Physiological Implications as to Survival During Immersion in Water at 75° F

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It has been determined in previously reported experiments that immersion at water temperatures of 75° F (23.8°C) may be limited by failure of the body's physiological compensatory mechanisms. This investigation was designed to study the physiological responses of subjects immersed to neck level in 75° F water for periods up to 12 hours. Measurements relating to the body loss of heat, energy, fluids, and electrolytes were obtained. It was found that a 12 hour period of immersion could not be tolerated by all of the subjects for various reasons: (1) loss of body heat with a reduction in deep body temperature to below the predetermined limiting temperature of 95° F; (2) extreme discomfort with muscle cramps following prolonged shivering; and, (3) decrease in blood glucose to levels below the predetermined limiting value of 60 mg per cent. The changes in blood morphology, blood electrolytes, oxygen utilization and urinary excretion during the period of immersion, in addition to the physiological changes which caused the termination of some experiments are directly related to tolerance of immersion. It was also found that some subjects experienced a significant adrenocortical stress response with subsequent adrenocortical insufficiency. These factors are of importance in survival from the involuntary immersion associated with disasters at sea.

THE MISADVENTURES OF LIFE occasionally subject humans to the necessity of existing on the surface of the sea for hours or days before the experience is terminated by rescue or death. In time of war, such occurrences are common-place. During World War II, the heroic accounts of merchant sailors who survived the rigors of floating in the North Sea made front page copy. Unfortunately, the exigencies of war demanded that only the experiences of the survivors be documented and the proportionate number who succumbed not be disclosed. Therefore, a false impression of the ability of man to survive in this adverse environment was engendered in the minds of not only the lay reader but of the professional mariner as well.

Following World War II, an analysis of well-documented cases of survival after water immersion was carried out by Molnar[1] based on data in the archives of the U. S. Navy Department. On the basis of this analysis, the Navy Department evolved a table of life expectancy for personnel immersed in water without protective clothing at various temperatures while supported by a life jacket. The graphic presentation of Molnar's data has been combined with the evolved Navy graph in Figure 1. This chart implies that immersion in water at 68° F and above is consistent with infinitely long survival. However, experiments by Reeves,*et al.*,[2] in which three young adult males were immersed for long periods in water at 75° F, 85° F, and 95° F do not support this view. Immersion in water at 95° F for 24 hours, resulted in no significant stress and demanded no energy workload greater than that of the body at rest in a warm room. At the 85° F immersion, it was necessary for the subjects to increase their metabolic heat output in order to maintain thermal homeostasis and their core temperature stabilized at a lower level than was normal for these subjects when comfortable in air. At the 75° F immersion temperature, however, the subjects would not voluntarily continue their immersion period for longer than 12 hours; their metabolic heat output was increased 2-3 times above that during the immersion at 95° F; the subjects shivered, experienced muscle cramps, and

