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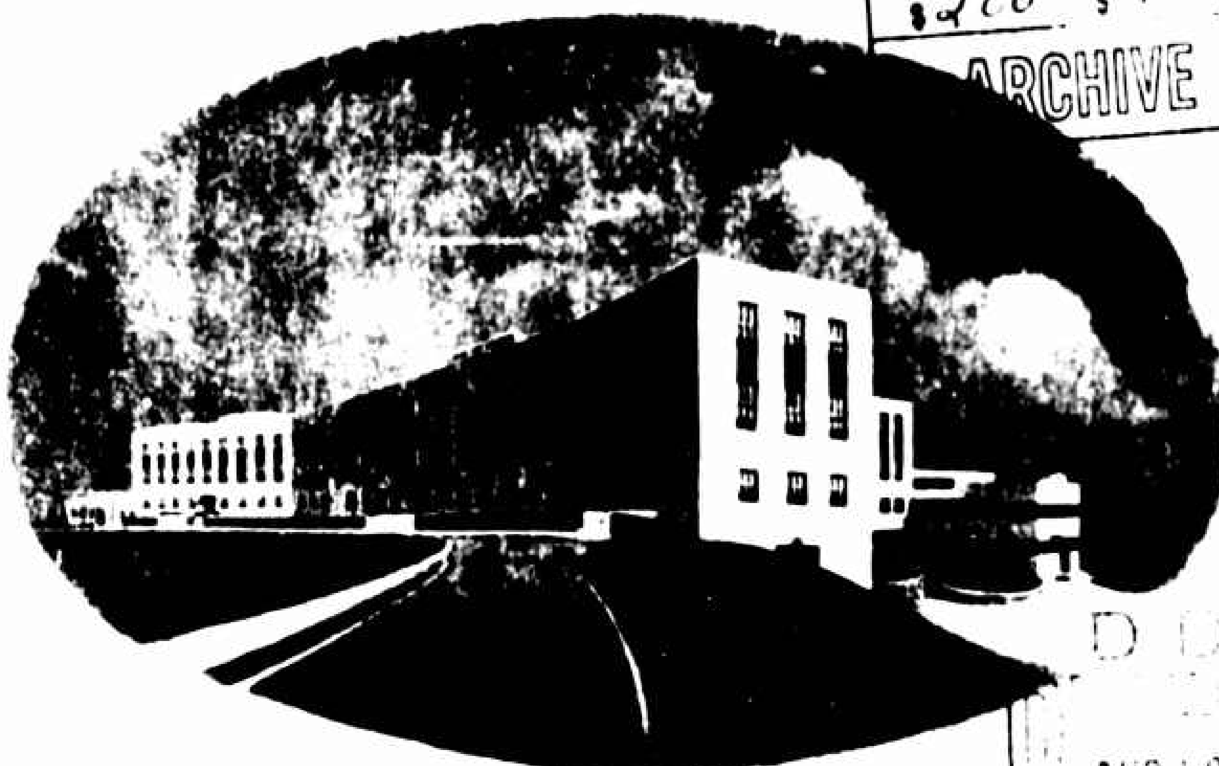

COMPARISON OF PHYSIOLOGICAL CHANGES DURING LONG TERM IMMERSION TO NECK LEVEL IN WATER AT 95°, 85°, and 75° F

RESEARCH REPORT

MF011.99-1001

REPORT NO. 9

COMPARISON OF PHYSIOLOGICAL CHANGES DURING LONG TERM IMMERSION TO NECK LEVEL IN WATER AT 95°, 85°, and 75° F

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ABSTRACT

Comparison of Physiological Changes During Long Term Immersion to the Neck Level in Water at 95°, 85°, and 75° F

This experiment was designed to evaluate the physiological changes which result from immersion of subjects in water to neck level for 24 hours at water temperatures of 95°, 85°, and 75° F. It had previously been determined that immersion of subjects in water below 95° F resulted in a heat loss from the body which was compensated by an increase in metabolic rate. Other changes in blood morphology and blood electrolytes had been shown to occur concomitantly with increased urinary excretion of water and electrolytes. Since the previous studies had been carried out over a relatively short period of time, the present experiments were designed to evaluate such changes over a 24-hour period, not only at 95° F water temperature but at lower water temperatures as well. It was found that the three subjects increased their metabolic rate when immersed in 85° F water and were able to maintain a "normal" deep body temperature over the 24-hour period. When immersed in the 75° F water, the increased oxygen consumption due to shivering was insufficient to maintain deep body temperature. In addition, the physiological discomfort of immersion at 75° F and "the spiritual failure" of those subjects caused the experiments to be terminated within 12 hours. The changes in the morphology and electrolyte content of the blood together with the hemoconcentration were associated with increased urinary water and electrolyte excretion and were progressive with time.

ACKNOWLEDGMENTS

The authors wish to gratefully acknowledge the assistance and advice of Captain E. L. Beckman, MC, USN, in the design and preparation of the experimental method. We also wish to express our appreciation to the technicians of the Environmental Stress Division, NMRI, Bethesda, especially HM1 Michael Green, HN Richard England, and HN John Parkinson for their invaluable assistance in all phases of the experiments.

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INTRODUCTION

Man has been attempting to survive at sea for many centuries; during recent decades he has been given methods of flotation, concentrated rations, shark-fighting equipment, signal flares and knives, but little has been done to alleviate the physiological problems of survival at sea, namely, exposure of the body to thermally conductive cold water. Body heat loss to the surrounding water and air constitutes the greatest hazard to such a person. The additional problem of body water loss through diuresis which accompanies immersion in water to the neck level brings the victim to the threshold of death days before the time he would perish on land when deprived of water and food. The Survival-at-Sea Chart[1] now used by the Armed Services was compiled from data of individual cases of survival and the conclusions drawn seem to be too broad. The implication is that one should be able to survive in water above 68° F indefinitely. From preliminary experiments, this does not appear to be the case.[2] However, since such studies were for 12 hours or less, the present experiments were designed to evaluate the physiological changes which result from immersion in water up to neck level for 24 hours at water temperatures of 95°, 85° and 75° F.

METHODS

The physical measurements of the three subjects are listed in Table I.

TABLE I PHYSICAL MEASUREMENTS OF SUBJECTS

SUBJECT	AGE (yrs)	HEIGHT (cm)	WEIGHT (kg)	SURFACE AREA (m^2)	BODY CONFIGURATION
JW	21	183	75	1.95	Medium
CM	21	184	80	2.01	Medium
JB	22	181	80	2.01	Medium
Average	21	182	78.3	1.99	

Each subject was instructed to: (1) abstain from alcoholic beverages 12 hours before the experiment; (2) obtain a normal night's sleep; and, (3) eat three doughnuts and one pint of white milk at 0700 the morning of the test with nothing thereafter for the 24 hours of the experimental period. Each subject collected a twenty-four hour urine sample as a control. Upon reporting to the laboratory, he had nude weight and height measurements and resting oxygen consumption determinations made. The oxygen content of the expired gas was measured on a Pauling-type oxygen analyzer, and the energy usage was calculated according to the formula of Weir.[3] Pre-immersion temperatures, a bipolar EKG (forehead-rectal), blood pressure (auscultation method), pulse and respiration rates were recorded. Core temperatures were measured by thermocouples placed on the tympanic membrane and protected from air currents and water by a foam rubber cup. Thermocouple rectal temperature probes were also used. Blood and urine specimens were collected before the subject entered the pool.

