33	20	27	761
JULY					
F	1	34	22	28	742
S	2	34	23	29	742
Sun	3	34	22	28	740
M	4	32	22	27	740
T	5	35	19	27	738
W	6	32	19	26	738
Th	7	29	18	23	740
F	8	32	19	26	741
S	9	36	21	29	740
Sun	10	37	23	30	741
M	11	36	19	27	742
T	12	38	25	32	740
W	13	38	26	32	738
Th	14	36	22	29	740
F	15	28	20	24	743
S	16	30	16	23	745
Sun	17	33	17	26	744
M	18	37	19	28	740
T	19	33	18	26	738

DAY	DATE	TEMPERATURE Max ^0C	TEMPERATURE Min ^0C	TEMPERATURE Mean ^0C	BAROMETRIC PRESSURE mm Hg
JULY					
W	20	26	15	21	743
Th	21	28	13	21	745
F	22	29	15	22	744
S	23	29	20	25	744
Sun	24	33	21	27	744
M	25	33	18	26	745
T	26	33	22	28	741
W	27	29	22	26	739
Th	28	32	21	27	738
F	29	28	17	23	741
S	30	28	15	22	743
Sun	31	29	16	23	743
AUGUST					
M	1	33	16	25	740
T	2	25	14	19	740
W	3	26	15	20	743
Th	4	27	12	20	742
F	5	29	15	22	742
S	6	31	16	23	741
Sun	7	31	16	23	738
M	8	30	17	23	739
T	9	28	16	22	741
W	10	19	16	18	739
Th	11	26	15	20	742

the summer. The men were presumable maximally acclimatized by July 1. There was an increase in the skin temperature with increasing heat stress.

Respiratory Metabolic Data. The pulmonary ventilation, respiratory quotient, oxygen consumed, and carbon dioxide produced are given in Tables III.7A and III.7B for the two subjects at rest in a cool room, and after 15 and 55 minutes of walking at 5.8 km per hr on the level in the hot room. The walking increased the metabolic rate about fourfold. Good steady states were achieved in each experiment, and there was no significant effect of increasing the thermal heat load from week to week.

The Metabolic Mixture. The metabolic mixture includes the grams of protein, carbohydrate, and fat metabolized and the energy and water produced from the three nutrients. Calculations of nutrient usage for the two subjects are given in Tables III.8A, III.8B. Over half the percentage of calories used in the walk was derived from fat.

Metabolic water increased from three- to fivefold between the rest and the walk (Table III.9) as did the energy production (Table III.10).

There was no significant effect of ambient thermal conditions on the percentage of calories derived from protein, carbohydrate, or fat, or on the metabolic water production, or the total calorie expenditure.

Rate of Sweating. The data for sweating are given for the two subjects in Tables III.11A and III.11B. The values for the arm plus body, the arm, and the body (minus arm) are given in sections A, B, and C. In each section, the surface area, the collection time, the volume, and the rate, calculated as a gross rate per hour and as a rate per square meter per hour, are shown. Table III.12 shows the various factors for calculating the dermal loss in total body sweat.

The major purpose of the environmental controls was achieved. With each increase of thermal stress, there was a corresponding increase in the rate of sweating, this occurring both for the naked body and for the enclosed forearm, as shown in Figure III.1. Furthermore, there was a good correlation between the total body and the forearm under the glove. However, the naked body sweated faster than the gloved forearm, as shown in Figure III.2. In twelve comparisons of Arm vs. Body, the body was faster, on a square meter basis, in ten experiments (B vs C in Tables III.11A and III.11B).

TABLE III.5. PHYSICAL CONDITIONS IN TREADMILL ROOM. SUMMER 1966. (NASA GRANT NGR 14-005-050).

Date of Experiment	Dry Bulb mean °C	Wet Bulb mean °C	Mean Water Vapor Tension mm Hg	Relative Humidity %	P4SR L/m^2
KACHADORIAN					
29 June	40.6	21.2	9	17	1.2
6 July	45.2	27.1	18	25	1.9
13 July	47.0	26.7	16	20	2.2
20 July	40.5	22.0	9	18	1.2
27 July	45.3	24.3	12	17	1.9
3 Aug	47.8	26.8	16	19	2.2
NELSON					
30 June	40.8	21.3	9	17	1.2
7 July	45.2	27.5	18	25	1.9
14 July	47.3	26.9	16	20	2.2
21 July	40.7	21.2	9	18	1.2
28 July	45.3	24.4	12	17	1.9
4 Aug	47.3	27.0	17	20	2.2

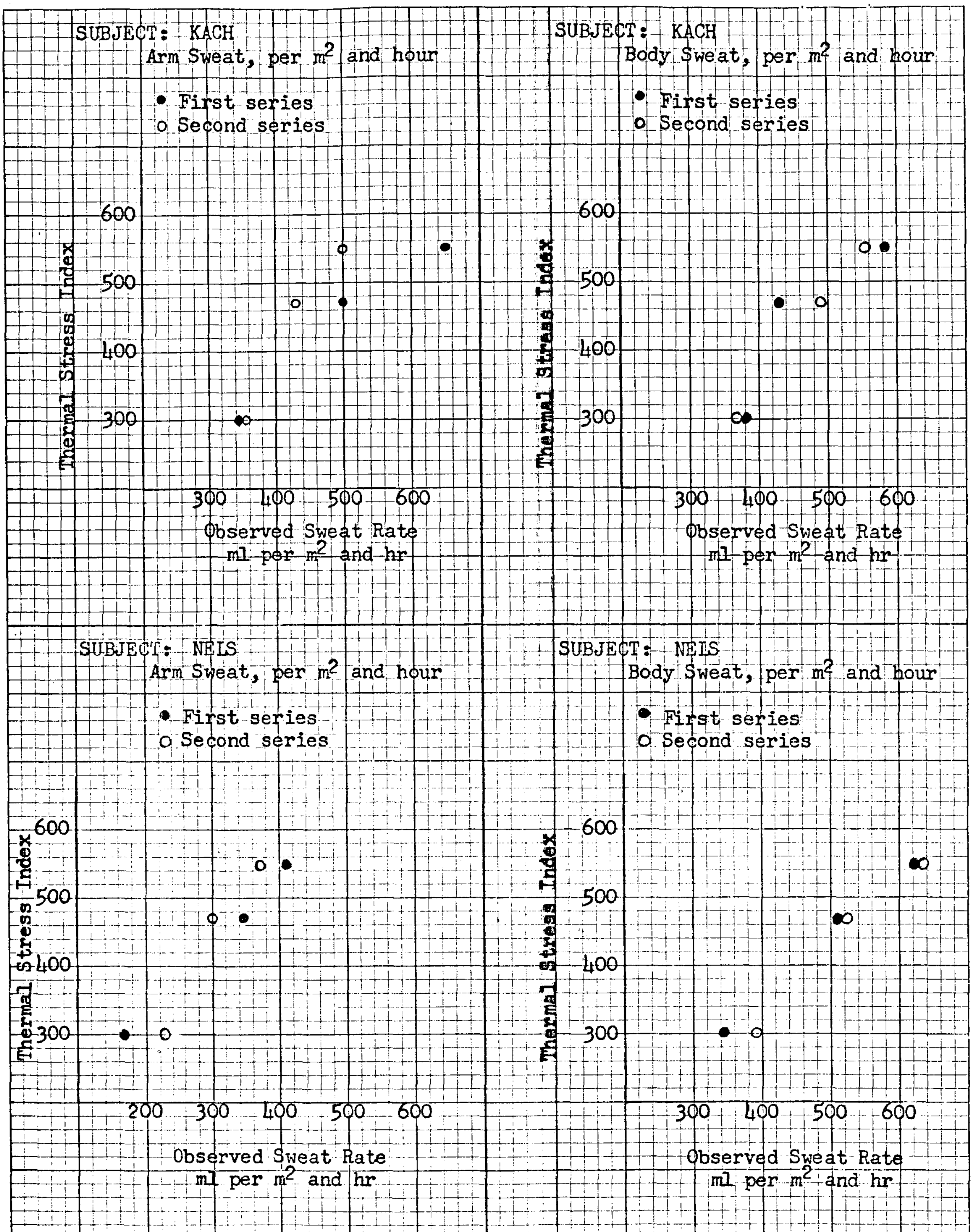

FIGURE III.1. Observed rates of sweating from arms covered with impermeable bag and total naked body compared with rates predicted by the thermal stress index of McArdle et al (1947). Summer 1966. (NASA GRANT NGR 14-005-050).

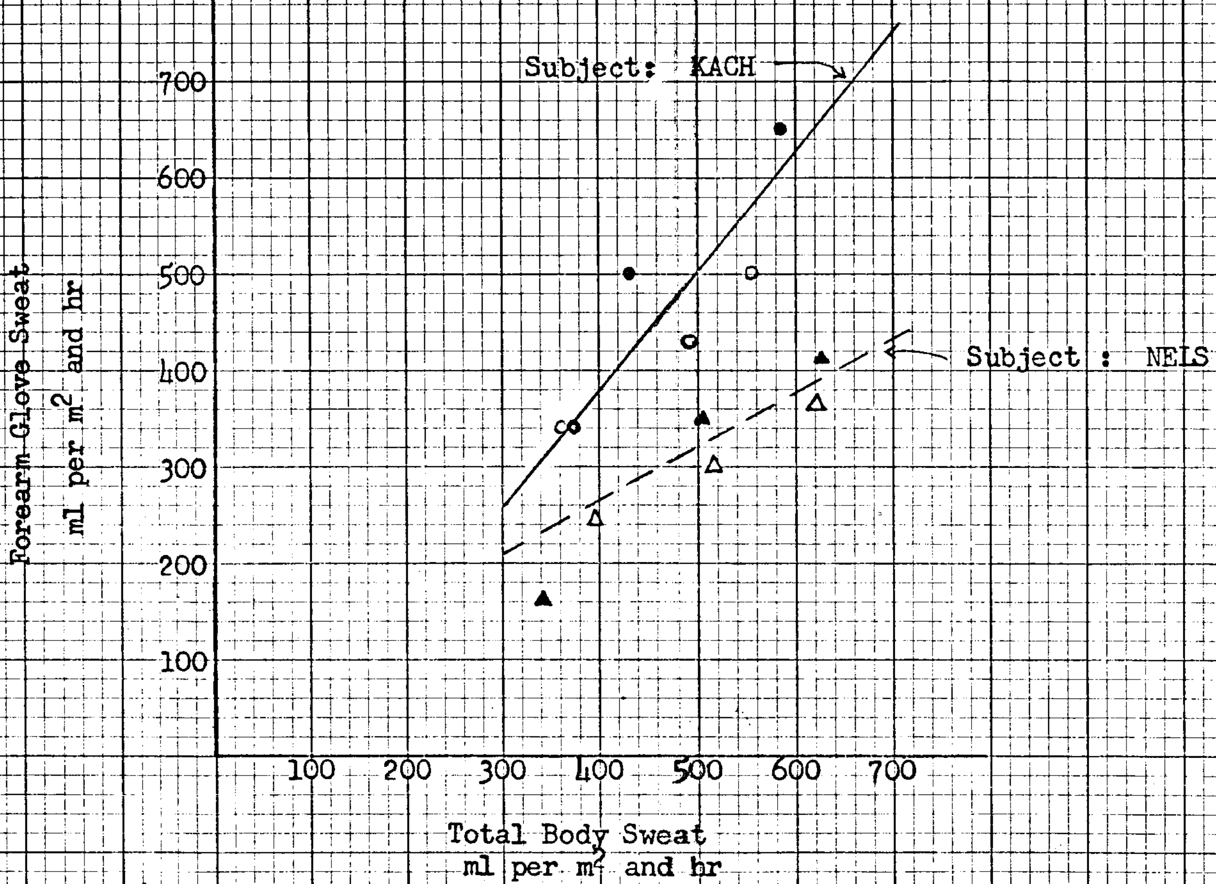

FIGURE III. 2. Observed rates of sweating from arms covered with impermeable bags compared with observed rates from total naked body. (NASA GRANT NGR 14-005-050). SUMMER 1966.