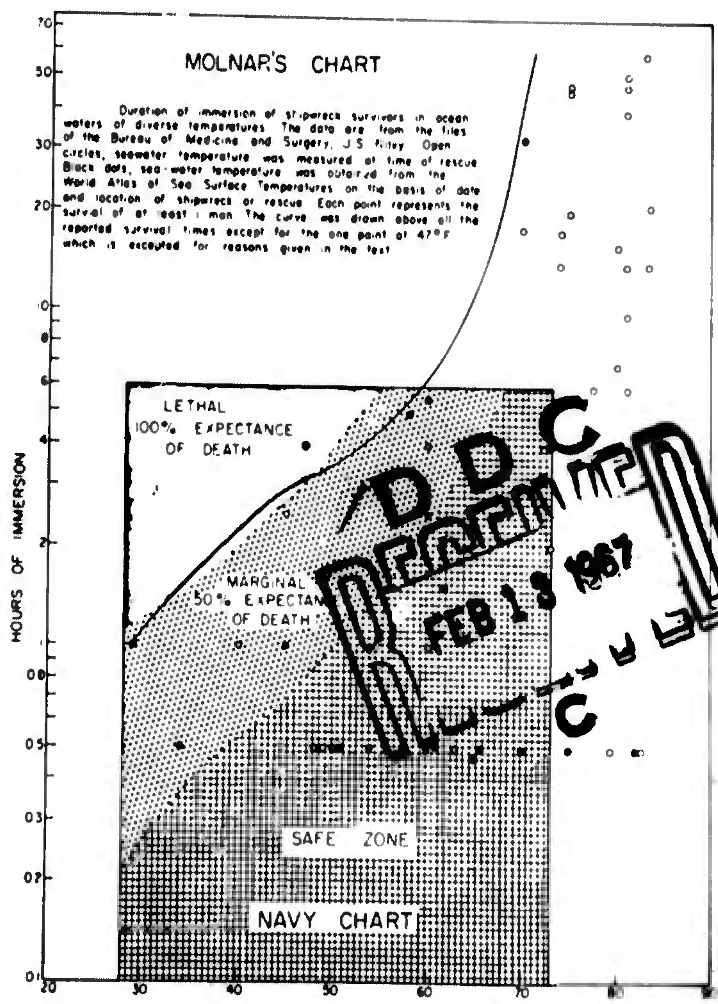

Fig. 1. Composite graph of Molnar's data and U. S. Navy chart.

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showed signs of significant adrenocortical stress. This study,[2] although only on three subjects, showed that immersion to neck level in water at 75° F was not innocuous and implied that such exposure cannot be survived indefinitely as suggested by the survival curves in Figure 1.

The experiments to be described were designed to extend the immersion studies of Reeves, *et al.*,[2] using a larger number of subjects with a greater diversity of body types immersed only at 75° F.

METHODS

A group of 24 male Naval personnel (officer and enlisted) were subjects for this experiment. Each subject was notified 48 hours before his participation and instructed to: (1) abstain from alcoholic beverages 12 hours before the experiment; (2) obtain a normal night's sleep; and, (3) eat a well-balanced breakfast prior to reporting to the laboratory. Subjects collected a twenty-four hour urine sample as a control. No food or water was taken by the subjects during the experiments. From the ranges of variation and the means of values of their physical characteristics, the description of the "mean man" who served as subject for these experiments is as follows: age 27.5 years (21-46), height 178 cm (166.4-187.3), weight 76.7 kg (62-119.2), surface area 1.93 (1.60-2.32).[3]

The subjects were immersed to neck level in a water-filled tank 10 ft. in diameter and 12 ft. deep, and wore a Navy Mark II pneumatic life vest. Continuous flow of water was maintained to ensure a constant surrounding temperature. Deep body core temperatures were measured by thermocouples placed on the tympanic membrane and protected by a foam rubber cup to preclude the possibility of such measurements being affected by air currents or water. Rectal temperature probes were also used. Esophageal thermocouples were used in some subjects for an additional evaluation of deep core temperature. Oxygen utilization was determined by measuring the amount of air in a gasometer during a known period of time. The oxygen content of the expired gas was measured on a Pauling-type oxygen analyzer and the energy usage was then calculated on the basis of oxygen consumption according to the formula of Weir.[4]

Electrolyte and water excretion of the subject were determined by analyses of urine samples collected at hourly intervals and compared with 24 hour control values. The subject was permitted to leave the tank for sample collection. Blood samples were drawn at 4-hour intervals and at the end of the immersion period for use in determining electrolyte content, specific gravity, osmolarity, and cellular components as described by Reeves, *et al.*[2] The subjects were requested to stay in the water as long as possible. The following criteria were established to limit the immersion period: (1) decrease in core temperature to 95° F; (2) decrease in blood sugar to 60 mg/100 ml; (3) persistent unrelieved muscle cramps in large muscle groups; (4) cardiac irregularities; and, (5) request of subject.

RESULTS

The subjects endured the immersion in water at F for a mean of 8.1 hours during which period t was observed a mean urinary excretion of 1.169 l (24-hour control, 1,434 liters); a weight loss of kilograms; an increased energy production 2.7 t the amount expended while resting (seated) prior to the experiment; a decrease in rectal temperature of 1.33° F; a decrease in tympanic membrane temperature of 1.08° F; and, a mean rate of body heat loss during immersion of 200 kcal/hr or 103 kcal/m²/hr. The rate of change in body core temperatures (rectal and tympanic) and the increase in energy output during the immersion are shown for a typical subject in Figure 2. This subject stablized his core temperature fairly well, but this was accomplished by increasing his energy expenditure from the pre-run value of 34 kcal/m²/hr to a maximum of 108 kcal/m²/hr during immersion. Figure 2 also shows that rectal and tympanic core temperatures were essentially stable between 4½ to 9½ hours of immersion. During this period, the heat loss from the body, i.e., the resultant sum of the losses by transfer to the water, to the air breathed, and to the air surrounding the exposed part of the body, and the evaporative losses through the pulmonary alveolae and the skin of the exposed head and neck, equaled the body heat generated. The mean caloric output during this period was 89.5 kcal/m²/hr most of which represents a conductive loss to the water surrounding the immersed subject.