The subjects, wearing swim trunks and a Navy Mk 2 pneumatic vest life preserver, were immersed to neck level in a water-filled metal tank 10 ft in diameter and 10 ft deep. An hourly urine specimen was collected, the subject being permitted to leave the tank for the sample. Such samples were pooled every four hours to coincide with blood collection. Core temperatures, blood pressure, pulse and respiration rates and oxygen consumption measurements were recorded hourly and at the end of the experiment. Every four hours and at the end of the immersion period, blood samples were taken. EKG recordings and grip tests were recorded at four-hour intervals while the subject was immersed. Body weight was measured before and after immersion.

Hourly urinary measurements were made of volume, specific gravity (urinometer), pH (Hydrion paper), protein and sugar content (Uristix), and acetone (acetone tablets). Leucocyte, erythrocyte, and total eosinophil counts, hemoglobin and hematocrit measurements, and a differential count were performed on each blood sample. Blood glucose determinations were performed every 4 hours during the experiment. Electrolyte measurements were made on all blood and urine specimens.

Although all experiments were planned for 24 hours of immersion, the following criteria were established to limit the experimental period: (1) decrease in core temperature to 95° F; (2) persistent unrelieved muscle cramps in large muscle groups; (3) cardiac irregularities; and, (4) request of the subject.

RESULTS

All three subjects were able to complete immersions for 24-hour periods in water at 95° and 85° F but requested termination of the experiments after 12 hours when immersed in water at 75° F. J.W. showed the most response to

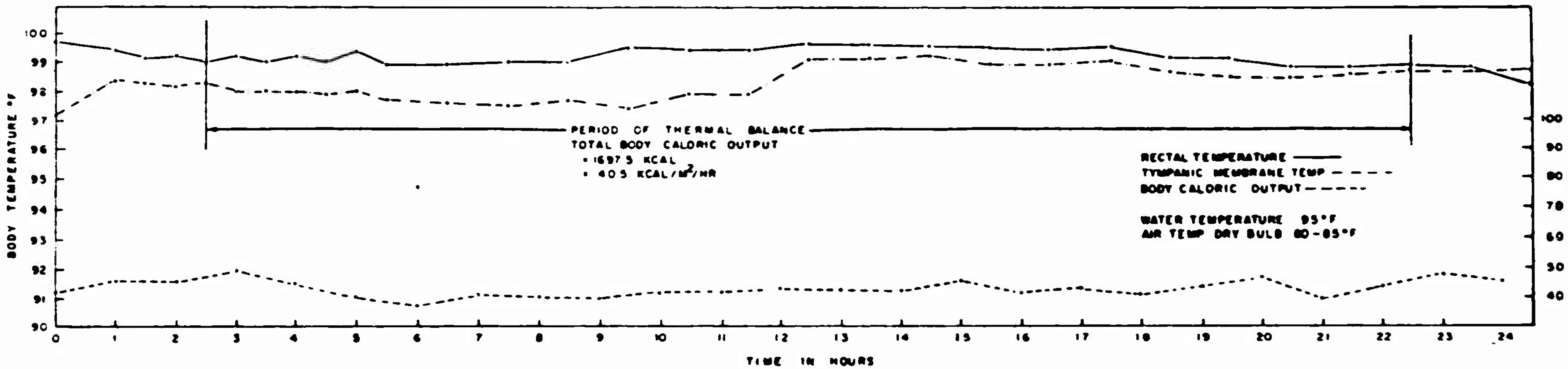

Figure 1: Body core temperatures and energy output during immersion in water at 95° F. (Subject, J. R.)

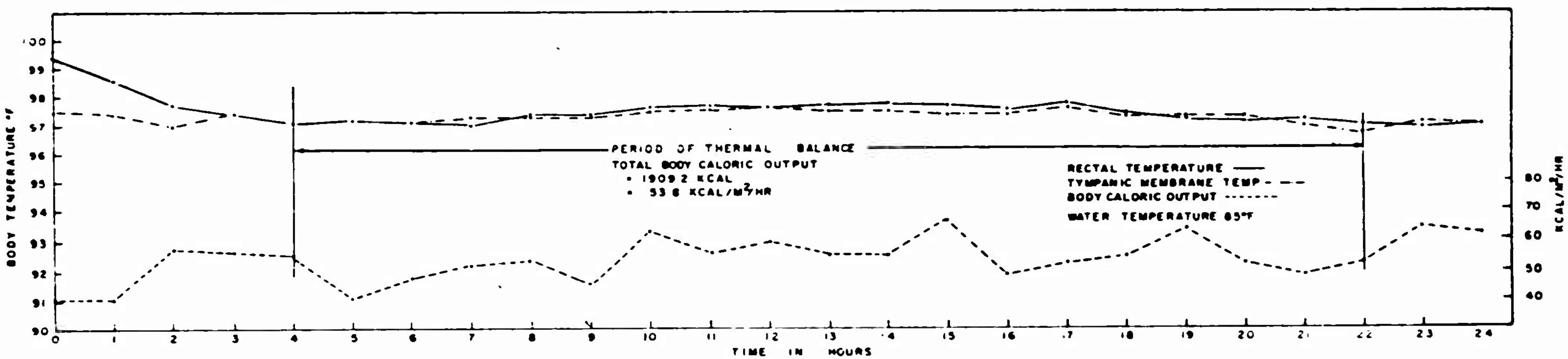

Figure 2. Rate of change of body core temperature and increase in energy output during immersion in water at 85° F. (Subject, J. B.)