TABLE III.6A. PHYSIOLOGICAL RESPONSES OF SUBJECTS. SUMMER 1966. (NASA GRANT NGR 14-005-050).

SUBJECT: KACH

	EXPERIMENT					
	29 June	6 July	13 July	20 July	27 July	3 Aug
A. AT REST (25°C)						
Pulse, beats/min	64	56	60	56	58	60
Blood pressure, mm Hg	126/68	130/74	118/60	106/58	118/64	120/68
Oral temperature, °C	36.1	36.1	36.5	36.1	36.3	36.3
Skin temperature, °C	30.0	32.2	33.1	32.7	31.7	31.1
B. DURING WALK (0-15 min)						
Pulse, beats/min	80	94	96	74	86	96
Blood pressure, mm Hg	-	-	-	-	-	-
Oral temperature, °C	36.9	37.8	37.1	36.3	36.8	37.3
Skin temperature, °C	36.2	38.7	38.7	36.1	37.4	38.4
C. DURING WALK (20-35 min)						
Pulse, beats/min	86	100	110	80	98	112
Blood pressure, mm Hg	-	-	-	-	-	-
Oral temperature, °C	37.2	37.8	37.4	36.6	37.2	37.8
Skin temperature, °C	36.2	37.0	35.6	36.6	37.4	37.9
D. DURING WALK (40-55 min)						
Pulse, beats/min	90	104	128	90	110	120
Blood pressure, mm Hg	130/70	130/58	130/70	122/68	116/68*	-
Oral temperature, °C	37.2	37.8	37.6	36.6	37.2	37.8
Skin temperature, °C	36.8	37.5	36.3	36.3	37.2	38.4

*Taken 20 min. later, after finishing walk.

TABLE III.6B. PHYSIOLOGICAL RESPONSES OF SUBJECTS. SUMMER 1966. (NASA GRANT NGR 14-005-050).

SUBJECT: NELS

	EXPERIMENT					
	30 June	7 July	14 July	21 July	28 July	4 Aug
A. AT REST (25°C)						
Pulse, beats/min	54	80	50	60	56	60
Blood pressure, mm Hg	110/78	120/98	106/70	110/66	106/69	100/68
Oral temperature, °C	35.7	37.5	36.0	36.3	36.4	36.8
Skin temperature, °C	32.3	29.3	29.5	32.0	31.5	32.2
B. DURING WALK (0-15 min)						
Pulse, beats/min	98	106	102	90	92	106
Blood pressure, mm Hg	-	-	-	-	-	-
Oral temperature, °C	36.2	37.8	36.8	36.7	37.0	37.3
Skin temperature, °C	35.8	35.9	36.0	35.0	36.0	36.3
C. DURING WALK (20-35 min)						
Pulse, beats/min	100	118	118	100	106	118
Blood pressure, mm Hg	-	-	-	-	-	-
Oral temperature, °C	36.3	38.0	37.6	37.2	37.2	37.9
Skin temperature, °C	36.2	35.1	36.3	33.0	35.5	36.8
D. DURING WALK (40-55 min)						
Pulse, beats/min	104	120	120	106	108	128
Blood pressure, mm Hg	116/76	94/64	90/56	108/72	110/70	106/36
Oral temperature, °C	36.3	38.0	38.0	37.0	37.3	38.0
Skin temperature, °C	35.5	34.1	36.5	34.4	36.2	37.6

TABLE III.7A. RESPIRATORY METABOLIC RESPONSES. SUMMER 1966. (NASA GRANT NGR 14-005-050).

SUBJECT: KACH

	EXPERIMENT					
	29 June	6 July	13 July	20 July	27 July	3 Aug
A. AT REST (25°C)						
Pulmonary ventilation, L/min	4.58	4.82	5.07	5.57	5.81	6.82
Respiratory quotient	0.70	0.82	0.71	0.74	0.72	0.84
O_2 consumed, ml/kg/min	3.54	3.14	3.31	3.41	3.57	3.39
CO_2 produced, ml/kg/min	2.50	2.60	2.36	2.55	2.60	2.87
B. DURING WALK (0-15 min)						
Pulmonary ventilation, L/min	17.2	18.0	20.7	17.3	17.2	17.4
Respiratory quotient	0.73	0.83	0.79	0.76	0.75	0.79
O_2 consumed, ml/kg/min	13.4	12.5	14.8	12.6	12.9	12.5
CO_2 produced, ml/kg/min	9.8	10.6	11.8	9.6	9.7	9.9
C. DURING WALK (40-55 min)						
Pulmonary ventilation, L/min	17.5	18.1	20.1	17.5	17.1	19.2
Respiratory quotient	0.74	0.81	0.78	0.73	0.74	0.78
O_2 consumed, ml/kg/min	13.0	13.3	15.2	12.9	12.8	13.2
CO_2 produced, ml/kg/min	9.6	10.8	11.9	9.4	9.6	10.3

TABLE III.7B. RESPIRATORY METABOLIC RESPONSES. SUMMER 1966.
(NASA GRANT NGR 14-005-050).

SUBJECT: NELS

	EXPERIMENT					
	30 June	7 July	14 July	21 July	28 July	4 Aug
A. AT REST (25°C)						
Pulmonary ventilation, L/min	7.83	4.73	3.82	4.26	4.54	4.50
Respiratory quotient	0.93	0.75	0.74	0.78	0.80	0.73
O_2 consumed, ml/kg/min	3.99	4.03	3.19	3.51	3.70	3.99
CO_2 produced, ml/kg/min	3.78	3.03	2.38	2.75	2.99	2.92
B. DURING WALK (0-15 min)						
Pulmonary ventilation, L/min	16.2	16.4	16.0	14.1	16.5	15.3
Respiratory quotient	0.79	0.77	0.81	0.78	0.80	0.79
O_2 consumed, ml/kg/min	13.3	14.5	13.5	14.2	13.6	13.6
CO_2 produced, ml/kg/min	10.6	11.2	11.1	11.1	11.1	10.8
C. DURING WALK (40-55 min)						
Pulmonary ventilation, L/min	17.7	16.9	23.1	16.0	16.6	15.7
Respiratory quotient	0.81	0.75	0.77	0.79	0.79	0.76
O_2 consumed, ml/kg/min	13.8	14.5	14.1	13.7	13.7	13.5
CO_2 produced, ml/kg/min	11.2	10.9	10.9	10.8	10.8	10.4

TABLE III.8A. METABOLIC MIXTURE: PERCENTAGE OF CALORIES DERIVED FROM PROTEIN, CARBOHYDRATE, AND FAT. SUMMER 1966. (NASA GRANT NGR 14-005-050).

SUBJECT: KACH

	EXPERIMENT					
	29 June	6 July	13 July	20 July	27 July	3 Aug
A. FROM PROTEIN						
At rest (25°C)	13.54	15.40	25.91	15.38	22.73	29.10
During walk:						
0-15 min	3.53	5.35	5.15	6.04	6.40	4.17
40-55 min	3.62	5.10	5.02	5.95	6.43	3.95
B. FROM CARBOHYDRATE						
At rest (25°C)	-5.14	37.55	-7.79	9.08	-1.73	39.05
During walk:						
0-15 min	7.35	47.59	30.43	18.23	15.38	30.05
40-55 min	12.03	36.05	24.91	7.46	12.09	24.87
C. FROM FAT						
At rest (25°C)	91.58	47.05	82.88	75.54	79.00	31.85
During walk:						
0-15 min	89.12	47.06	64.41	75.72	78.22	65.78
40-55 min	84.35	58.85	70.07	86.59	81.48	71.18

TABLE III.8B. METABOLIC MIXTURE: PERCENTAGE OF CALORIES DERIVED FROM PROTEIN, CARBOHYDRATE, AND FAT. SUMMER 1966. (NASA GRANT NGR 14-055-050).

SUBJECT: NELS	EXPERIMENT					
	30 June	7 July	14 July	21 July	28 July	4 Aug
A. FROM PROTEIN						
At rest (25^oC)	29.23	10.24	34.84	33.50	29.66	28.38
During walk:						
0-15 min	5.83	2.75	3.45	5.82	4.81	2.77
40-55 min	5.61	2.78	3.34	6.03	4.82	2.81
B. FROM CARBOHYDRATE						
At rest (25^oC)	74.01	12.13	-0.27	15.68	25.60	-1.70
During walk:						
0-15 min	30.04	23.11	39.57	25.29	36.49	31.37
40-55 min	35.15	16.04	23.25	28.03	28.39	20.79
C. FROM FAT						
At rest (25^oC)	-3.24	77.10	65.44	50.82	44.74	73.32
During walk:						
0-15 min	64.13	74.15	56.98	68.89	58.70	65.86
40-55 min	59.24	81.19	73.41	65.94	66.79	76.40

TABLE III.9. METABOLIC MIXTURE: METABOLIC WATER. SUMMER 1966. (NASA GRANT NGR 14-005-050).

(VALUES ARE EXPRESSED AS GRAMS PER HOUR.)

SUBJECT	CONDITION	EXPERIMENT					
		29 June	6 July	13 July	20 July	27 July	3 Aug
KACH	At rest (25°C)	8.178	8.292	7.308	8.052	8.030	8.620
	During walk:						
	0-15 min	39.976	34.878	38.640	31.290	31.760	32.370
	40-55 min	32.508	35.556	39.162	30.888	31.320	33.730
		30 June	7 July	14 July	21 July	28 July	4 Aug
NELS	At rest (25°C)	9.426	8.064	5.796	6.836	7.480	7.340
	During walk:						
	0-15 min	28.614	30.582	29.856	30.368	30.100	29.510
	40-55 min	30.156	29.772	29.592	29.485	29.390	28.340

TABLE III.10. METABOLIC MIXTURE: ENERGY PRODUCTION. SUMMER 1966.
(NASA GRANT NGR 14-005-050).