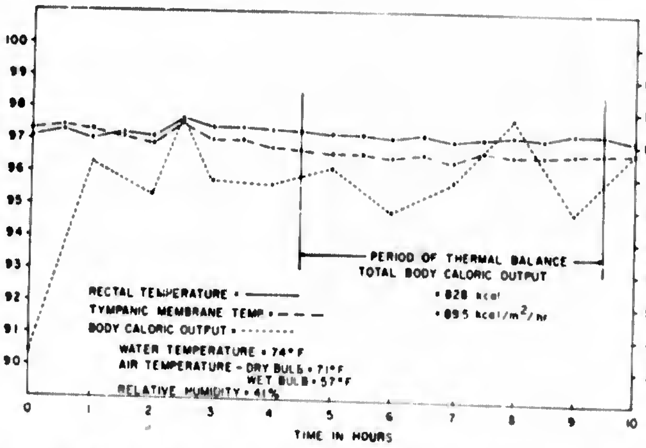

Fig. 2. Rate of change in body core temperatures and increase in energy output of a typical subject during immersion.

Not all subjects were able to maintain their body temperature by increased energy output, as is shown in Figure 3. The rate of heat loss of this asthenic subject was characterized by a rapid decrease in both tympanic and rectal temperatures within the first hour after immersion, followed by a slower progressive decrease in core temperature during the second hour. In an effort to combat this rapid rate of heat loss, this subject increased his energy (heat) output to 137 kcal/m²/hr from a basal rate of 43 kcal/m²/hr. This subject's body did not reach a thermal steady state and the experiment was terminated because of the rapid rate of heat loss and critical decrease in core temperature. The rate of heat loss was calculated from the caloric output, measured from oxygen con-

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sumption plus the quantity of heat lost by the total body mass. The body heat loss per unit time is equal to the mass times the mean thermal capacity of the body tissues (0.83) times the decrease in body temperature per unit time.[5] This calculation is based upon the assumption that the rate of cooling is constant.

Although the mean "voluntary" immersion period of the 24 subjects was 8.1 hours, only 6 of the 24 subjects completed the immersion test period of 12 hours. Of these, five were tested during the summer months when the ambient air temperature in the laboratory varied from 85° F to 100° F with a relative humidity of 65-95 percent. Only one subject sustained 12 hours of immersion during the winter months when the temperature varied from 72°-78° F with a relative humidity of 30-40 percent in the air above the tank. Of the 18 subjects who did not undergo 12 hours of immersion, two were removed from the tank when their body temperature dropped to 95° F. No subject was removed because of cardiac irregularities. Thirteen of the experiments were terminated when the subjects developed severe and persistent cramps in major groups of muscles, i.e., quadriceps femoris or the

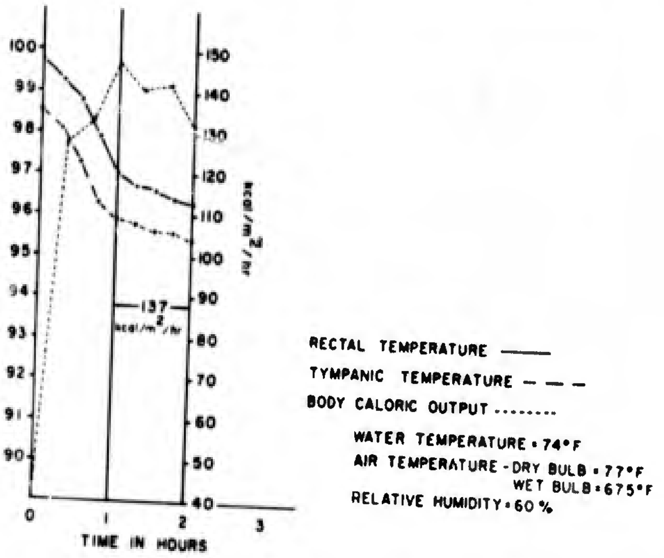

Fig. 3. Rate of change in body core temperatures and increase in energy output of an asthenic subject during immersion.

erector spinae groups. The muscle cramps (tonic spasms) generally commenced after 3-4 hours of immersion and progressively worsened. At first, the spasms could be relieved by massage or by the warming which occurred during the hourly emergence for urine collection. The spasms generally recurred after reentering the water and persisted. The subjects were removed after the spasms had progressed to this state, at which time they were extremely painful.