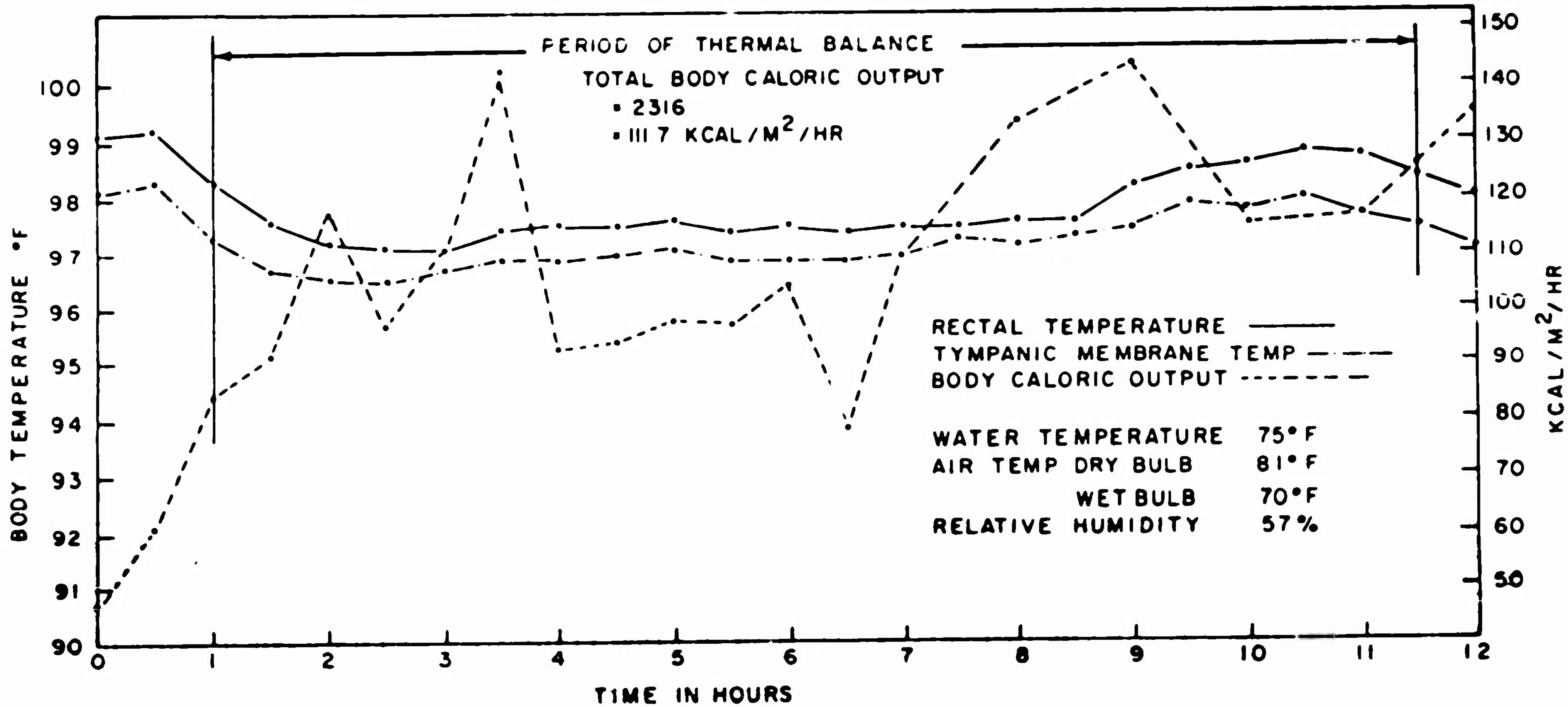

Figure 3. Rate of change of body core temperatures and increase in energy output during immersion in water at 75° F. (Subject J. B.)

cold while C.M. displayed ... least. Rectal temperature readings were usually higher than tympanic. Diurnal variations in temperature recordings were also noted in the 24-hour immersions. At 95° F, considered to be a neutral temperature, all three subjects maintained their normal temperatures, and although the subjects did cool somewhat, they rewarmed spontaneously without any obvious muscular exertion. Figure 1 typifies the energy output and rectal/tympanic temperatures of subject J.B. at 95° F. At 85° F, during the first two to three hours, core temperatures stabilized 0.7 - 1° F lower than the control values and continued at approximately that level for the remainder of the experiment, Figure 2. At 75° F cooling was more marked during the first three hours, with a fall in core temperature of approximately 2.0° F. Stabilization occurred at this lower level until the eighth or ninth hour when a temperature rise of 0.5° - 1.0° F was noted. Moderately severe shivering undoubtedly contributed to this increase in temperature, Figure 3. As can be noted in Figures 2 and 3 after the initial temperature loss, deep body temperature was maintained by an increase in metabolic rate by shivering. Thus, thermal balance was maintained with total body heat loss just equaling energy production. Table II lists the total energy output as calculated from oxygen utilization[3] measurements ($kcal/m^2/hr$) for each subject during immersion at each temperature. During the 95° and 85° F immersions, C.M., the best insulated of the three subjects, had a work ratio of less than 1. Only during the 75° F immersion did it increase to 1.6 - 1.9 for the last three hours of that experiment. Work ratio, as used here is a comparison of the $kcal/m^2/hr$ used by the body in relation to the $kcal/m^2/hr$ used by the subject sitting quietly by the pool before the test, Figure 4. J.B. and J.W., on the other hand, had to produce energy by shivering during both the 85° and

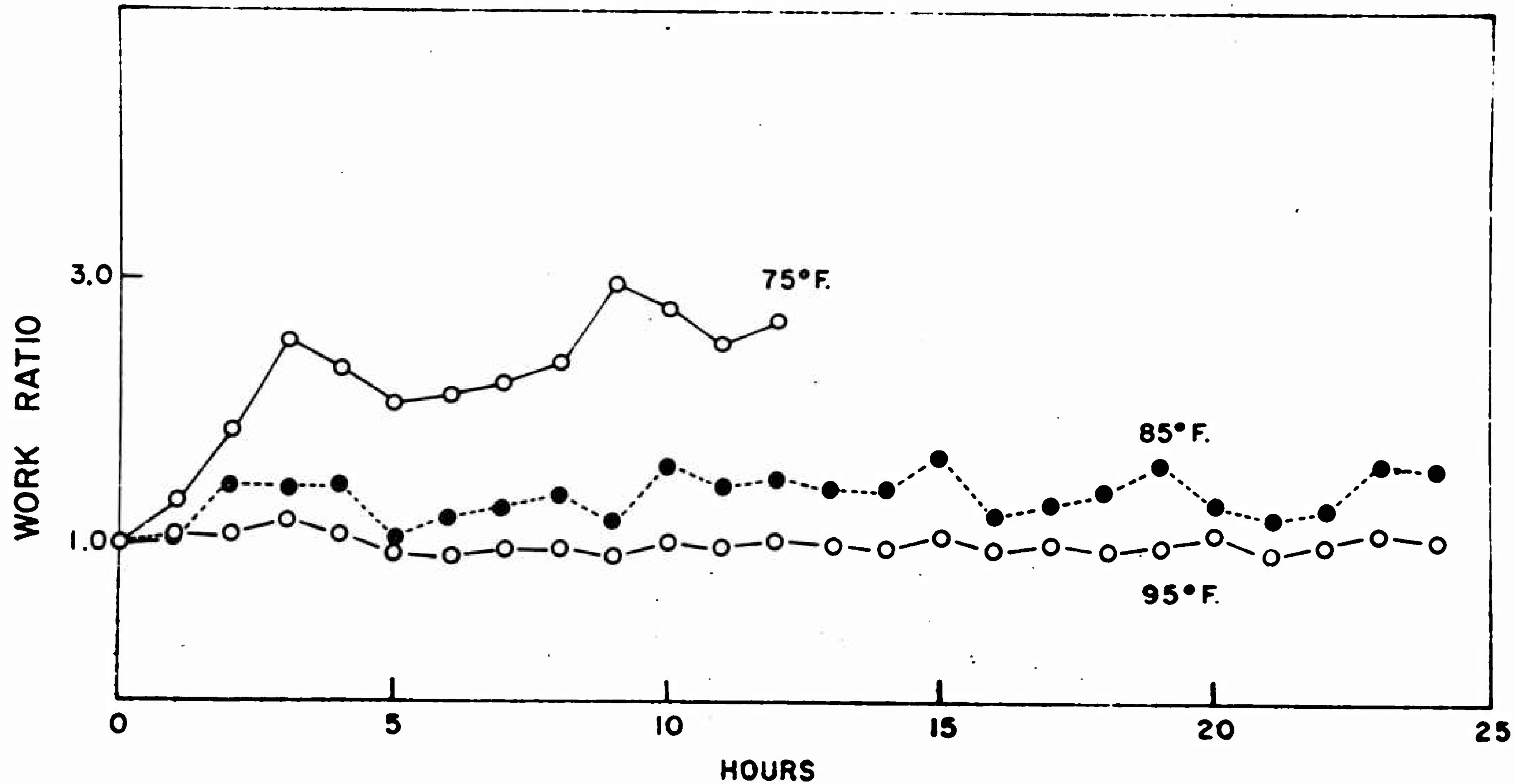

Figure 4. Change in work ratio during immersion in water at 95°, 85°, and 75° F.