(VALUES ARE EXPRESSED AS KILOCALORIES PER KILOGRAM BODY WEIGHT PER HOUR.)

SUBJECT	CONDITION	EXPERIMENT					
		29 June	6 July	13 July	20 July	27 July	3 Aug
KACH	At rest (25°C)	0.969	0.878	0.889	0.933	0.965	0.936
	During walk:						
	0-15 min	3.735	3.562	4.139	3.495	3.570	3.497
	40-55 min	3.637	3.735	4.254	3.551	3.550	3.691
		30 June	7 July	14 July	21 July	28 July	4 Aug
NELS	At rest (25°C)	1.137	1.114	0.855	0.949	1.012	1.073
	During walk:						
	0-15 min	3.745	4.065	3.814	3.974	3.887	3.825
	40-55 min	3.896	4.031	3.939	3.833	3.831	3.774

TABLE III.11A. SWEAT RATES. SUMMER 1966.
(NASA GRANT NGR 14-005-050).

SUBJECT: KACH

	EXPERIMENT					
	29 June	6 July	13 July	20 July	27 July	3 Aug
A. ARM + BODY*						
Surface area, m^2	1.95	1.95	1.95	1.93	1.94	1.94
Collection time, min.	73	74	76	71	72	71
Volume, ml.	866	1065	1463	816	1124	1264
Rate: ml/hour.	711	864	1155	690	937	1068
ml/hour/m^2	365	443	592	358	483	551
B. ARM+						
Surface area, m^2	0.22	0.22	0.22	0.22	0.22	0.22
Collection time, min.	60	60	60	60	60	60
Volume, ml.	71	110	143	71	95	110
Rate: ml/hour.	71	110	143	71	95	110
ml/hour/m^2	323	500	650	323	432	500
C. BODY**						
Surface area, m^2	1.73	1.73	1.73	1.71	1.72	1.72
Collection time, min.	73	74	76	71	72	71
Volume, ml, calculated.	795	955	1320	745	1029	1154
Rate: ml/hour.	640	754	1012	619	842	958
ml/hour/m^2	370	436	585	362	490	557

* Total body for weight loss.
\+ Portion enclosed in impermeable bags.
**(Arm + body) minus (Arm).

TABLE III.11B. SWEAT RATES. SUMMER 1966.
(NASA GRANT NGR 14-005-050).

SUBJECT: NELS

	EXPERIMENT					
	30 June	7 July	14 July	21 July	28 July	4 Aug
A. ARM + BODY*						
Surface area, m^2	1.78	1.78	1.78	1.79	1.79	1.78
Collection time, min.	72	86	77	74	75	74
Volume, ml.	685	1242	1372	826	1095	1294
Rate: ml/hour	570	870	1070	670	876	1049
ml/hour/m^2	320	490	600	374	489	589
B. ARM+						
Surface area, m^2	0.22	0.22	0.22	0.22	0.22	0.22
Collection time, min.	60	60	60	60	60	60
Volume, ml.	37	78	91	50	66	80
Rate: ml/hour	37	78	91	50	66	80
ml/hour/m^2	167	350	410	227	300	364
C. BODY**						
Surface area, m^2	1.56	1.56	1.56	1.57	1.57	1.56
Collection time, min.	72	86	77	74	75	74
Volume, ml, calculated	650	1166	1282	776	1029	1214
Rate: ml/hour	533	792	979	620	810	969
ml/hour/m^2	342	507	627	395	516	621

* Total body for weight loss.
\+ Portion enclosed in impermeable bags.
** (Arm + body) minus (Arm).

TABLE III.12. TOTAL BODY SWEAT: DILUTION RELATIONS. SUMMER 1966. (NASA GRANT NGR 14-005-050).

SWEAT		EXPERIMENT					
Value	Unit	29 June	6 July	13 July	20 July	27 July	3 Aug
KACH							
Gross value*	gm	870	1070	1470	820	1130	1270
Gross value+	ml	866	1065	1463	816	1124	1264
Gross value** (minus arm sweat)	ml	795	955	1320	745	1029	1154
H_2O added	ml	5000	5000	5000	5000	5000	5000
Dilution factor‡		6.289	5.236	3.788	6.711	4.859	4.332
NELS							
Gross value*	gm	690	1250	1380	830	1100	1300
Gross value+	ml	687	1244	1373	826	1095	1294
Gross value** (minus arm sweat)	ml	650	1166	1282	776	1029	1214
H_2O added	ml	5000	5000	5000	5000	5000	5000
Dilution factor‡		7.692	4.288	3.900	6.443	4.859	4.118

* Measured by body weight loss; includes arm bag sweat.

\+ Calculated from formula: $vol = \frac{gm}{1.005}$

** Arm bag sweat measured in ml (see Table 11).

‡ Calculated from equation factor; 5000 ÷ (Gross value - Arm); assume total evaporation.

In summary, the rate of sweating and the skin temperature increased with increasing thermal stress. At the same time excellent steady states were achieved, with no real differences between experiments in pulse rate, oral temperature, blood pressure, or oxygen consumption. In other words, we have changes in the rate of sweating as the single variable in studying sweat chemistry associated with a rising skin temperature.

IV. CHEMICAL COMPOSITION OF SWEAT IN RELATION TO RATE OF SWEATING

The excretion of various substances in the sweat is expressed in three ways in Tables IV.1 through IV.6. Data for each subject are tabulated on separate pages identified as "A" and "B". The data for arm bag sweat are listed first (Tables IV.1, IV.2, and IV.3), and then those for the total body (Tables IV.4, IV.5, and IV.6). First the absolute concentrations are given (Tables IV.1 and IV.4); second, the absolute excretion rate with time (Tables IV.2 and IV.5); and finally, the excretion rate per square meter of skin and hour (Tables IV.3 and IV.6).

Previous work done in this laboratory on the relation between the rate of sweating and the chemical composition of the sweat produced has been presented by Adams et al (Adams, R., Johnson, R. E., and Sargent, F. II: The osmotic pressure (freezing point) of human sweat in relation to its chemical composition. Quart. J. Exp. Physiol. 43:241-257 (3), 1958). For present purposes, some of the data are summarized in Table IV.7 and Table IV.8, together with comparable data in the four series of experiments with our two subjects. Generally speaking, the chemistry of the sweat was similar in both studies. The sweat was hypertonic when compared with values for normal blood plasma. About 90 percent of the osmotic pressure could be accounted for by the sum of Na, K, NH_3, Cl, lactate, and urea. Na and Cl were close in value, and both strongly hypotonic to serum. K, NH_3, and lactate were strongly hypertonic to serum. Urea was about isotonic.

When the changes in rates of sweating were scrutinized in relation to the composition of the glove sweat, interesting similarities but also differences between our data and those of Adams et al (1958) emerged. The similarities as sweat rate increased were rises in Na and Cl. The differences were no change in K and an increase in pH in our subjects. Our two subjects behaved differently with respect to NH_3 and lactate, showing either no change or the same as the subjects of Adams et al (1958). For urea, one showed a decrease, the other an increase.

TABLE IV.1A. CHEMISTRY OF ARM SWEAT: CONCENTRATION. SUMMER 1966. (NASA GRANT NGR 14-005-050).

SUBJECT: KACH

CONSTITUENT		EXPERIMENT					
Name	Unit	29 June	6 July	13 July	20 July	27 July	3 Aug
Na	mEq/L	37.1	54.0	51.0	44.0	31.0	43.0
K	"	5.7	5.1	5.2	5.1	3.8	5.1
Mg	"	0.3	0.2	0.1	0.2	0.1	0.4
Ca	"	0.9	0.2	0.4	0.5	0.3	0.3
Cl	"	29.8	43.9	45.5	32.5	26.3	40.8
Lactate	"	16.5	12.7	12.2	15.1	15.0	13.8
NH_3	"	1.4	2.1	2.0	2.5	1.7	2.1
Urea	mM/L	5.0	7.8	7.9	7.8	6.3	8.0
Total N	mg/L	340.0	217.0	335.0	414.0	260.0	340.0
Creatinine	"	1.0	0.6	0.8	0.5	0.6	0.5
Osmolarity	mOsm/L	105.0	118.0	127.0	103.0	115.0	115.0
pH		4.68	5.35	5.02	4.92	5.12	5.92

TABLE IV.1B. CHEMISTRY OF ARM SWEAT: CONCENTRATION. SUMMER 1966. (NASA GRANT NGR 14-005-050).

SUBJECT: NELS

CONSTITUENT		EXPERIMENT					
Name	Unit	30 June	7 July	14 July	21 July	28 July	4 Aug
Na	mEq/L	49.0	41.0	60.0	38.0	45.0	57.0
K	"	6.1	7.0	5.1	5.4	5.0	5.6
Mg	"	0.8	0.4	0.4	0.7	0.4	0.3
Ca	"	0.8	0.5	0.1	0.4	0.2	0.3
Cl	"	44.8	38.3	52.9	34.8	38.2	51.4
Lactate	"	14.7	13.6	13.0	15.0	14.5	15.8
NH_3	"	3.5	1.8	2.1	3.1	2.1	2.1
Urea	mM/L	11.6	10.3	8.9	11.4	9.5	10.4
Total N	mg/L	610.0	442.0	380.0	510.0	463.0	430.0
Creatinine	"	1.3	0.7	0.6	0.7	0.6	0.9
Osmolarity	mOsm/L	139.0	138.0	146.0	113.0	117.0	148.0
pH		5.85	6.61	7.10	6.45	6.78	7.50

TABLE IV.2A. CHEMISTRY OF ARM SWEAT: EXCRETION RATE (TIME). SUMMER 1966. (NASA GRANT NGR 14-005-050).

SUBJECT: KACH

CONSTITUENT		EXPERIMENT					
Name	Unit	29 June	6 July	13 July	20 July	27 July	3 Aug
Na	mEq/hr	2.63	5.94	7.29	3.12	2.95	4.73
K	"	0.41	0.56	0.74	0.36	0.36	0.56
Mg	"	0.02	0.02	0.01	0.01	0.01	0.04
Ca	"	0.06	0.02	0.06	0.04	0.03	0.03
Cl	"	2.11	4.83	6.50	2.31	2.50	4.48
Lactate	"	1.18	1.40	1.74	1.07	1.65	1.52
NH_3	"	0.10	0.23	0.29	0.18	0.19	0.23
Urea	mM/hr	0.35	0.86	1.13	0.55	0.69	0.88
Total N	mg/hr	24.14	23.90	47.90	29.40	24.70	37.40
Creatinine	"	0.07	0.07	0.11	0.04	0.07	0.05
Osmolarity	mOsm/hr	7.46	12.98	18.16	7.31	10.93	12.65

TABLE IV.2B. CHEMISTRY OF ARM SWEAT: EXCRETION RATE (TIME). SUMMER 1966. (NASA GRANT NGR 14-005-050).