One experiment was terminated because of the subject's extreme nausea and a severe headache. Blood sugar determination taken when this subject emerged disclosed a blood glucose level of 57 mg/100 ml. This subject's symptoms were attributable to the hypoglycemia.

Two subjects were removed from the water at their own request. They were acutely uncomfortable and refused to continue the experiment despite an offer of additional incentive pay. These subjects did not exhibit any of the criteria for termination and were thought to represent the group of survivors who succumbed to "spiritual failure," described by Critchley.[6] However, one of these subjects was subsequently found to have had a blood sugar below 60 mg/100 ml on the immediate post-emergence sample. Three of the subjects who were removed because of severe cramps were also found to have had blood glucose levels below 60 mg/100 ml at the time of termination of the experiment. In all, five subjects had blood glucose levels below 60 mg/100 ml at the time of termination of their immersion. The mean loss of body weight during immersion was 1.7 kg which represented both the urinary output and the "insensible" weight losses from the skin and lungs. Although weight loss was greater for longer immersions, the individual variations in water loss patterns were remarkable.

The mean values for the hematological measurements made are shown in Table I. The data were analyzed in three groups according to immersion periods of: (1) less than 4 hours; (2) 4 hours or more, but less than 8 hours; and, (3) more than 8 hours. Mean hematocrit, hemoglobin content, number of

TABLE I. MEAN CHANGES IN BLOOD AND PLASMA VALUES DURING IMMERSION

MEASUREMENTS	NUMBER OF SUBJECTS	CONTROL	IMMERSION PERIODS 2-4 hours	4-8 hours	8-12 hours
HEMATOCRIT mm/100 mm	4	42.1	46.2*		
	10	43.4	48.1*	48.6	
	9	46.1	50.9N.S.	51.5*	50.8
HEMOGLOBIN g/100 ml	4	15.2	15.6**		
	10	15.0	16.5**	16.6	
	9	15.3	16.6*	17.0	16.7
ERYTHROCYTE COUNT Million/mm³	4	4.93	5.27N.S.		
	10	4.99	5.47**	5.38	
	9	5.05	5.30*	5.37	5.38
PLASMA SPECIFIC GRAVITY	4	1.0272	1.0299*		
	10	1.0269	1.0297*	1.0299	
	9	1.0281	1.0288N.S.	1.0306*	1.0294

*p=<.01
**p=<.05
N.S.=Not Significant

erythrocytes per mm,[3] and plasma specific gravity values increased significantly from the control values when analyzed for variance. The increases were approximately the same for each group with the exception of the 8-12 hour group whose hematocrit and plasma specific gravity values varied significantly only after 4-8 hours of immersion. These changes reflect a progressive hemoconcentration. Since the values for specific gravity relate to the water content of the plasma, the increases in plasma specific gravity in each group indicate a decrease in the water content which was progressive with the duration of immersion. However, in the group of subjects immersed longer than 8 hours, the mean specific gravity of the plasma increased from a control value of 1.0281 to a maximum of 1.0306 after 8 hours, but then decreased to 1.0294 by the end of the period of immersion. This decrease in specific gravity suggests that the process of hemoconcentration was reversed after 8 hours, possibly by transudation of extracellular fluid into the blood. This decrease in specific gravity occurred in 5 of 7 subjects but when analyzed for variance did not prove to be statistically significant.

The mean value of the plasma electrolyte measurements obtained are shown in Table II. These data were also analyzed in three groups as in Table I. The only consistent changes observed were an increase in the plasma osmolarity during the first period of immersion followed by a decrease thereafter. These changes were of small magnitude, and of doubtful significance when analyzed for variance. Other changes in plasma electrolytes were variable and apparently unrelated to the duration of immersion or to the ability of the subject to adapt to the immersion stress.

Whereas the changes in electrolyte levels of the blood during immersion were not significant, the urinary excretion rate of these electrolytes were more striking, as shown in Table III.