TABLE II TOTAL ENERGY OUTPUT DURING IMMERSION TO NECK LEVEL IN WATER AT 95°, 85°, and 75° F

Subject	Control	95° F	Control	85° F	Control	75° F
C.M.	49.6	47.2	46.6	46.4	46.2	67.4
J.B.	42.8	40.5	40.6	53.8	44.1	111.7
J.W.	44.5	39.9	40.8	58.5	41.3	145.1

75° immersions. J.B.'s work ratio during the 75° F experiment increased during some measurements more than three times the normal rate while J.W., the leanest of the three men shivered most vigorously at 75° F with work ratios approximately four times the normal value 75% of the immersion period.

All three subjects showed similar pulse rate patterns, the highest rate at 95° F (approximately 65 bpm) and the lowest at 85° F (approximately 50 bpm). During peaks of shivering at 75° F the pulse rate of J.W. doubled as his metabolic rate increased four times. Systolic pressures averaged 150 mm during the 75° F immersions for all three subjects and tended to remain at about 125 mm Hg during immersions at 85° and 95° F. Diastolic pressure averaged 80 mm Hg for J.B. and C.M. while for J.W. during the 85° F immersion, it rose gradually from 80 mm to 110 mm Hg. Pulse pressure averaged 70 mm for the 75° F immersion and 30 mm Hg at 85° and 95° F.

Although long term immersions have been said to be debilitating, no reliable indication of this weakness was shown by the grip test which seemed to be unaffected by the immersions. In several cases it had increased by the end of the immersion period. The subjects, however, noted a generalized feeling of weakness, especially upon emerging from the 75° immersion, but were unable to localize it beyond the large leg muscles or as a general feeling of moderate tiredness.

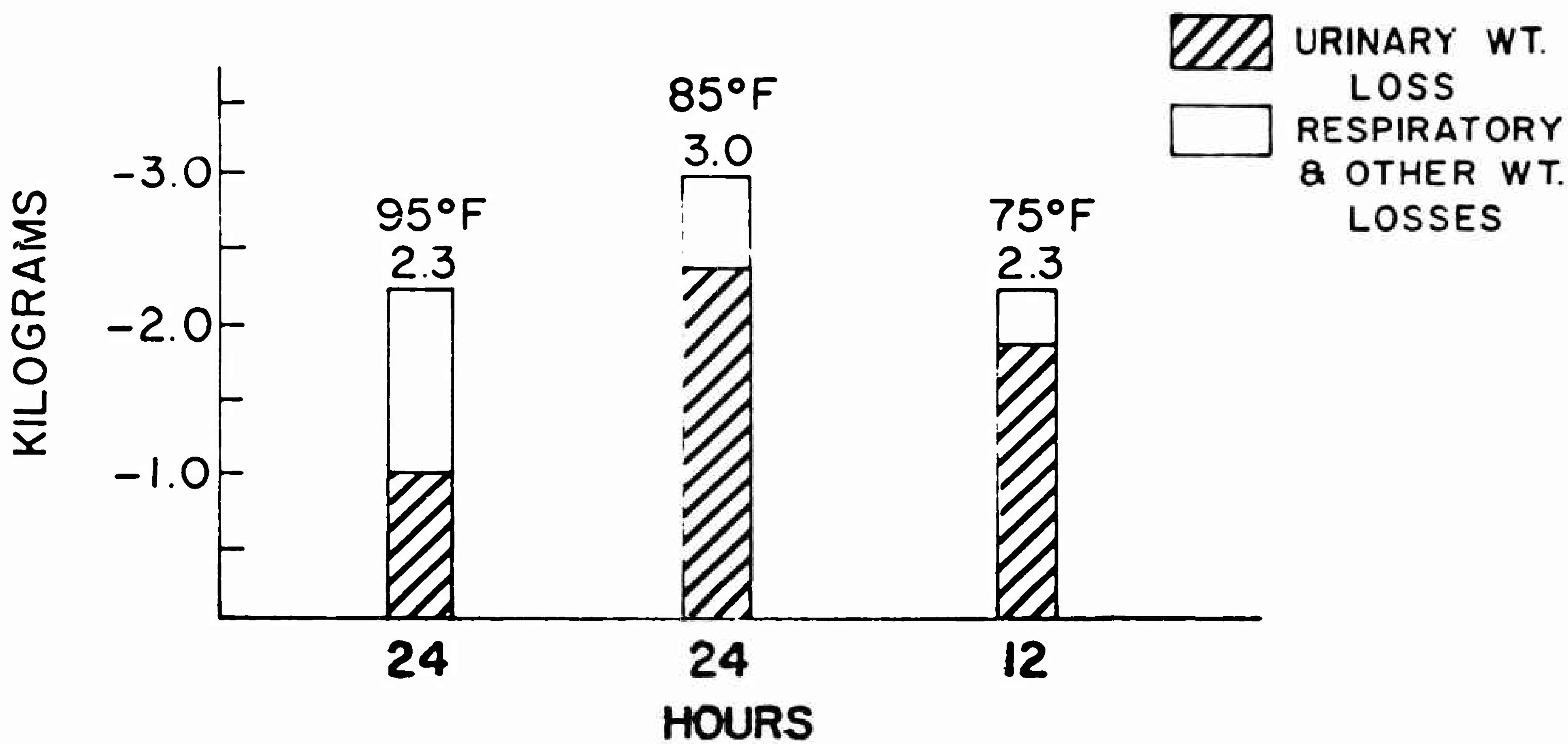

Figure 5. Weight loss during immersion in water at 95°, 85° and 75° F.

Weight loss of 2 kg or more occurred during all three immersions with an average of 3 kg loss during the 85° F immersions, Figure 5.

Table III lists the hematological measurements of one of the subjects. Hematocrit, hemoglobin and serum specific gravity values increased for all three subjects during all immersion studies, indicating definite hemoconcentration. The plasma specific gravity values, however, decreased during the last four hours for all three subjects at 75° F; it appeared this was true at other temperatures as well. Erythrocyte counts remained essentially unchanged for all conditions while leucocyte counts increased approximately 50% at 85° and 95° F, and 79% at 75° F. Total eosinophil counts as well as the percentage of lymphocytes decreased in J.B. and J.W., the two subjects stressed the most during the 75° F immersion.

TABLE IV BLOOD GLUCOSE LEVELS OF C.M. DURING IMMERSION IN WATER AT 95°, 85° AND 75° F

DURATION (hrs)	95° F	85° F	75° F
CONTROL	104	81	82
After 4 hrs	96	65	84
8	94	70	48
12	86	72	53
16	90	68	
20	90	62	
24	78	62	

In general blood urea nitrogen values remained stable, as did the blood glucose values for two of the subjects. C.M., on the other hand, had a decrease in blood glucose at all three temperatures. By the end of the 75° F immersion,

TABLE III CHANGES IN BLOOD AND PLASMA VALUES DURING IMMERSION AT 95°, 85° AND 75° F

	95°			85°			75°			
MEASUREMENT	Control	12 hr	24 hr*	Control	12 hr	24 hr	Control	4 hr	8 hr	12 hr
HEMATOCRIT (mm/100 mm)	43	48	51	44	50	50	44	52	50	51
HEMOGLOBIN (g/100 ml)	15.3	16.2	17.1	14.9	18.0	17.8	15.3	18.4	17.6	16.4
PLASMA-SPECIFIC GRAVITY	1.0276	1.0276	1.0290	1.0270	1.0303	1.0270	1.0270	1.0309	1.0314	1.0309
LEUCOCYTES (mm^3)	7800	10,300	13,100	7,100	9,900	7,400	6,250	8,050	1[illegible],000	12,300
LYMPHOCYTES (%)	43	32	36	42	34	33	42	28	28	21
EOSINOPHILS (mm^3)	22	22	67	88.8	88.8	155.4	99.9	111.1	55.5	66.[illegible]
BLOOD GLUCOSE (mg/100 ml)	106	104	98	108	94	89	81	82	80	88

* Subject J.B.