SUBJECT: NELS

CONSTITUENT		EXPERIMENT					
Name	Unit	30 June	7 July	14 July	21 July	28 July	4 Aug
Na	mEq/hr	1.81	3.20	5.46	1.90	2.97	4.56
K	"	0.23	0.55	0.46	0.27	0.33	0.45
Mg	"	0.03	0.03	0.04	0.05	0.03	0.02
Ca	"	0.03	0.04	0.01	0.02	0.01	0.02
Cl	"	1.66	3.00	4.81	1.74	2.52	4.11
Lactate	"	0.54	1.06	1.18	0.75	0.96	1.26
NH_3	"	0.13	0.14	0.19	0.20	0.14	0.17
Urea	mM/hr	0.43	0.80	0.81	0.57	0.63	0.83
Total N	mg/hr	22.60	34.50	34.60	25.50	30.56	34.00
Creatinine	"	0.05	0.06	0.06	0.03	0.04	0.07
Osmolarity	mOsm/hr	5.14	10.76	13.29	5.65	7.72	11.84

TABLE IV.3A. CHEMISTRY OF ARM SWEAT: EXCRETION RATE (TIME AND SURFACE AREA). SUMMER 1966. (NASA GRANT NGR 14-005-050).

SUBJECT: KACH

CONSTITUENT		EXPERIMENT					
Name	Unit	29 June	6 July	13 July	20 July	27 July	3 Aug
Na	$mEq/m^2/hr$	12.0	27.0	33.2	14.2	13.4	21.5
K	"	1.8	2.6	3.4	1.6	1.6	2.6
Mg	"	0.10	0.10	0.06	0.06	0.04	0.20
Ca	"	0.30	0.10	0.30	0.20	0.10	0.15
Cl	"	9.6	22.0	29.5	10.5	11.4	20.4
Lactate	"	5.4	6.4	7.9	4.9	7.5	6.9
NH_3	"	0.4	1.0	1.3	0.8	0.9	1.0
Urea	$mM/m^2/hr$	1.6	3.9	5.2	2.5	3.2	4.0
Total N	$mg/m^2/hr$	109.8	108.6	217.7	133.6	112.3	170.0
Creatinine	"	0.32	0.32	0.49	0.17	0.26	0.24
Osmolarity	$mOsm/m^2/hr$	33.9	59.0	82.6	33.2	49.7	57.5

TABLE IV.3B. CHEMISTRY OF ARM SWEAT: EXCRETION RATE (TIME AND SURFACE AREA). SUMMER 1966. (NASA GRANT NGR 14-005-050).

SUBJECT: NELS

CONSTITUENT		EXPERIMENT					
Name	Unit	30 June	7 July	14 July	21 July	28 July	4 Aug
Na	$mEq/m^2/hr$	8.2	14.5	24.8	8.6	13.5	20.7
K	"	1.0	2.5	2.1	1.2	1.5	2.0
Mg	"	0.14	0.14	0.16	0.16	0.12	0.11
Ca	"	0.10	0.20	0.04	0.09	0.06	0.11
Cl	"	7.5	13.6	21.9	7.9	11.5	18.7
Lactate	"	2.5	4.8	5.4	3.4	4.4	5.7
NH_3	"	0.6	0.6	0.9	0.9	0.6	0.8
Urea	$mM/m^2/hr$	2.0	3.6	3.7	2.6	2.9	3.8
Total N	$mg/m^2/hr$	102.7	156.8	157.3	115.9	138.9	156.5
Creatinine	"	0.22	0.25	0.25	0.15	0.19	0.34
Osmolarity	$mOsm/m^2/hr$	23.4	48.9	60.4	25.7	35.1	53.8

TABLE IV.4A. CHEMISTRY OF TOTAL BODY SWEAT: CONCENTRATION.* SUMMER 1966. (NASA GRANT NGR 14-005-050).

SUBJECT: KACH

CONSTITUENT		EXPERIMENT					
Name	Unit	29 June	6 July	13 July	20 July	27 July	3 Aug
Na	mEq/L	23.9	20.9	36.0	34.2	38.9	39.0
K	"	3.1	4.2	4.5	3.4	3.4	3.9
Mg	"	2.6	4.5	3.4	4.6	2.4	2.2
Ca	"	0.9	1.0	0.7	1.3	0.7	0.4
Cl	"	17.9	44.0	33.7	26.2	33.3	34.7
Lactate	"	13.6	12.7	11.5	11.8	10.9	10.8
NH_3	"	1.8	1.9	1.4	1.4	1.7	1.9
Urea	mM/L	11.9	6.2	6.5	7.0	6.4	6.1
Total N	mg/L	471.7	267.0	223.5	328.8	286.7	255.6
Creatinine	"	0.9	1.1	0.8	0.9	0.4	0.7
Osmolarity	mOsm/L	75.5	120.4	98.5	87.2	97.2	99.6
pH		6.15	6.22	6.25	6.44	6.62	6.64

* Back-calculated to original body sweat volume (excluding arm bag sweat).

TABLE IV.4B. CHEMISTRY OF TOTAL BODY SWEAT: CONCENTRATION.* SUMMER 1966. (NASA GRANT NGR 14-005-050).

SUBJECT: NELS

CONSTITUENT		EXPERIMENT					
Name	Unit	30 June	7 July	14 July	21 July	28 July	4 Aug
Na	mEq/L	14.6	39.0	54.6	32.9	38.9	57.7
K	"	1.5	5.1	3.5	3.2	3.4	3.7
Mg	"	1.9	3.3	3.5	4.2	2.9	2.5
Ca	"	0.8	0.43	0.4	0.6	0.7	0.7
Cl	"	15.4	35.2	48.4	25.1	33.3	47.4
Lactate	"	8.0	9.0	9.5	9.8	15.3	10.3
NH_3	"	1.1	1.2	1.4	1.4	1.4	1.2
Urea	mM/L	4.1	8.9	4.4	7.6	7.6	7.7
Total N	mg/L	223.1	274.4	273.0	322.2	291.5	317.0
Creatinine	"	0.2	0.6	0.5	0.6	0.6	0.5
Osmolarity	mOsm/L	61.5	107.2	117.0	83.8	111.8	131.8
pH		6.58	7.42	6.95	6.05	6.85	7.35

* Back-calculated to original body sweat volume (excluding arm bag sweat).

TABLE IV.5A. CHEMISTRY OF TOTAL BODY SWEAT*: EXCRETION RATE (TIME). SUMMER 1966. (NASA GRANT NGR 14-005-050).

SUBJECT: KACH

CONSTITUENT		EXPERIMENT					
Name	Unit	29 June	6 July	13 July	20 July	27 July	3 Aug
Na	mEq/hr	15.3	15.8	36.8	21.2	32.8	37.4
K	"	2.0	3.2	4.6	2.1	2.9	3.7
Mg	"	1.7	3.4	3.4	2.8	2.0	2.1
Ca	"	0.6	0.8	0.7	0.8	0.6	0.4
Cl	"	11.5	33.2	34.1	16.2	28.0	33.2
Lactate	"	8.7	9.6	11.6	7.3	9.2	10.3
NH_3	"	1.2	1.4	1.4	0.9	1.4	1.8
Urea	mM/hr	7.6	4.7	6.6	4.3	5.4	5.8
Total N	mg/hr	301.9	201.3	226.2	203.5	241.4	244.9
Creatinine	"	0.60	0.87	0.77	0.58	0.33	0.66
Osmolarity	mOsm/hr	48.3	90.8	99.7	54.0	81.8	95.4

* Excluding arm bag sweat.

TABLE IV.5B. CHEMISTRY OF TOTAL BODY SWEAT*: EXCRETION RATE (TIME). SUMMER 1966. (NASA GRANT NGR 14-005-050).

SUBJECT: NELS

CONSTITUENT		EXPERIMENT					
Name	Unit	30 June	7 July	14 July	21 July	28 July	4 Aug
Na	mEq/hr	7.8	30.9	53.5	20.4	31.5	55.9
K	"	0.8	4.0	3.4	2.0	2.8	3.6
Mg	"	1.0	2.6	3.4	2.6	2.3	2.4
Ca	"	0.4	0.3	0.4	0.4	0.6	0.7
Cl	"	8.2	27.9	47.4	15.6	26.9	45.9
Lactate	"	4.3	7.1	9.3	6.1	12.4	10.0
NH_3	"	0.6	1.0	1.4	0.9	1.1	1.2
Urea	mM/hr	2.2	7.0	4.3	4.7	6.2	7.5
Total N	mg/hr	118.9	217.3	267.3	199.8	236.1	307.2
Creatinine	"	0.12	0.48	0.46	0.40	0.47	0.52
Osmolarity	mOsm/hr	32.8	84.9	114.5	52.0	90.6	127.7

* Excluding arm bag sweat.

TABLE IV.6A. CHEMISTRY OF TOTAL BODY SWEAT: EXCRETION RATE (TIME AND SURFACE AREA). SUMMER 1966. (NASA GRANT NGR 14-005-050).

SUBJECT: KACH

CONSTITUENT		EXPERIMENT					
Name	Unit	29 June	6 July	13 July	20 July	27 July	3 Aug
Na	$mEq/m^2/hr$	8.8	9.1	21.3	12.4	19.1	21.7
K	"	1.2	1.8	2.7	1.2	1.7	2.2
Mg	"	1.0	2.0	2.0	1.6	1.1	1.2
Ca	"	0.3	0.5	0.4	0.5	0.3	0.2
Cl	"	6.6	19.2	19.7	9.5	16.3	19.3
Lactate	"	5.0	5.5	6.7	4.3	5.3	6.0
NH_3	"	0.7	0.8	0.8	0.5	0.8	1.0
Urea	$mM/m^2/hr$	4.4	2.7	3.8	2.5	3.1	3.4
Total N	$mg/m^2/hr$	174.5	116.4	130.8	119.0	140.3	142.4
Creatinine	"	0.34	0.50	0.45	0.34	0.19	0.38
Osmolarity	$mOsm/m^2/hr$	27.9	52.5	57.6	31.6	47.6	55.5

TABLE IV.6B. CHEMISTRY OF TOTAL BODY SWEAT: EXCRETION RATE (TIME AND SURFACE AREA). SUMMER 1966. (NASA GRANT NGR 14-005-050).

SUBJECT: NELS

CONSTITUENT		EXPERIMENT					
Name	Unit	30 June	7 July	14 July	21 July	28 July	4 Aug
Na	$mEq/m^2/hr$	5.0	19.8	34.3	13.0	20.1	35.8
K	"	0.5	2.6	2.2	1.3	1.8	2.3
Mg	"	0.6	1.7	2.2	1.7	1.5	1.6
Ca	"	0.3	0.2	0.3	0.3	0.4	0.2
Cl	"	5.5	17.8	30.3	9.9	17.2	29.4
Lactate	"	2.8	4.6	6.0	3.9	7.9	6.4
NH_3	"	0.4	0.6	0.9	0.6	0.7	0.7
Urea	$mM/m^2/hr$	1.4	4.5	2.8	3.0	3.9	4.8
Total N	$mg/m^2/hr$	76.2	139.3	171.3	127.3	150.4	204.6
Creatinine	"	0.08	0.31	0.29	0.25	0.30	0.20
Osmolarity	$mOsm/m^2/hr$	21.0	54.4	73.4	33.1	57.7	81.9

TABLE IV.7. THE RELATION BETWEEN RATE OF SWEATING AND THE CHEMICAL COMPOSITION OF GLOVE SWEAT: DATA OF ADAMS ET AL (1958)* COMPARED WITH DATA OF JOHNSON ET AL (1966)+. SUMMER 1966. (NASA GRANT NGR 14-005-050).