Although blood values were obtained every 4 hours or at the termination of the immersion if less than 4 hours, urinary samples were obtained hourly and pooled to make up four-hour samples, so as to relate the urinary data to those on the blood. The mean rate of urinary excretion was consistently increased to more than 3 times normal during the first 4 hours of immersion. Diuresis continued during the 4-8 period but decreased to the control rate during the 8-12 hours of immersion. The rates of urinary excretion during the first and second days after the experiment were below the control rates as would be expected during a period of rehydration. The increase in rate of urinary excretion was reflected throughout all groups of subjects by a

TABLE II. PLASMA ELECTROLYTE LEVELS BEFORE AND DURING IMMERSION TO NECK LEVEL IN WATER AT 75° F.

			IMMERSION PERIODS		
MEASUREMENT	NUMBER OF SUBJECTS	CONTROL	2-4 hours	4-8 hours	8-12 hours
OSMOLARITY	4	282.7	286.5		
mosm/l	10	285.8	293.8	290.6	
	9	289.6	297.4	291.4	277.2
SODIUM	4	143.6	145.5		
meq/l	10	144.5	[illegible]	142.8	
	9	142.6	137.1	137.6	134.8
POTASSIUM	4	4.9	5.1		
meq/l	10	5.2	5.2	5.3	
	9	5.1	5.1	4.8	4.6

TABLE III. MEAN URINARY EXCRETION RATES BEFORE, DURING, AND AFTER IMMERSION TO NECK LEVEL IN WATER AT 75° F.

			IMMERSION PERIOD			POST IMMERSION	
MEASUREMENT	NUMBER OF SUBJECTS	CONTROL	2-4 hours	4-8 hours	8-12 hours	24 hours	48 hours
OUTPUT	5	89.2	211.4			26.9	36.8
ml/hr	10	59.0	179.3	84.0		39.9	42.8
	9	48.8	233.5	102.7	49.2	42.4	44.5
OSMOLARITY	5	49.8	107.4			23.6	31.1
Mosm/hr	10	42.5	129.6	48.9		34.6	38.1
	9	37.5	106.6	57.1	27.3	34.9	36.3
SODIUM	5	9.7	20.5			4.6	5.9
meq/hr	10	8.4	21.5	12.1		5.2	6.4
	9	8.6	21.3	12.8	7.1	7.1	4.5
POTASSIUM	5	6.6	13.0			1.7	2.3
meq/hr	10	2.9	8.2	3.8		2.6	2.7
	9	2.6	6.6	4.4	2.6	2.3	2.4
CALCIUM	5	0.36	0.58			0.27	0.32
meq/hr	10	0.38	0.21	0.08		0.13	0.30
	9	0.36	0.44	0.13	0.11	0.11	0.11

parallel change in the rate of sodium and potassium excretion as well as of total electrolyte. Three of the five individuals making up the group lasting less than four hours had large control levels of urinary excretion and sodium and potassium output. These relatively large control values are thought to relate to the high milk consumption of these three subjects.

Changes in blood morphology, blood glucose content, and rate of urinary excretion of 17-hydroxycorticosteroids (17-OHCS) were evaluated as indicative of adrenocortical response to stress, Table IV. The mean number of circulating leucocytes increased almost to double the control value by the end of the immersion period for the three groups. A small relative decrease in the number of circulating lymphocytes was found. The changes in the total circulating eosinophils as a result of immersion were variable. One of the subjects immersed 12 hours started with a control eosinophil count of 622/cu mm and maintained approximately that level throughout the experiment. There was, however, no significant change in mean values. The concentration of 17-OHCS in the urine increased significantly during the period of immersion.

Five subjects showed significant changes indicative of an adrenocortical stress response, Table V. Three of them maintained a high and increased level of steroid excretion throughout their entire experimental periods. These individuals were in exceptionally good physical condition and were able to exercise continuously during the experiment. The other two subjects, however, showed a decrease in their urinary corticosteroid excretion to below their control in the experimental period just preceding its termination. A decrease in corticosteroid excretion below control levels was observed

TABLE IV. MEAN VALUES MEASURED AS INDICATIVE OF ADRENAL CORTICAL STRESS.