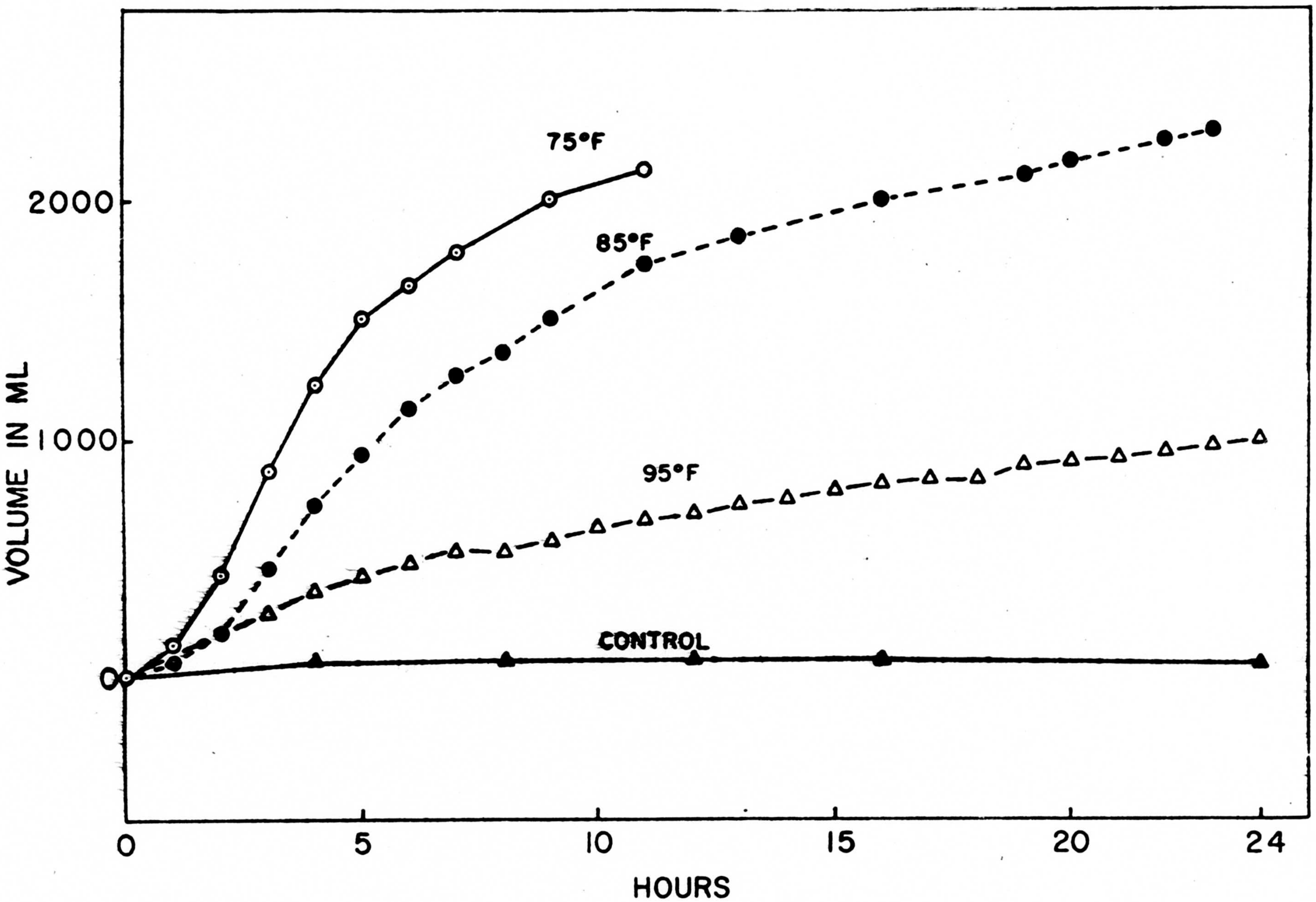

Figure 6. Cumulative urinary output during immersion in water at 95°, 85°, and 75° F.

the blood glucose level in this subject had reached 53 mg/100 ml, Table IV. Serum glutamic oxalacetic transaminase (SGOT), serum glutamic pyruvic transaminase (SGPT), and lactic dehydrogenase (LDH) levels were measured during the 75° F immersion but showed no significant changes. Serum electrolyte values showed no consistent change during any of the immersions.

As observed in previous immersion studies, the most striking finding was that of increased urinary output, maximal levels occurring within the first hour of the 95° F immersion and within the first and second hours of the 85° and 75° F immersions with steadily diminishing urinary output during the latter hours of each experiment. Figure 6 are graphs showing the cumulative urinary output of one of the subjects; at 95° F the average hourly output stabilized at 22-32 ml/hr during the last 12 hours, at 85° F between 40-45 ml/hr during the last 12 hours, and at 75° F, around 40 ml/hr during the last four hours of the 12-hour immersion, Table V. Thus at 75° F, the diuresis caused by water immersion although diminished had not abated. The specific gravity showed a tendency to drop from control values above 1.020 to below 1.010, even as low as 1.002. The return toward normal levels was concomitant with a decrease in hourly output. The relationship between specific gravity and urine volume was one of inverse proportion.

Along with the increased volume of urine excreted, there was an increased excretion of most of the urinary constituents measured during the first four hours at 95°, during the first eight hours at 85° and 75° F, Table V. Figure 7 shows graphically the total output of the urinary constituents during immersion at 95°, 85° and 75° F compared to control values of personnel under normal conditions, i.e.,: (1) replacement of food and

TABLE V. AVERAGE URINARY EXCRETION RATES DURING IMMERSION IN WATER AT 95°, 85°, and 75° F.