	Adams et al*		Johnson et al+	
	"Experimental"	"Control"	Subject KACH mean	Subject NELS mean
Specimens, number	374	74	6	6
Sweat rate in one glove, ml/hr	39	42	50	34
Osmolarity, mOsm/L	163	108	114	134
Cations, mEq/L				
Na	41	27	41	48
K	12	8	5	6
NH_3	10	7	2	2
Sum	(63)	(42)	(48)	(56)
Anions, mEq/L				
Cl	38	26	36	44
Lactate	20	17	14	14
Sum	(58)	(43)	(50)	(58)
Urea, mM/L	19	15	7	10
Sum of solutes	(140)	(100)	(105)	(124)

* Adams, R., Johnson, R. E., and Sargent, F. II: The osmotic pressure (freezing point) of human sweat in relation to its chemical composition. Quart. J. Exp. Physiol. 43:241-257 (3), 1958.

\+ Present progress report.

TABLE IV.8. CHANGES IN THE CHEMICAL COMPOSITION OF GLOVE SWEAT WITH CHANGES IN RATE OF SWEATING: DATA OF ADAMS ET AL (1958)* COMPARED WITH DATA OF JOHNSON ET AL (1966)+. SUMMER 1966. (NASA GRANT NGR 14-005-050).

	Change with Increased Sweat Rate		
	Adams et al*	Johnson et al+	
	"Experimental Subjects"	Subject KACH	Subject NELS
Osmolarity	Decrease	Increase	Increase
Cations			
Na	Increase	Increase	Increase
K	Decrease	None	None
NH_3	Decrease	None	Decrease
Mg and Ca	(not measured)	Decrease	Decrease
Anions			
Cl	Increase	Increase	Increase
Lactate	None	Decrease	None
Urea	Decrease	Increase	Decrease
Total Nitrogen	(not reported)	Decrease	Decrease
pH	None	Increase	Increase

* Adams, R., Johnson, R. E., and Sargent, F. II: The osmotic pressure (freezing point) of human sweat in relation to its chemical composition. Quart. J. Exp. Physiol. 43:241-257 (3), 1958.

\+ Present progress report.

Some of the discrepancies between the present experiments and those reported by Adams et al (1958) may be explained by a crucial difference in treatment of the data. Adams et al (1958) compared twelve "control" subjects and eighty-three "experimental subjects" against each other at whatever rates of sweating the subjects happened to have on the day of the experiment. We have arranged to have the subject compared with himself at different specified rates of sweating on different days. Thus, it might be that subjects with higher natural rates of sweating have lower osmolarities in the sweat than do subjects with lower natural rates of sweating, whereas any one subject might increase his osmolarity with increasing rates of sweating.

When our data are examined in the light of the above hypothesis (Tables IV.1A and IV.1B, and Fig. III.2) the postulate is well followed by osmolarity, ammonia, urea, and potassium. However, Na and Cl are still different in the two groups of data.

The regularity of the change of pH is striking. Within Subject KACH and Subject NELS it increased with increased rates of sweating. But it was consistently higher in Subject NELS than in Subject KACH, although the latter's rate of sweating was typically higher.

Adams et al (1958) added up the solutes and found that, in many specimens, the osmolarity as measured by freezing point was greater than the sum of the solutes, i.e. there was an "osmotic deficit". They also compared the sum of the cations Na, K and NH_3 with the sum of the anions Cl and lactate and found close agreement generally. However, an "anionic deficit" was found in some specimens. We have made these two sets of calculations and added a third. When the sum of urea nitrogen plus ammonia nitrogen is subtracted from the total organic nitrogen, in most specimens there is evidence of a "residual nitrogen", probably amino acids not directly measured. The "residual nitrogen" generally correlates well with the "osmotic deficit" and may be a clue to the "unknown osmol" postulated by Adams et al (1958). Our calculations are given in Tables IV.9, and IV.10.

V. COMPARISON OF THE CHEMICAL COMPOSITION OF ARM SWEAT COLLECTED IN IMPERMEABLE BAGS AND TOTAL BODY SWEAT, EVAPORATED ON THE SKIN

From both the theoretical and the practical points of view it is of considerable importance to know whether the total body sweat can be represented by a sample from a small area. Numerous studies have been made on this point, but the results are inconclusive. See the review by Robinson and Robinson (1954) on this point (Robinson, S. and Robinson, A. M.: The chemical composition of sweat, Physiol. Rev. 34: 202-220 (April) 1954). Generally it seems to be agreed

TABLE IV.9. ARM SWEAT: RESIDUAL NITROGEN, IONIC BALANCE, AND OSMOLARITY IN RELATION TO INDIVIDUAL COMPONENTS. SUMMER 1966. (NASA GRANT NGR 14-005-050).

SUBJECT: KACH

Calculation	Unit	Experiment 29 June	6 July	13 July	20 July	27 July	3 Aug
Total N	mAtoms/L	24.3	15.5	23.9	29.6	18.6	24.3
$(NH_3+Urea)N$	"	11.3	14.3	17.8	18.1	14.4	18.0
Residual N	"	+13.0	+ 1.2	+ 6.1	+11.5	+ 4.2	+ 6.3
Σ Cations	mEq/L	45.3	61.5	58.7	52.3	36.9	50.7
Σ Anions	"	46.1	56.6	57.7	47.6	41.3	54.6
Ionic deficit	"	+ 0.8	- 4.9	- 1.0	- 4.7	+ 4.4	+ 3.9
Σ Solutes	mOsm/L	96.3	124.3	124.3	107.6	84.5	113.3
Osmolarity	"	105.0	118.0	127.0	103.0	115.0	115.0
Osm. deficit	"	- 8.7	+ 6.3	- 2.7	+ 4.6	-30.5	+ 1.7

SUBJECT: NELS

Calculation	Unit	30 June	7 July	14 July	21 July	28 July	4 Aug
Total N	mAtoms/L	43.5	31.5	26.8	36.4	33.1	30.4
$(NH_3+Urea)N$	"	26.8	22.4	20.0	25.9	21.1	22.8
Residual N	"	+16.7	+ 9.2	+ 6.8	+10.5	+11.9	+ 7.6
Σ Cations	mEq/L	60.2	50.6	67.8	47.5	52.7	65.2
Σ Anions	"	59.5	51.9	65.9	49.8	52.8	67.2
Ionic deficit	"	- 0.7	+ 1.3	- 1.8	+ 2.3	+ 0.1	+ 2.0
Σ Solutes	mOsm/L	131.3	112.8	142.6	108.8	115.0	142.8
Osmolarity	"	139.0	138.0	146.0	113.0	117.0	148.0
Osm. deficit	"	- 7.7	-25.2	- 3.4	- 4.2	- 2.0	- 5.2

TABLE IV.10. TOTAL BODY SWEAT: RESIDUAL NITROGEN, IONIC BALANCE, AND OSMOLARITY IN RELATION TO INDIVIDUAL COMPONENTS. SUMMER 1966. (NASA GRANT NGR 14-005-050).

SUBJECT: KACH

Calculation	Unit	Experiment 29 June	6 July	13 July	20 July	27 July	3 Aug
Total N	mAtoms/L	23.8	19.1	20.3	23.5	20.5	18.3
$(NH_3+Urea)N$	"	25.6	14.2	14.3	15.4	14.6	14.0
Residual N	"	- 1.8	+ 4.9	+ 6.0	+ 8.1	+ 5.9	+ 4.3
Σ Cations	mEq/L	32.4	32.6	46.0	45.0	47.2	47.3
Σ Anions	"	31.9	56.7	45.2	38.0	45.0	45.5
Ionic deficit	"	- 0.5	+24.1	- 0.8	- 7.0	- 2.3	- 1.8
Σ Solutes	mOsm/L	76.2	95.4	97.7	89.9	98.5	98.8
Osmolarity	"	75.5	120.4	98.5	87.7	97.2	99.6
Osm. deficit	"	+ 0.6	-25.0	- 0.8	+ 2.2	+ 1.3	- 0.8

SUBJECT: NELS

Calculation	Unit	30 June	7 July	14 July	21 July	28 July	4 Aug
Total N	mAtoms/L	15.9	19.6	19.5	21.6	21.1	22.6
$(NH_3+Urea)N$		9.2	19.0	10.3	16.6	16.7	16.5
Residual N	"	+ 5.7	+ 0.6	+ 9.2	+ 5.1	+ 4.5	+ 6.1
Σ Cations	mEq/L	20.0	49.2	63.4	42.3	47.3	65.8
Σ Anions	"	23.4	44.2	57.8	34.9	48.8	57.7
Ionic deficit	"	+ 3.4	- 5.0	- 5.6	- 7.3	+ 0.6	- 8.1
Σ Solutes	mOsm/L	47.5	102.2	125.7	84.8	103.8	131.1
Osmolarity	"	61.5	107.2	117.0	83.8	111.8	131.8
Osm. deficit	"	-14.0	- 5.0	+ 8.7	+ 1.0	- 8.0	- 0.7

that different areas differ in the composition of the sweat collected at a single moment.

We have seen in Section III of this report (Fig. III.2) that over a wide range of sweating, the rate under the impermeable glove on a square meter and hour basis was closely correlated with the rate on the whole naked body in a dry, hot room.

Comparison of arm sweat on a per meter and hour basis (Tables IV.3A and IV.3B) with total body sweat on the same basis (Tables IV.6A and IV.6B) leads to the general conclusion that the dermal loss of anions, cations, and nitrogenous substances is similar in arm and total body sweat.

Direct comparison of the data for the two types of sweat are facilitated by summary Tables V.1 and V.2. The first of these tables lists cations and anions for the two subjects; the second lists nitrogenous constituents and osmolarity. The two subjects yielded similar findings. The two ions contributing the most were Na and Cl, with about equal contributions to dermal loss. In Subject KACH, the glove sweat tended to be higher; in Subject NELS the reverse was true. The other important anion is lactate. It was about the same for both subjects, and again the glove sweat tended to be higher for Subject KACH, lower for Subject NELS. K was about the same for both subjects in both types of sweat. Big differences were found for both Mg and Ca, which were far lower in arm sweat than in total body sweat. This was true for both subjects at all rates of sweating.

Of the nitrogenous constituents, no consistent differences were discernible between subjects or types of sweating. The urea behaved differently in the first series and the second series of experiments. In the former the arm sweat tended to be lower; in the latter, it tended to be higher for Subject KACH. The reverse was true for Subject NELS. For NH_3, the values were very similar for both subjects in both types of sweat. No consistent pattern occurred for creatinine.