MEASUREMENT	NUMBER OF SUBJECTS	CONTROL	IMMERSION PERIOD 2-4 hours	4-8 hours	8-12 hours	POST IMMERSION 24 hours	48 hours
LEUCOCYTES Million/mm³	4	8,713	16,150				
	10	7,895	11,743	13,913			
	9	8,575	11,689	13,889	15,117		
LYMPHOCYTES (%)	4	35.0	19.0				
	10	36.1	27.0	22.2			
	9	35.5	27.9	28.3	25.2		
TOTAL EOSINOPHILS mm³	4	102.5	152.6				
	10	73.3	83.3	97.1			
	9	162.8	219.7	220.8	163.5		
BLOOD GLUCOSE mg/100ml	4	87.8	80.5				
	10	83.0	76.0	72.6			
	9	84.0	78.7	74.6	74.8		
17-OHCS (Urine) mg/hr	4	0.48	0.82			0.14	0.16
	10	0.32	1.22	0.70		0.42	0.40
	9	0.29	1.42	0.31	0.33	0.38	0.16

TABLE V. MEASUREMENTS INDICATIVE OF ADRENALCORTICAL STRESS

MEASUREMENT	SUBJECT	CONTROL	2-4 hrs	4-8 hrs	8-12 hrs	24 hrs	48 hrs
LEUCOCYTES Million/mm³	R. A.	6,900	10,625	20,200			
	E. J.	10,600	13,100	13,500			
	H. J.	12,200	20,350	22,200	21,775		
	J. B.	6,050	8,050	11,000	12,300		
	R. W.	8,025	9,700	10,500	12,475		
LYMPHOCYTES (%)	R. A.	47	31	20			
	E. J.	31	28	15			
	H. J.	26	14	15	10		
	J. B.	32	28	28	21		
	R. W.	48	39	32	13		
EOSINOPHILS Million/mm³	R. A.	88.8	99.9	66.6			
	E. J.	99.9	88.8	133.2			
	H. J.	122.1	700.4	644.2	210.9		
	J. B.	99.9	111.1	55.5	66.6		
	R. W.	33.3	33.3	44.4	33.3		
BLOOD GLUCOSE mg/100 ml	R. A.	88	84	57			
	E. J.	86	84	79			
	H. J.	79	76	79	61		
	J. B.	81	82	80	88		
	R. W.	79	74	88	105		
17-OHCS (Urinary) mg/hr	R. A.	0.33	2.07	0.64		0.24	0.24
	E. J.	0.44	3.13	0.49		0.24	0.43
	H. J.	0.19	2.46	0.46	0.14	0.88	
	J. B.	0.32	3.86	0.39	0.07		
	R. W.	0.34	3.30	0.55	0.36	0.17	0.24

during the first and second 24-hour periods following the experimental exposure in some of these subjects.

DISCUSSION

These experiments provide insight into certain physiological aspects of the probability of survival from prolonged immersion in water at 75° F. Only six (25 percent) of the subjects were able to continue the immersion for a 12-hour period and only one of these was tested in an isothermal environment with air temperature equal to the water temperature. None of the subjects endured such stress for more than 12 hours although three of them had voluntarily experienced 24 hours of immersion at 85° F and 95° F. Two subjects were removed owing to a rapid loss of body heat with reduction in body core temperature to approximately 95° F. Thus, 8 percent of the test group were unable to maintain thermal equilibrium at a safe level when immersed in water at 75° F. One of these subjects was cooled to 95° F in 2 hours and the other in 10 hours. Although a deep body temperature of 95° F does not represent the maximal heat deficit that the body can withstand, this endpoint is significant because below this core temperature cardiac irregularities are common and the organism becomes poikilothermic.[7]

Thirteen of the subjects (54 percent) were taken from the tank because of severe, persistent cramps in large groups of muscles. The implications of such tonic spasms are far-reaching in terms of survival. The pain was intense and incapacitating. Furthermore, spasms of a large group of muscles limit the body's ability to generate heat. The occurrence of muscle cramps would therefore signify the limit of thermal balance and the onset of a critical heat loss and drop in body temperature.

Brandy was administered to seven of the subjects when they were no longer able to tolerate the muscle cramps. In some subjects, 2 ounces of brandy given in warm water was sufficient to relieve the muscle cramps temporarily so that the subject could continue the experimental immersion. However, the cramps returned with equal intensity after approximately one hour and the exposure was extended for a 2-hour period in only one subject. It was also observed that the warming effect of emergence for a few minutes required for sample collection relieved muscle spasm when it first occurred. It was not apparent whether this was a result of the warming effect of the air or of the interruption of the cold stimulus in the shivering reflex arc. Critchley[5] described the loss of the will to live as "spiritual failure" and lists it as the cause of 20 percent of the deaths among immersed survivors. The fact that one of our two cases of "spiritual failure" actually was suffering from hypoglycemia together with the fact that 5 of the 24 subjects (21 percent) had hypoglycemia, suggests that hypoglycemia may be the major physiological factor in the so-called "spiritual failure" of shipwrecked survivors.