URINE SAMPLE	OUTPUT Total ml	OUTPUT /hr	OSMOLARITY Total mosm	OSMOLARITY /hr	SODIUM Total meq	SODIUM /hr	POTASSIUM Total meq	POTASSIUM /hr	CALCIUM Total meq	CALCIUM /hr	CHLORIDE Total meq	CHLORIDE /hr	UREA Total grams	UREA /hr	CREATININE Total grams	CREATININE /hr	PHOSPHATE Total mg	PHOSPHATE /hr	17-OHCS Total mg	17-OHCS /hr
									CONTROLS											
12 hr NRC*	297	25	420	35	35.2	2.9	36.0	3.0	1.90	0.11	56.4	4.7	4.40	0.37	0.23	0.02	414.4	34.5	4.02	0.34
24 hr RC**	1237	52	1090	45	217.8	9.1	96.5	4.0	7.40	0.31	184.4	7.7	15.50	0.65	1.71	0.07	967.0	40.3	8.10	0.34
									95°F											
After 4 hrs	323	81	373	93	51.3	12.8	27.7	6.9	0.62	0.15	58.4	14.6	3.00	0.75	0.30	0.07	135.3	34.0	1.99	0.50
8	161	40	113	28	31.7	7.9	11.2	2.8	0.11	0.03	29.5	7.4	1.70	0.43	0.22	0.06	142.8	35.8	0.66	0.16
12	163	41	136	34	27.6	6.9	9.9	2.5	0.16	0.04	21.6	5.4	1.30	0.33	0.19	0.05	146.5	36.8	1.07	0.27
16	88	22	49	12	14.7	3.7	5.1	1.3	0.26	0.05	10.1	2.5	1.10	0.28	0.22	0.05	95.9	24.0	0.94	0.24
20	97	24	92	23	11.3	2.8	7.9	2.0	0.27	0.07	11.7	2.9	1.60	0.40	0.32	0.08	119.3	29.8	1.00	0.25
24	108	27	128	32	16.5	4.1	10.3	2.6	0.35	0.09	15.3	3.8	1.40	0.35	0.27	0.07	120.8	30.3	1.57	0.39
Total 24 hrs	960	40	891	37	153.2	6.4	72.1	3.0	1.77	0.07	146.6	6.1	10.10	0.42	1.51	0.06	761.6	31.8	7.23	0.30
									85°F											
After 4 hrs	922	230	274	69	118.7	29.7	49.8	12.5	0.21	0.05	116.2	29.1	3.20	0.80	0.29	0.07	158.1	39.5	2.52	0.63
8	597	149	247	62	83.3	20.8	26.5	6.6	0.24	0.06	65.0	16.3	1.70	0.43	0.22	0.06	166.4	41.6	1.51	0.38
12	290	74	77	19	36.0	9.0	11.2	2.8	0.30	0.08	30.2	7.6	0.88	0.22	0.09	0.02	91.2	22.8	0.50	0.13
16	163	41	83	21	26.3	6.6	7.3	1.8	0.36	0.09	16.8	4.2	1.20	0.30	0.14	0.04	60.0	15.0	0.63	0.16
20	182	45	81	20	18.5	4.6	9.2	2.3	0.30	0.10	16.2	4.1	1.10	0.28	0.14	0.04	68.9	17.2	0.63	0.16
24	167	41	87	22	20.7	5.2	11.9	3.0	0.50	0.14	18.8	4.7	0.66	0.17	0.12	0.03	70.7	17.7	0.93	0.25
Total 24 hrs	2318	97	849	35	296.4	12.4	116.0	4.8	1.96	0.08	263.2	11.0	8.68	0.36	0.99	0.04	615.3	25.6	6.74	0.28
									75°F											
After 4 hrs	1098	277	459	115	70.0	17.5	22.9	5.8	1.84	0.46	82.0	20.5	3.82	0.30	1.20	0.30	112.1	28.0	6.08	1.52
8	470	117	222	56	42.8	10.7	17.2	4.3	0.52	0.13	38.5	9.6	0.65	0.14	0.59	0.15	85.5	21.4	1.24	0.31
12	167	42	62	16	23.0	5.8	9.7	2.4	0.52	0.13	19.5	4.9	0.11	0.05	0.19	0.05	36.8	9.2	1.04	0.26
Total 12 hrs	1735	145	743	62	135.8	11.3	49.8	4.2	2.88	0.24	140.0	11.7	4.58	0.38	0.66	0.06	234.0	19.5	8.36	0.70

*NRC - Non-Replacement of food and water
**RC - Replacement of food and water

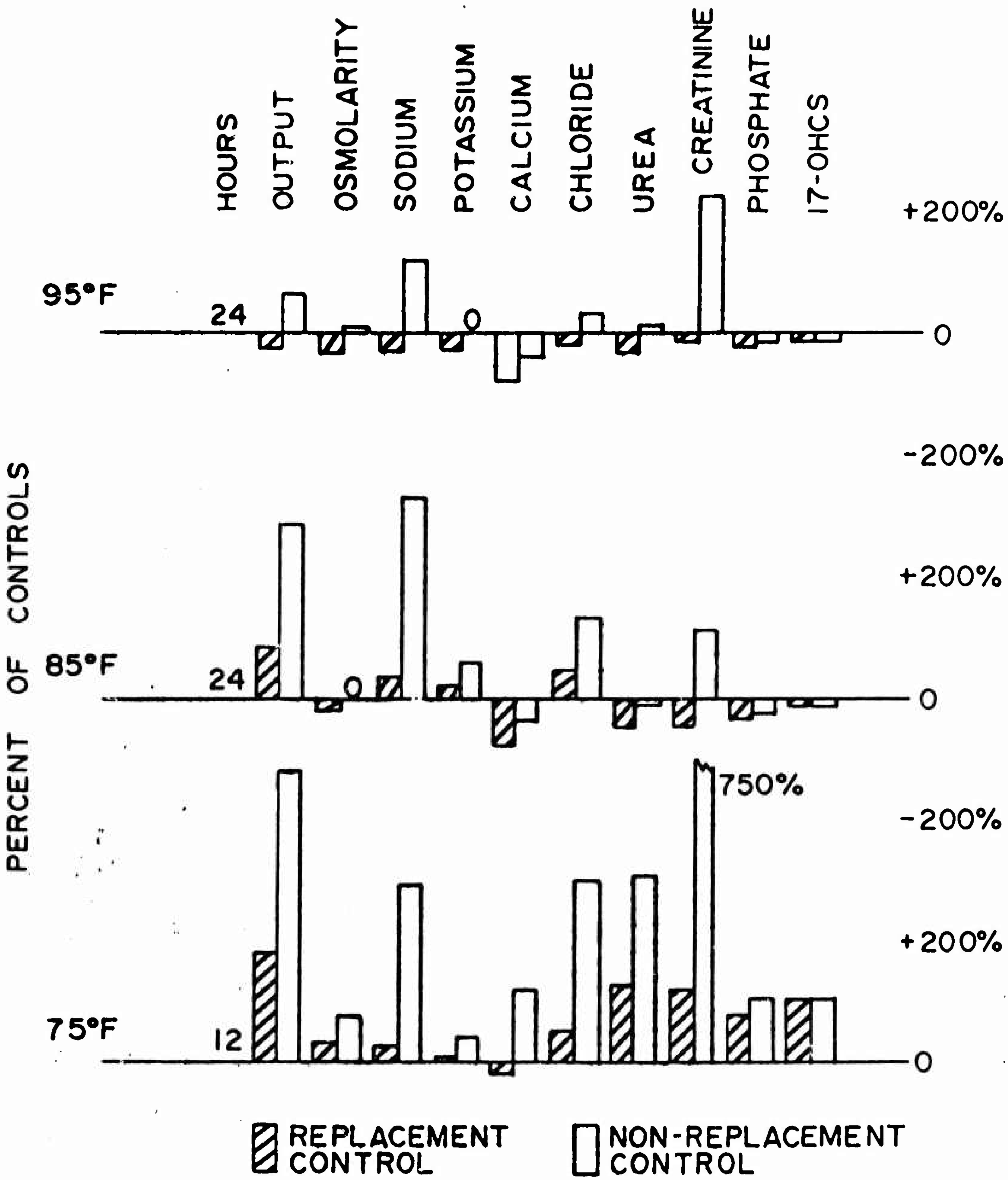

Figure 7. Percent change from control values in urinary excretion patterns during immersion to neck level in water at 95°, 85°, and 75° F.