With respect to total osmolarity, these two subjects reacted differently. For Subject KACH the arm sweat was higher; for Subject NELS it was lower.

The dermal loss of each substance measured was of the same order of magnitude at a given rate of sweating when arm sweat was compared with total body sweat. We conclude that on a square meter and hour basis total body dermal loss in a hot, dry environment can be calculated approximately from glove sweat collected in impermeable bags.

TABLE V.2. ARM SWEAT VERSUS TOTAL BODY SWEAT. SUMMER 1966. (NASA GRANT NGR 14-005-050).

Date	Ammonia $mEq/hr/m^2$		Urea $mM/hr/m^2$		Total N $mg/hr/m^2$		Creatinine $mg/hr/m^2$		Osmolarity $mOsm/hr/m^2$	
	Arm	Body	Arm	Body	Arm	Body	Arm	Body	Arm	Body
SUBJECT: KACH										
29 June	0.4	0.7	1.6	4.4	110	175	0.3	0.3	33.9	27.9
6 July	1.0	0.8	3.9	4.3	109	116	0.3	0.5	59.0	52.5
13 July	1.3	0.8	5.2	3.8	218	131	0.5	0.5	82.6	57.6
20 July	0.8	0.5	2.5	2.5	134	119	0.2	0.3	33.2	31.6
27 July	0.9	0.8	3.2	3.1	112	140	0.3	0.2	49.7	47.6
3 Aug	1.0	1.0	4.0	3.4	170	142	0.2	0.4	57.5	55.5
SUBJECT: NELS										
30 June	0.6	0.4	2.0	1.4	103	76	0.2	0.1	23.4	21.0
7 July	0.6	0.6	3.6	4.5	157	139	0.3	0.3	48.9	54.4
14 July	0.9	0.9	3.7	2.8	157	171	0.3	0.3	60.4	73.4
21 July	0.9	0.6	2.6	3.0	116	127	0.2	0.3	25.7	33.1
28 July	0.6	0.7	2.9	3.9	139	150	0.2	0.3	35.1	57.7
4 Aug	0.8	0.7	3.8	4.8	157	205	0.3	0.2	53.8	81.9

TABLE V.1. ARM SWEAT VERSUS TOTAL BODY SWEAT. SUMMER 1966. (NASA GRANT NGR 14-005-050).

SUBJECT: KACH (VALUES ARE EXPRESSED AS MILLIEQUIVALENTS PER HOUR AND SQUARE METER.)

	Na		K		Mg		Ca		Cl		Lactate	
Date	Arm	Body	Arm	Body	Arm	Body	Arm	Body	Arm	Body	Arm	Body
29 June	12.0	8.8	1.8	1.2	0.1	1.0	0.3	0.3	9.6	6.6	5.4	5.0
6 July	27.0	9.1	2.6	1.8	0.1	2.0	0.1	0.5	22.0	19.2	6.4	5.5
13 July	33.2	21.3	3.4	2.7	0.1	2.0	0.3	0.4	29.5	19.7	7.9	6.7
20 July	14.2	12.4	1.6	1.2	0.1	1.6	0.2	0.5	10.5	9.5	4.9	4.3
27 July	13.4	19.1	1.6	1.7	0.1	1.1	0.1	0.3	11.4	16.3	7.5	5.3
3 Aug	21.5	21.7	2.6	2.2	0.2	1.2	0.2	0.2	20.4	19.3	6.9	6.0

SUBJECT: NELS

Date	Na Arm	Na Body	K Arm	K Body	Mg Arm	Mg Body	Ca Arm	Ca Body	Cl Arm	Cl Body	Lactate Arm	Lactate Body
30 June	8.2	5.0	1.0	0.5	0.1	0.6	0.1	0.3	7.5	5.5	2.5	2.8
7 July	14.5	19.8	2.5	2.6	0.1	1.7	0.2	0.2	13.6	17.8	4.8	4.6
14 July	24.8	34.3	2.1	2.2	0.2	2.2	0.1	0.3	21.9	30.3	5.4	6.0
21 July	8.6	13.0	1.2	1.3	0.2	1.7	0.1	0.3	7.9	9.9	3.4	3.9
28 July	13.5	20.1	1.5	1.8	0.1	1.5	0.1	0.4	11.5	17.2	4.4	7.9
4 Aug	20.7	35.8	2.0	2.3	0.1	1.6	0.1	0.2	18.7	29.4	5.7	6.4

VI. SUMMARY AND CONCLUSIONS FOR THE PERIOD JULY 1, 1966 TO DECEMBER 31, 1966.

1. A simple and versatile system has been devised for measuring oxygen consumption and carbon dioxide production in man. Expired gas is measured in a spirometer and stored in metalized bags without measurable loss of carbon dioxide for at least three hours. It is analyzed during passage through a thermal conductivity meter for CO_2 and a paramagnetic O_2 meter in tandem. The metabolic mixture can be calculated by means of a simple computer program.

2. Two men were caused to sweat at desired rates by walking at a constant pace on the level in a hot, dry room at temperatures successfully predicted by the thermal heat stress index of McArdle et al (1948). Arm sweat was collected in impermeable bags. Total body sweat was collected from the body by washing down with distilled water. Rates of sweating from the total body were chosen to range from 570 ml per hour to 1170 ml per hour.

3. The rates of sweating and the skin temperature increased with increasing thermal stress. Excellent steady states were achieved, with no differences between experiments in pulse rate, oral temperature, blood pressure, or oxygen consumption.

4. Measurements were made of total osmolarity, pH, Na, K, Mg, Ca, Cl, lactate, NH_3, urea, creatinine and total N.

5. When the relation between rate of sweating and chemical concentration in glove sweat was studied, certain regularities appeared. There were rises in osmolarity, Na, Cl and pH with increased rate of sweating. Lactate, Mg, Ca, NH_3, and total N all diminished. Urea and creatinine did not change regularly. The sweat was always hypotonic to blood plasma.

6. When total body sweat was compared with glove sweat certain correlations were quite good. The dermal losses of water, Na, K, NH_3, Cl, lactate, urea, total N, and total osmols were of the same order of magnitude for total body and glove sweat when expressed on the basis per square meter of skin and hour. It is concluded that, for practical purposes, glove sweat can be used to predict total body sweat with respect to the substances measured except for Mg and Ca. These elements were far lower per square meter and hour in arm sweat than they were in total body sweat.

7. Certain discrepancies between the present results and those reported by us and others previously are discussed. It is postulated that changes within a given subject with changing sweat rate may not be the same as would be predicted from a whole population of

subjects sweating at different rates all at the same time. In particular, osmotic concentration in the sweat might increase in one subject with increased sweat rate, whereas in the population, those with the highest sweat rate might have the lowest osmotic concentration.

APPENDIX A

A VERSATILE SYSTEM FOR MEASURING OXYGEN CONSUMPTION IN MAN[1]

by Robert E. Johnson, Frances Robbins, Renold Schilke, Paul Molé, Janet Harris, and Diane Wakat

from the Human Environmental Research Unit, Department of Physiology and Biophysics, University of Illinois, Urbana, Illinois. (Paper in press, to appear in the Journal of Applied Physiology, Vol. 22, February 1967.)

The system described below has been tested during a fifteen week graduate course on the physiology of human activity and also in eight weeks of a summer research program. It has proved to be reliable and versatile for measuring the respiratory exchange at rest, during moderate exercise, and during hard work. It has also been used in the study of alveolar air, normal expiration, and hyperventilation. The problem of storing gas in plastic bags without diffusion of carbon dioxide has been solved by the fabrication of metalized polyethylene bags.

METHODS

The system is shown schematically in Fig. A1, and the items, their catalog identifications, and commercial sources are given in Table A1.

Expired air is measured with a suitable respirometer. At rest the Tissot gasometer is used; for moderate exercise, the Kofrányi-Michaelis respirometer, and for hard work, high capacity -- low resistance dry gasometers. Details of calibration and use are given by Consolazio, Johnson, and Pecora (1, pp. 12-16 and 40-50).

Samples of expired air are collected and stored in metalized bags. These metalized collection bags are constructed from a film consisting of a sheet of aluminum sandwiched between two layers of polyethylene film, creating a structure virtually impermeable to O_2 and CO_2 as well as water vapor. (The material is manufactured by 3M Company, Film and Allied Products Division, and is obtainable through Kapak Industries, Minneapolis, Minnesota, and other distributors. It is identified as Scotchpak Film, not

[1]This work was supported in part by NASA Grant 14-005-050 to the University of Illinois (Urbana).

transparent, metalized for low permeability.) The bags can be made in any desired size or shape, heat being used to form and seal the seams. Any commercial sealer may be used provided it is set for polyethylene. For moderate work, we fabricate bags approximately 25 cm by 25 cm square. In one of the corners a polyethylene tube (3.8 mm I.D. x 4.8 mm O.D.) is sealed, the outer end of which is attached to a one-way metal stopcock. Male-female slip connections and tygon tubing are used as needed for transferring gas. These bags are filled with air and tested for leakage by applying moderate pressure under water before they are used. A vacuum line at a pressure of about 4 cm Hg is used to evacuate the bags, which are subsequently ready for use without flushing.

In routine daily use the metalized bags last for several weeks. The two commonest causes of failure are puncture holes during careless handling, and breakdown of the seal around the metal stopcock. Defective bags are detected by the daily under-water check, and are discarded.

Expired air, which has been collected in the metalized bags with any of the systems mentioned above, is passed through a drying column attached to a paramagnetic oxygen meter and a thermal conductivity CO_2 meter.

Analyses are made in an air-conditioned room kept at 23^{o}-$25^{o}C$ and 45-55% relative humidity. The analyzers are very sensitive to changes in pressure and temperature. Other precautions for maximum sensitivity, stability, and accuracy include: careful leveling of the bags, oxygen analyzer, and carbon dioxide analyzer; avoidance of kinks, pressures on the bags, or improper turning of taps, all of which lead to pressure changes in the system; changing the drying columns and absorbing columns after at most one hour's use and always at the beginning of a run; and warming the analyzers up by turning them on at least 45 minutes before the pump is started. The oxygen analyzer may be set for any range. When the range is 10 to 25% O_2 at 760 mm total pressure, the smallest division corresponds to 0.2% and estimates to 0.02% may be made. The carbon dioxide analyzer may be set by changing the gain. If the range has been set for 0 to 8% CO_2 at 760 mm total pressure, the smallest scale division corresponds to 0.04% and extimates to 0.01% may be made.

For determining exact percentages of oxygen and carbon dioxide, the system is first calibrated using room air and a gas mixture containing O_2, CO_2, and N_2 which has been previously analyzed with

Lloyd's modification of the Haldane apparatus.[2] A metalized bag containing an aliquot of this tank gas is hooked up to the apparatus after the room air has been analyzed and prior to the introduction of the unknown samples. Calibration curves can then be drawn and percentages of oxygen and carbon dioxide calculated. The oxygen consumption and carbon dioxide production can then be computed (Consolazio et al., 1, pp. 5-55).