Many subjects showed a decrease in corticosteroid excretion below control levels during the first and second 24-hour periods following the experimental exposure. This observation suggests that immersion stress produced a significant adrenocortical stress response which was followed by a relative adrenocortical insufficiency of varied severity in some subjects.

Although only two subjects developed a critical thermal imbalance, it can readily be appreciated that all of them suffered some thermal loss even at a water temperature of 75° F, which is 7° above that predicted by Molnar[1] as tolerable for an indefinite period of time. The rate of heat loss was calculated for all subjects, and plotted against the specific gravity of the individual based on the formula of height and weight developed by Cowgill.[8] The specific gravity values were then equated with percent body fat after the formulation of Rathbun and Pace.[9] It is readily apparent from Figure 4 that the rate of body heat loss is directly related to specific gravity and inversely related to the percentage of body fat. From a survival point of view, it would, therefore, seem that the subjects with the lowest specific gravity might fare the best in a survival situation. This is borne out by the fact that subjects who "survived" the test the shortest period of time are represented by the circles at the top of the curve, and those of the lowest specific gravity are the ones who stayed in the full 12 hours. However, it is significant to note that the "pyknic" subject represented by the circle with a specific gravity of 1.015 had a rate of heat loss not significantly different, in fact, slightly higher, than 4 of the other subjects. One difference between these subjects is that the "pyknic" individual weighed 119 kg. He had a body mass 1.6-1.8 times that of the other subjects and thus had a much larger "heat engine" with which to generate heat. The rate of heat loss from a body immersed in cold water is primarily a function of the area of the body exposed to

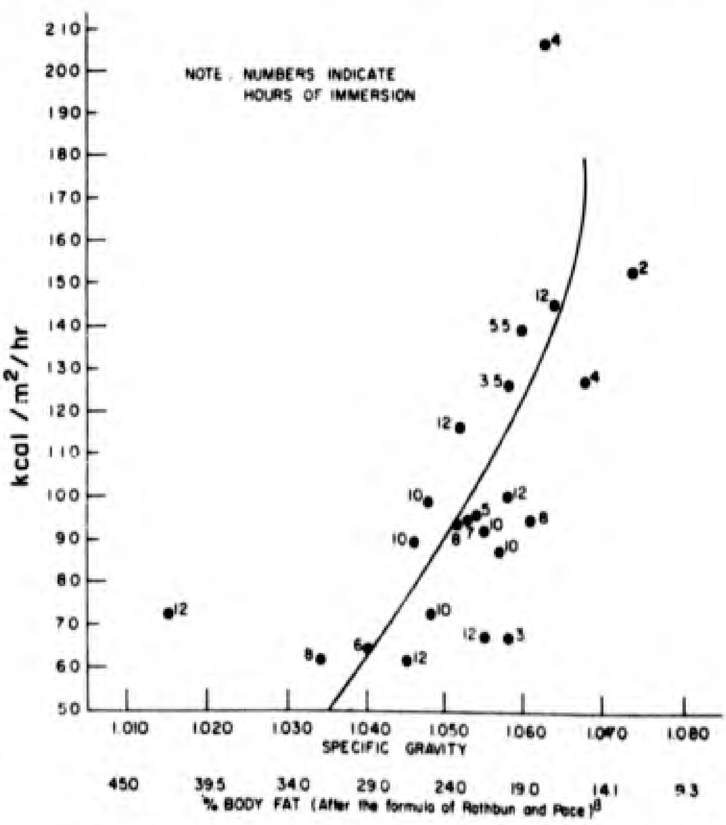

Fig. 4. Relationship of rate of heat loss vs. body specific gravity in 23 nude subjects immersed to neck level in 75° F water.

the co.l and the thermal conductivity of that area. Adipose tissue has a lower thermal conductivity than muscle and skin. Likewise, the "pyknic" subject was relatively short but had a body surface of 2.3 m^2 which was not significantly greater than that of the tall subjects. This subject not only had a large capacity "heat engine" but also a relatively small, conductive surface which was well insulated and therefore was ideally constituted to withstand the stress of cold water immersion. The 12-hour immersion was least stressful to this "pyknic" subject.