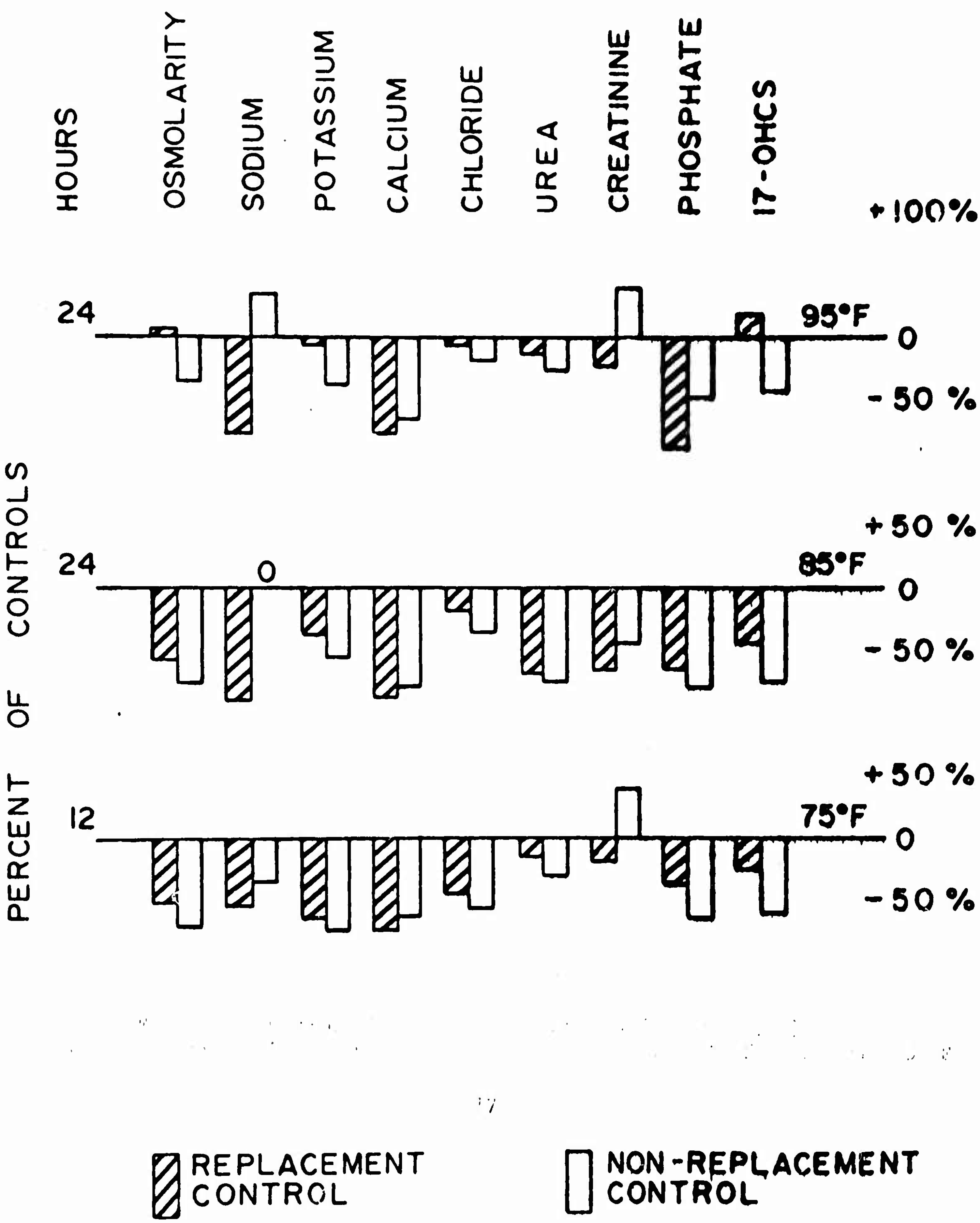

Figure 8. Percent change in concentration (mg or meq/ml) from control values during immersion to neck level in water at 95°, 85°, and 75° F.

liquid (RC), (2) non-replacement of food and liquid (NRC). At all three temperatures there occurred a water diuresis accompanied by an increased loss of sodium, chloride, and creatinine, while at 75° F, there was an increased loss of all constituents. However, a comparison of the concentration (mg or meq/ml) of the various urinary constituents excreted during immersion with replacement and non-replacement controls shows that the loss was that of water, Figure 8.

Acetone, suggesting lipid catabolism, occurred in the urine of [illegible] B. after 20 hours at 85° F but in C. M. and J. W. after only 4 and 8 hours, respectively, at 75° F. Neither protein nor glucose were found in any of the urine samples. The pH tended toward increasing acidity throughout the experiments at all temperatures.

DISCUSSION

The primary purpose of these experiments was to determine the physiological effects of 24 hours of immersion in water at 95°, 85° and 75° F in order to extend data from previous studies conducted for periods of 12 hours or less. Such temperatures were initially chosen to simulate three physiologically distinct conditions; 95° F, neutral in its thermal effects upon the body; 85° F, a moderate temperature which can be tolerated for long periods of time[4] but cool enough to cause peripheral vasoconstriction resulting in intermittent bouts of shivering for temperature maintenance, and 75° F, a stressful condition for even a short period of time which requires strenuous shivering for adequate maintenance of body temperature. Previous experimentation has demonstrated that water immersion elicits a loss of body water and electrolytes and a loss of body heat with a concomitant increase in rate of metabolism, the extent of which is dependent upon the temperature of the water and the duration of exposure. Beckman and co-workers[5] noted in their simulation of zero G conditions that all seven subjects displayed diuresis for the duration of their immersions at 94° F. The specific gravity of their urine decreased from control values of 1.020 to a low of 1.001, and remained in a low range (1.001 - 1.005) throughout the experiment, even though the subjects were increasingly dehydrated. The diuresis was therefore thought to be essentially a loss of free water. Graveline and Jackson[6] observed similar diuretic effects in each of five subjects who were completely submerged for six-hour immersions at 91.3° F. The urinary specific gravity varied from 1.002 - 1.004, with a corresponding drop in osmolarity from 878 mosm/liter, the control value, to 289 mosm/liter. Graveline and Barnard[7] in a similar approach to hypodynamic conditions, found that each of four subjects immersed for 24 hours at 92.3° F showed low specific gravity polyuria for the duration of the test. Recent studies demonstrated that a profuse diuresis accompanied immersions of nine or less hours and lasted for the entire duration of the immersions, whether or not the fluid excreted was replaced.[2] Urinary specific gravities fell below 1.010, while blood specific gravities and hematocrits rose. There was also a rise in post-immersion leucocyte and total eosinophil counts over control values. Reeves et al[8] in studies in which fluids were not replaced during immersions of 12 hours at 87° and 94° F, noted similar urinary excretion patterns showing a definite water diuresis. During the first two hours, urine excretion amounted to 7-12 times the non-replacement rate, tapering off to twice this amount by the end of the immersion. Total excretion of electrolytes was increased during both immersion temperatures but concentrations of each when calculated meq/ml showed decreases varying from 9 - 83%. Hemoconcentration was observed in all immersions, reflected by rises in hemoglobin content and specific gravity of blood and serum. All subjects in the nonreplacement experiments lost between 1.6 and 2.0 kg during their immersions.

The probable mechanism underlying this diuresis is probably threefold. First, vasoconstriction of peripheral blood vessels when a person is immersed in water below that of body temperature causes an increase in the volume of blood squeezed toward the heart. In addition, the hydrostatic pressure of the water counterbalances that within the blood vessels preventing pooling and increasing at the same time the central blood volume. Aiding these phenomena is that of negative pressure breathing which results when the external pressure applied to the body immersed up to neck level exceeds the pressure of the inspired air. A low pressure area is thus created in the thoracic cage which floods with blood. A larger proportion than normal is shunted into the atria. Stroke volume is therefore increased.[9, 10] It has been hypothesized[11] that volume receptors in the atria, as a result of the increased blood volume effect a reduction in the secretion of ADH, thereby precipitating the diuresis. Such effect, called the Gauer-Henry reflex, appears to be mediated by way of the vagal afferents to the hypothalamus.