Alveolar air can be introduced into the system by connecting the drying column to a corrugated plastic tube attached to a Douglas valve. The plastic tube is one meter in length and 2.5 cm in diameter. The distal end contains a rubber stopper with a 1-cm hole. This allows the machine to maintain an adequate yet not excessive flow of expired air through the system. Tygon tubing (5 mm lumen) coming from the drying column is inserted into the plastic tube directly adjacent to the Douglas valve connection. The subject breathes normally. A specimen of alveolar air is then obtained by a complete expiration at the end of a normal breath. After this expiration he then breathes normally again. The maximum deflection for carbon dioxide and the minimum for oxygen represent alveolar concentrations.

RESULTS AND DISCUSSION

Table A2 shows the constancy of the composition of gas stored in metalized film bags. Table A2-A is for gas mixture stored in one metalized, polyethylene bag over a period of 24 hours, as analyzed with a Haldane apparatus (Lloyd's modification[2]). The tank gas had been previously analyzed and found to contain 16.59% O_2 and 5.27% CO_2.

Table A2-B shows the stability of the same gas mixture stored in 12 such bags and analyzed with the paramagnetic oxygen meter and thermal conductivity CO_2 meter. The sensitivity of the system is 0.01% CO_2 and 0.02% O_2. The reproducibility is excellent, the coefficient of variation being less than 1% in routine use.

Table A3 illustrates a suitable routine for analyzing several expired air samples. Duplicate bags of each sample are analyzed, such as Rest 1-A and Rest 1-B, and Walk 1-A and Walk 1-B. Each experimental series is bracketed by analysis of a standard gas mixture and room air in case any drift occurs in the machines.

Tables A4 and A5 are work sheets for use during an experiment

[2]Lloyd Gas Analysis Apparatus, Model GC-370, Gallenkamp Co., Ltd., London, England.

in which O_2 consumption, CO_2 production and the metabolic mixture are calculated (Consolazio et al.[1], pp. 313-336). The information can easily be programmed into a computer as desired. Temperature conversions are given in Tables A6, A7, A8, and A9.

ACKNOWLEDGEMENT

We thank Dr. John M. Kinney, Department of Surgery, College of Physicians and Surgeons, Columbia University, New York for instructions on the fabrication of the metalized polyethylene bags for respiratory use.

[1] Consolazio, C. F., R. E. Johnson, and L. J. Pecora. Physiological Measurements of Metabolic Functions in Man. New York: McGraw-Hill Book Co., 1963.

TABLE A1. Components of a versatile system for measuring oxygen consumption in man

Item	Catalog Description	Commercial Source
Respirometer	Tissot	Arthur H. Thomas, Philadelphia
Respirometer	Kofrányi-Michaelis	Max Planck Institute, Göttingen, West Germany
Spirometer	Type "CD4"	Parkinson Cowan Industrial Products, Ltd., London, England
Metal stopcock	One-way, Type MS01-T	Becton, Dickinson and Co., Rutherford, New Jersey
O_2 analyzer	Paramagnetic O_2 Meter, Model C2	Beckman Instruments Co., Fullerton, California
CO_2 analyzer	Thermal Conductivity Meter, "Pulmo-Analysor" Type 44A-2	Godart-Mijnhardt NV, De Bilt, Netherlands

TABLE A2. Stable composition of gas mixtures stored in bags of metalized polyethylene film

A. Prolonged Storage, one bag*

	Hours Stored 0	1/2	24
O_2, percent	16.60	16.56	16.61
CO_2, percent	5.27	5.25	5.19

B. Three-Hour Storage, 12 bags+

	0	1 hr		2 hr		3 hr	
		Mean	Range	Mean	Range	Mean	Range
O_2, percent	16.59	16.58	16.48 to 16.60	16.60	16.58 to 16.63	16.59	16.59 to 16.61
CO_2, percent	5.27	5.27	5.25 to 5.28	5.26	5.23 to 5.31	5.27	5.25 to 5.29

* Analyzed with Haldane-Lloyd apparatus.
+ Analyzed with paramagnetic oxygen meter and thermal conductivity CO_2 meter.

TABLE A3. Results for duplicate bags in one typical experiment

Time of Day	Sample	O_2* %	CO_2* %
2:41 p.m.	Room Air	20.90	0
2:45	Standard+	16.59	5.27
2:48	Rest 1A	17.35	3.15
2:51	Walk 1A	15.86	4.26
2:54	Walk 2A	16.05	4.01
2:56	Standard+	16.59	5.27
3:00 p.m.	Room Air	20.90	
3:06	Standard+	16.59	5.27
3:16	Rest 1B	17.35	3.12
3:19	Walk 1B	15.84	4.22
3:23	Walk 2B	16.05	3.98
3:26	Standard+	16.59	5.27
3:29	Room Air	20.90	0

* Converted to correct value from dial readings and calibration curves.

\+ Analyzed with the Haldane-Lloyd apparatus.

TABLE A4. Program for calculating respiratory metabolism

PAGE____OF____PAGES

SUBJECT________________________ DATE______________

AGE____yr HT____cm WT____kg ACTIVITY__________

1. Specimen code		
2. Pulmonary Ventilation a. Meter Temp. °C		
b. P_{Bar} mm Hg		
c. STPD Factor (nomogram*)		
d. Meter Factor		
e. V_2 at T_2		
f. V_1 at T_1		
g. $\Delta V/\Delta T$ in min		
h. $\dot{V} = c \times d \times g$		
3. Oxygen Consumed a. O_2 Reading (Beckman)		
b. % O_2 (Calibration curve)		
c. "True O_2" (nomogram+)		
d. L/min = 2h x 3c/100		
e. gm/min = 3d x 1.4290		
4. CO_2 Expired a. CO_2 Reading (Godart)		
b. CO_2 % (Calibration curve)		
c. L/min = 2h x 4b/100		
d. gm/min = 4c x 1.9769		
5. R. Q. (nomogram+)		
6. O_2 ml/kg/min		
7. CO_2 ml/kg/min		

* Fig. 1-1 in Consolazio et al. (1, p.7)
\+ Fig. 1-2 in Consolazio et al. (1, p.10)

TABLE A5. Program for calculating the metabolic mixture*

DATE________________________________ PAGE____OF____PAGES

SUBJECT_____________________________ EXPT________________

N.B. N_u, O_2, and CO_2 must all be for the <u>same</u> time period.

Calculation:		Prot. gm	CHO gm	Fat gm	H_2O met gm	Total heat+, kcal
Factors	N_u gm x	+6.25	-2.56	-1.94	-1.04	-2.98
	O_2 L x	-----	-2.91	+1.69	+0.062	+3.78
	CO_2 L x	-----	+4.12	-1.69	+0.662	+1.16
Period	Measurement					
	N_u, gm					
	O_2, L					
	CO_2, L					
	Sum					
	N_u, gm					
	O_2, L					
	CO_2, L					
	Sum					

* This table is modified from Consolazio, Johnson, and Pecora (1, p. 316).

\+ The factors used for computing net metabolizable energy are 4.1 kcal per gm for protein and carbohydrate, and 9.3 kcal per gm for fat.

TABLE A.6. TEMPERATURE CONVERSION: FAHRENHEIT INTO CENTIGRADE

°F → ↓	0	1	2	3	4	5	6	7	8	9
					↓°C↓					
-50	-45.6	-46.1	-46.7	-47.3	-47.8	-48.4	-48.9	-49.5	-50.0	-50.6
-40	-40.0	-40.6	-41.1	-41.7	-42.2	-42.8	-43.3	-43.9	-44.4	-45.0
-30	-34.4	-35.0	-35.6	-36.1	-36.7	-37.3	-37.8	-38.4	-38.9	-39.5
-20	-28.9	-29.5	-30.0	-30.9	-31.1	-31.7	-32.2	-32.8	-33.3	-33.9
-10	-23.3	-23.9	-24.4	-25.0	-25.6	-26.1	-26.7	-27.2	-27.8	-28.4
0-	-17.8	-18.3	-18.9	-19.4	-20.0	-20.6	-21.1	-21.7	-22.2	-23.3
0+	-17.8	-17.2	-16.7	-16.1	-15.6	-15.0	-14.4	-13.9	-13.3	-12.8
10	-12.2	-11.7	-11.1	-10.6	-10.0	- 9.4	- 8.9	- 8.3	- 7.8	- 7.2
20	- 6.7	- 6.1	- 5.6	- 5.0	- 4.4	- 3.9	- 3.3	- 2.8	- 2.2	- 1.7
30	- 1.1	- 0.6	0	0.6	1.1	1.7	2.2	2.8	3.3	3.9
40	4.4	5.0	5.6	6.1	6.7	7.2	7.8	8.3	8.9	9.4
50	10.0	10.6	11.1	11.7	12.2	12.8	13.3	13.9	14.4	15.0
60	15.6	16.1	16.7	17.2	17.8	18.3	18.9	19.4	20.0	20.6
70	21.1	21.7	22.2	22.8	23.3	23.9	24.4	25.0	25.6	26.1
80	26.7	27.2	27.8	28.3	28.9	29.4	30.0	30.6	31.1	31.7
90	32.2	32.8	33.3	33.9	34.4	35.0	35.6	36.1	36.7	37.2
100	37.8	38.3	38.9	39.4	40.0	40.6	41.1	41.7	42.2	42.8
110	43.3	43.9	44.4	45.0	45.6	46.1	46.7	47.2	47.8	48.3
120	49.0	49.4	50.0	50.6	51.1	51.7	52.2	52.8	53.3	53.9
130	54.4	55.0	55.6	56.1	56.7	57.2	57.8	58.3	58.9	59.4
140	60.0	60.6	61.1	61.7	62.2	62.8	63.3	63.9	64.4	65.0
150	65.6	66.1	66.7	67.2	67.8	68.3	68.9	69.4	70.0	70.6