The diuresis, naturesis and increased urinary potassium excretion during immersion have been previously described by Graveline[10] and were confirmed in these experiments.

The results of these studies do not appear to be in agreement with the predicted "life expectancy" chart used by the U. S. Navy nor with the chart of shipwreck survival times compiled by Molnar, (Figure 1). On these charts, the survival times for immersion in water at 75° F are infinitely long, i. e., 48 hours or longer. The disparity between the results of these experiments and these charts may be explained in part by the fact that some of the "shipwrecked" survivors were wearing various amounts of clothing so that their surface insulation was significantly increased. In addition, these cases of survival may well represent the extreme rather than the mean survival time. These experiments herein reported were terminated on the basis of personal discomfort or body heat loss, which are not critical indicators of survival. The mean rate of body heat loss from the subjects was 200 kcal/hr. Since unconsciousness occurs when the body temperature drops to 31.1° C (88° F), *i.e.*, a decrease of 6° C, this would equal body heat loss for the mean subject of 76.7 kg x 0.83 (specific heat of body) x 6° C – 382 kcal. If the body became incapable of generating any more heat, then the mean subject would lose 382 kcal at a rate of 200 kcal/hr and would cool to a terminal temperature in less than 2 hours! Although the occurrence of persistent muscle spasms would not signal a complete loss of muscle heat generation, it would indicate the beginning of a progressive decline in body temperature. Terminal hypothermia and subsequent cardiac arrhythmias and unconsciousness would be expected to follow. Therefore, it would not be safe to extrapolate the experimental voluntary tolerance times for more than 2-3 hours in predicting the survival time for nude subjects.

In addition, the muscle spasms experienced by subjects of these experiments and by survivors of ship disasters[11,12] were excruciatingly painful. Some provision should be made to protect immersed personnel from these effects. Provision of alcohol or an analgesic in the flotation garment must be considered. Likewise the excellent tolerance to cold immersion demonstrated by a few subjects who had a marked adrenocortical stress response suggests that the therapeutic use of adrenocorticoid compounds might be beneficial in extending the survival time of all immersed personnel. A nutritional supplement would also appear to be needed. Further research is required to evaluate these concepts.

CONCLUSIONS

Voluntary tolerance times of immersion to neck level in water at 75° F for 24 nude Naval personnel varied from 2-12 hours with "mean" tolerated duration of 8 hours.

The immersion exposures were terminated because of excess loss in core temperature (2 subjects); nausea and headache due to hypoglycemia (2 subjects); severe persistent muscle cramps (13 subjects); and, "spiritual failure" (1 subject).

Loss of body water (urinary and evaporative loss) varied from 1-2 kilograms and was related to the duration of the immersion exposure.

Blood morphology studies demonstrated significant hemoconcentration.

Five subjects showed a marked adrenocortical stress response followed by a relative adrenocortical insufficiency which was considered to be contributory to the termination of the voluntary exposure period of 3 of these subjects.

The results of these experiments do not agree with standard Navy charts for survival time of unprotected personnel immersed in water at 75° F.

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13. ABSTRACT

It has been determined in previously reported experiments that immersion at water temperatures of 75° F (23.8° C) may be limited by failure of the body's physiological compensatory mechanisms. This investigation was designed to study the physiological responses of subjects immersed to neck level in 75° F water for periods up to 12 hours. Measurements relating to the body loss of heat, energy, fluids, and electrolytes were obtained. It was found that a 12 hour period of immersion could not be tolerated by all of the subjects for various reasons: (1) loss of body heat with a reduction in deep body temperature to below the predetermined limiting temperature of 95° F; (2) extreme discomfort with muscle cramps following prolonged shivering; and, (3) decrease in blood glucose to levels below the predetermined limiting value of 60 mg per cent. The changes in blood morphology, blood electrolytes, oxygen utilization and urinary excretion during the period of immersion, in addition to the physiological changes which caused the termination of some experiments are directly related to tolerance of immersion. It was also found that some subjects experienced a significant adrenocortical stress response with subsequent adrenocortical insufficiency. These factors are of importance in survival from the involuntary immersion associated with disasters at sea.

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