In the present series of immersions there was a water diuresis at all three temperatures, as had been observed in previous experiments. The quantity of urine excreted during the first 12 hours of the immersions was greatest at 85° F (95° F, 646 ml; 85° F, 1808 ml; 75° F, 1735 ml). If the peripheral vasoconstriction was almost maximal as expected at this temperature, and other factors remained constant, there would have been approximately the same volume of blood in the central circulation at both 85° and and 75° F. The pulse rate at 85° F was lower, allowing greater atrial filling and therefore a greater stimulus for a Gauer-Henry reflex diuresis while at 75°, the pulse rate was significantly higher and possibly allowed less atrial filling.

With the extension of the experimental period to 24 hours, the question of the total fluid and electrolyte loss was partially answered. During the last 12 hours of immersion at 95° F the average hourly output of water and electrolytes stabilized at approximately the values for non-replacement controls; at 85° F, a water diuresis still persisted 1.8 times that of the NRC and, while all 75° F experiments were terminated at the end of 12 hours, water and electrolyte excretion were still greater than the NRC (Table V). Thus although cold water diuresis probably does not continue as long as the subject is immersed, it is still apparent at the end of 24 hours at 85°, and at the end of 12 hours at 75° F.

Dehydration became readily apparent after four hours of immersion at all temperatures with a rise in hematocrit of approximately 16%. No discernable change was noted in the erythrocyte count, but the serum specific gravity for all three subjects at 75° F decreased during the last four hours indicating that hemoconcentrations might have been reversed by extracellular fluid reentering the vascular system.

The three subjects, immersed in these experiments, had approximately the same height and weight, Table I. The best insulated of the three subjects, C.M. shivered the least and had a work ratio below 1 0 during immersion at 95° and 85° F, and only during the last three hours of immersion at 75° F did his work ratio go as high as 1.9. Physiologically his body attempted maintenance of body heat by a decrease in core temperature to a lower threshold where it stabilized for the remainder of each immersion period and by an increased utilization of carbohydrate and fat. This was only partially successful as his blood glucose decreased during every immersion, (Table IV), falling the last eight hours at 75° F to 48 and 53 mg/100 ml. Lipid catabolism was evident at both 85° and 75° F, during the latter immersion after only 4 hours. The other two subjects, on the other hand, who shivered vigorously at 75° F, and moderately at 85° F, demonstrated fluctuating core temperatures, apparently varying with the duration and intensity of shivering. J.B.'s rectal temperature at 75° was warmer than at 85° F for nine of the twelve hours, and his tympanic temperature at 75° F rose above the 95° level at the ninth hour. J.W.'s tympanic temperature at 85° F was warmer than at 95° F for half of the immersion period; his rectal temperature at 75° was warmer than, or equal to, that at 85° for five of the twelve hours. Both these subjects maintained normal blood glucose levels at 85° F. At 75° F J.W., who had a work ratio of 4 times his normal rate and who shivered most vigorously, had a decrease in blood glucose (108 to 70 gm/100 ml) by the end of the second hour; it remained at this level for the rest of the immersion.

Thus, it appears that immersion at 95° F was a restful experience for all the subjects with apparent conservation of the body's energy supply, Table III. At 85° F a small increase of heat production was necessary in two of the subjects to maintain thermal balance while immersion at 75° F proved to be quite stressful for all three subjects, as indicated by decreases in blood glucose for two of them, decreases in lymphocytes and eosinophils and an increase in total leucocytes for all three. Urinary 17-hydroxy-corticosteroid excretion increased tenfold in J.B. and more than double in C.M. and J.W. Thus, although originally, immersion at 75° F had been planned for a 24-hour period, it was limited to 12 hours after the first subject to be immersed at that temperature requested termination because of an intense headache and muscle spasms. The other two subjects motivated to complete an equal time period were not able to continue longer than 12 hours, C.M. because of a very low blood sugar, and J.W. because of uncontrollable shivering accompanied by spasms of large muscle groups.

CONCLUSIONS

1. The diuresis resulting from immersion to neck level, studied previously for shorter periods of time, was shown in these experiments to decrease to non-replacement control levels during the last 12 hours at 95° F but was still 80% increased by the end of 24 hours at 85° F and 60% increased at the end of 12 hours at 75° F.

2. Along with the water diuresis there occurred increased excretion of all electrolytes; the amount excreted increased as the temperature of the water decreased. A naturesis occurred at all temperatures with an increased output of all other electrolytes at 75° F.

3. Hemoconcentration accompanied the immersion diuresis and occurred during all immersions.

4. The Survival-at-Sea Chart now used by the Armed Services shows 68° F as the temperature above which one should be able to survive indefinitely. The present studies planned for 24 hours at 95°, 85°, and 75° F imply that such a division point is too low for survival for long periods of time in water at temperatures as low as 75° F. The tolerance times of all three subjects at 75° F was approximately 12 hours. Physiological efforts to maintain body heat approached a threshold as demonstrated by low blood sugar values, uncontrollable shivering and spasms in large muscle groups. Thus, thermal balance was not able to be maintained for long periods of time at temperatures as low as 75° F.

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Security Classification

DOCUMENT CONTROL DATA - R&D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) Naval Medical Research Institute National Naval Medical Center Bethesda, Maryland 20014	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b. GROUP

3. REPORT TITLE

COMPARISON OF PHYSIOLOGICAL CHANGES DURING LONG TERM IMMERSION TO THE NECK LEVEL IN WATER AT 95°, 85°, and 75°F

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

Medical research interim report

5. AUTHOR(S) (Last name, first name, initial)

REEVES, Elizabeth (n); WEAVER, Joseph W.; BENJAMIN, James J.; MANN, Charles H.

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
August 1966	24	11

8a. CONTRACT OR GRANT NO.	9a. ORIGINATOR'S REPORT NUMBER(S)
b. PROJECT NO.	MF 011.99-1001, Report No. 9
c.	9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)
d.	

10. AVAILABILITY/LIMITATION NOTICES

Distribution of this document is unlimited.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY Bureau of Medicine and Surgery Navy Department Washington, D. C.

13. ABSTRACT

This experiment was designed to evaluate the physiological changes which result from immersion of subjects in water to neck level for 24 hours at water temperatures of 95°, 85°, and 75° F. It had previously been determined that immersion of subjects in water below 95° F resulted in a heat loss from the body which was compensated by an increase in metabolic rate. Other changes in blood morphology and blood electrolytes had been shown to occur concomitantly with increased urinary excretion of water and electrolytes. Since the previous studies had been carried out over a relatively short period of time, the present experiments were designed to evaluate such changes over a 24-hour period, not only at 95° F water temperature but at lower water temperatures as well. It was found that the three subjects increased their metabolic rate when immersed in 85° F water and were able to maintain a "normal" deep body temperature over a 24-hour period. When immersed in the 75° F water, the increased oxygen consumption due to shivering was insufficient to maintain deep body temperature. In addition, the physiological discomfort of immersion at 75° F and "the spiritual failure" of those subjects caused the experiments to be terminated within 12 hours. The changes in the morphology and electrolyte content of the blood together with the hemoconcentration were associated with increased urinary water and electrolyte excretion and were progressive with time.

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
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