$$C = (F - 32) \times (5/9)$$

$$F = (C \times 9) / (5) + (32)$$

C 0.1 = F 0.3

F 0.1 = C 0.03

TABLE A.7. TEMPERATURE CONVERSION: CENTIGRADE INTO FAHRENHEIT

°C → ↓	0	1	2	3	4	5	6	7	8	9
					↓°F↓					
-50	-58.0	-59.8	-61.6	-63.4	-65.2	-67.0	-68.8	-70.6	-72.4	-74.2
-40	-40.0	-41.8	-43.6	-45.4	-47.2	-49.0	-50.8	-52.6	-54.4	-56.2
-30	-22.0	-23.8	-25.6	-27.4	-29.2	-31.0	-32.8	-34.6	-36.4	-38.2
-20	- 4.0	- 5.8	- 7.6	- 9.4	-11.2	-13.0	-14.8	-16.6	-18.4	-20.2
-10	14.0	12.2	10.4	8.6	6.8	5.0	3.2	1.4	- 0.4	- 2.2
0-	32.0	30.2	28.4	26.6	24.8	23.0	21.2	19.4	17.6	15.8
0+	32.0	33.8	35.6	37.4	39.2	41.0	42.8	44.6	46.4	48.2
10	50.0	51.8	53.6	55.4	57.2	59.0	60.8	62.6	64.4	66.2
20	68.0	69.8	71.6	73.4	75.2	77.0	78.8	80.6	82.4	84.2
30	86.0	87.8	89.6	91.4	93.2	95.0	96.8	98.6	100.4	102.2
40	104.0	105.8	107.6	109.4	111.2	113.0	114.8	116.6	118.4	120.2
50	122.0	123.8	125.6	127.4	129.2	131.0	132.8	134.6	136.4	138.2
60	140.0	141.8	143.6	145.4	147.2	149.0	150.8	152.6	154.4	156.2
70	158.0	159.8	161.6	163.4	165.2	167.0	168.8	170.6	172.4	174.2
80	176.0	177.8	179.6	181.4	183.2	185.0	186.8	188.6	190.4	192.2
90	194.0	195.8	197.6	199.4	201.2	203.0	204.8	206.6	208.4	210.2
100	212.0	213.8	215.6	217.4	219.2	221.0	222.8	224.6	226.4	228.2
110	230.0	231.8	233.6	235.4	237.2	239.0	240.8	242.6	244.4	246.2
120	248.0	249.8	251.6	253.4	255.2	257.0	258.8	260.6	262.4	264.2
130	266.0	267.8	269.6	271.4	273.2	275.0	276.8	278.6	280.4	282.2
140	284.0	285.8	287.6	289.4	291.2	293.0	294.8	296.6	298.4	300.2
150	302.0	303.8	305.6	307.4	309.2	311.0	312.8	314.6	316.4	318.2

$$F = (C \times 9) / (5) + (32)$$

$$C = (F - 32) \times (5/9)$$

C 0.1 = F 0.3

F 0.1 = C 0.03

TABLE A.8. RECTAL TEMPERATURE CONVERSION: FAHRENHEIT INTO CENTIGRADE

°F → ↓	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	↓°C↓									
90	32.2	32.3	32.3	32.4	32.4	32.5	32.6	32.6	32.7	32.7
91	32.8	32.8	32.9	32.9	33.0	33.0	33.1	33.2	33.2	33.3
92	33.3	33.4	33.4	33.5	33.6	33.6	33.7	33.7	33.8	33.8
93	33.9	33.9	34.0	34.0	34.1	34.2	34.2	34.3	34.3	34.4
94	34.4	34.5	34.6	34.6	34.7	34.7	34.8	34.8	34.9	34.9
95	35.0	35.0	35.1	35.2	35.2	35.3	35.3	35.4	35.4	35.5
96	35.6	35.6	35.7	35.7	35.8	35.8	35.9	35.9	36.0	36.0
97	36.1	36.2	36.2	36.3	36.3	36.4	36.4	36.5	36.6	36.6
98	36.7	36.7	36.8	36.8	36.9	36.9	37.0	37.0	37.1	37.2
99	37.2	37.3	37.3	37.4	37.4	37.5	37.6	37.6	37.7	37.7
100	37.8	37.8	37.9	37.9	38.0	38.0	38.1	38.2	38.2	38.3
101	38.3	38.4	38.4	38.5	38.6	38.6	38.7	38.7	38.8	38.8
102	38.9	38.9	39.0	39.0	39.1	39.2	39.2	39.3	39.3	39.4
103	39.4	39.5	39.6	39.6	39.7	39.7	39.8	39.8	39.9	39.9
104	40.0	40.0	40.1	40.2	40.2	40.3	40.3	40.4	40.4	40.5
105	40.6	40.6	40.7	40.7	40.8	40.8	40.9	40.9	41.0	41.0
106	41.1	41.2	41.2	41.3	41.3	41.4	41.4	41.5	41.6	41.6
107	41.7	41.7	41.8	41.8	41.9	41.9	42.0	42.0	42.1	42.2
108	42.2	42.3	42.3	42.4	42.4	42.5	42.6	42.6	42.7	42.7
109	42.8	42.8	42.9	42.9	43.0	43.0	43.1	43.2	43.2	43.3
110	43.3	43.4	43.4	43.5	43.6	43.6	43.7	43.7	43.8	43.8
111	43.9	43.9	44.0	44.0	44.1	44.2	44.2	44.3	44.3	44.4
112	44.4	44.5	44.6	44.6	44.7	44.7	44.8	44.8	44.9	44.9
113	45.0	45.0	45.1	45.2	45.2	45.3	45.3	45.4	45.4	45.5
114	45.6	45.6	45.7	45.7	45.8	45.8	45.9	45.9	46.0	46.0

TABLE A.9. RECTAL TEMPERATURE CONVERSION: CENTIGRADE INTO FAHRENHEIT

°C → ↓	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
						↓°F↓				
30	86.0	86.2	86.3	86.5	86.7	86.9	87.0	87.2	87.4	87.6
31	87.8	88.0	88.2	88.3	88.5	88.7	88.9	89.0	89.2	89.4
32	89.6	89.8	90.0	90.2	90.3	90.5	90.7	90.9	91.0	91.2
33	91.4	91.6	91.8	92.0	92.2	92.3	92.5	92.7	92.9	93.0
34	93.2	93.4	93.6	93.8	94.0	94.2	94.3	94.5	94.7	94.9
35	95.0	95.2	95.3	95.5	95.7	95.9	96.0	96.2	96.4	96.6
36	96.8	97.0	97.2	97.3	97.5	97.7	97.9	98.0	98.2	98.4
37	98.6	98.8	99.0	99.2	99.3	99.5	99.7	99.9	100.0	100.2
38	100.4	100.6	100.8	101.0	101.2	101.3	101.5	101.7	101.9	102.0
39	102.2	102.4	102.6	102.8	103.0	103.2	103.3	103.5	103.7	103.9
40	104.0	104.2	104.3	104.5	104.7	104.9	105.0	105.2	105.4	105.6
41	105.8	106.0	106.2	106.3	106.5	106.7	106.9	107.0	107.2	107.4
42	107.6	107.8	108.0	108.2	108.3	108.5	108.7	108.9	109.0	109.2
43	109.4	109.6	109.8	110.0	110.2	110.3	110.5	110.7	110.9	111.0
44	111.2	111.4	111.6	111.8	112.0	112.2	112.3	112.5	112.7	112.9
45	113.0	113.2	113.3	113.5	113.7	113.9	114.0	114.2	114.4	114.6
46	114.8	115.0	115.2	115.3	115.5	115.7	115.9	116.0	116.2	116.4
47	116.6	116.8	117.0	117.2	117.3	117.5	117.7	117.9	118.0	118.2
48	118.4	118.6	118.8	119.0	119.2	119.3	119.5	119.7	119.9	120.0
49	120.2	120.4	120.6	120.8	121.0	121.2	121.3	121.5	121.7	121.9

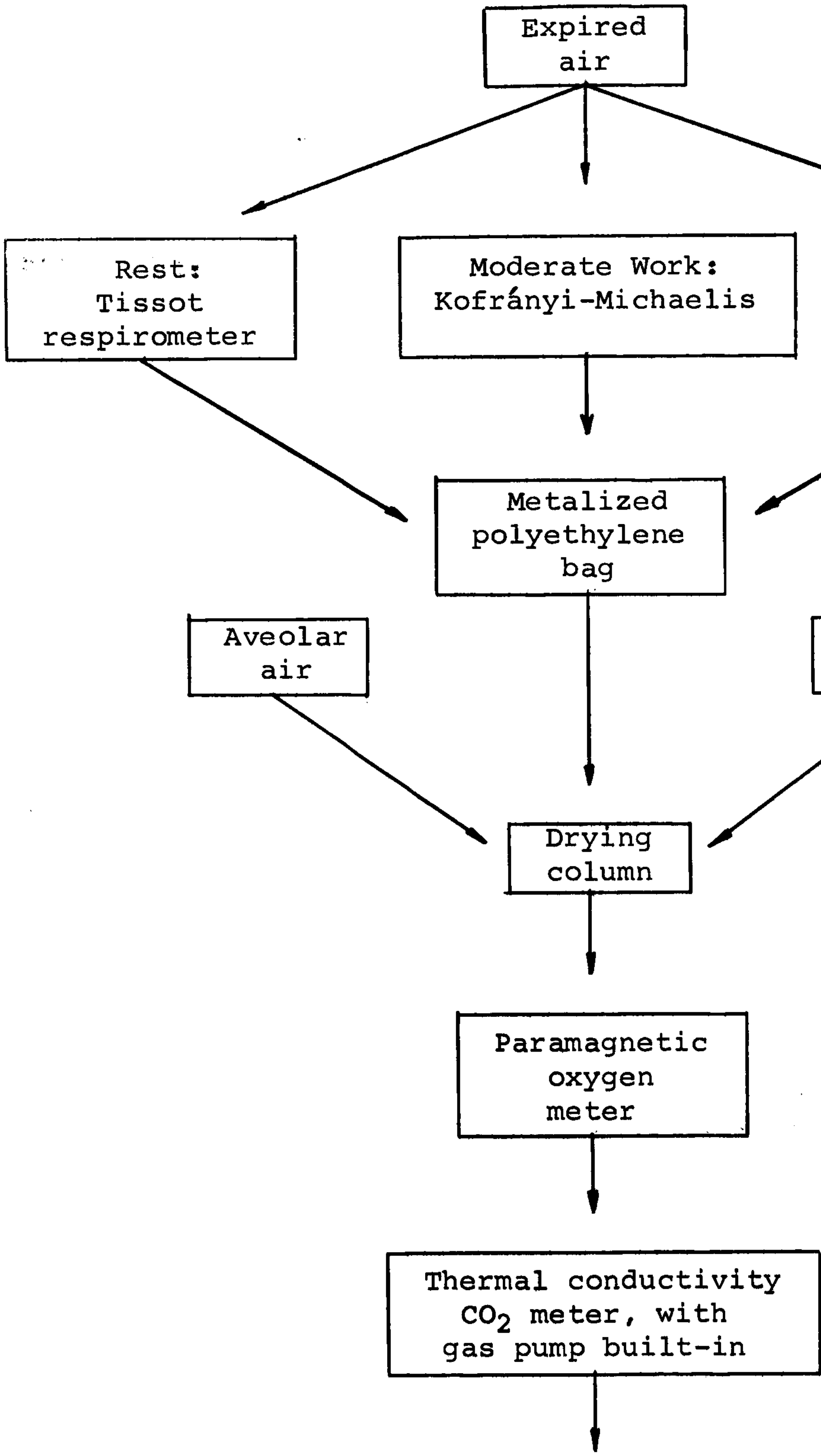

FIG. A1. Block diagram of system for estimating oxygen consumption in man.

APPENDIX B. LIST OF TABLES AND CHARTS IN THIS REPORT

TABLES

CHARTS