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CONTRACT NO: DAMD17-88-C-8013

TITLE: THERMAL RESPONSES DURING EXTENDED WATER IMMERSION: COMPARISONS OF REST AND EXERCISE, AND LEVELS OF IMMERSION

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REPORT DATE: November 10, 1991

TYPE OF REPORT: Final Report

PREPARED FOR: U.S. ARMY MEDICAL RESEARCH AND DEVELOPMENT COMMAND
Fort Detrick, Frederick, Maryland 21702-5012

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1a. REPORT SECURITY CLASSIFICATION Unclassified	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release; distribution unlimited
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S)	5. MONITORING ORGANIZATION REPORT NUMBER(S)
6a. NAME OF PERFORMING ORGANIZATION Queens College of CUNY Dept. of Health & Physical Education 6b. OFFICE SYMBOL (if applicable)	7a. NAME OF MONITORING ORGANIZATION
6c. ADDRESS (City, State, and ZIP Code) 65-30 Kissena Blvd. Flushing, NY 11367	7b. ADDRESS (City, State, and ZIP Code)
8a. NAME OF FUNDING/SPONSORING ORGANIZATION U.S. Army Medical Research & Development Command 8b. OFFICE SYMBOL (If applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER Contract No. DAMD17-88-C-8013
8c. ADDRESS (City, State, and ZIP Code) Fort Detrick Frederick, Maryland 21702-5012	10. SOURCE OF FUNDING NUMBERS PROGRAM ELEMENT NO. 62787A PROJECT NO. 3E1-62787A879 TASK NO. BD WORK UNIT ACCESSION NO. WUDA314855

11. TITLE (Include Security Classification)
Thermal Responses During Extended Water Immersion: Comparisons of Rest and Exercise, and Levels of Immersion

12. PERSONAL AUTHOR(S)
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13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
Final Report	FROM 6/16/88 TO 6/15/91	10 November 1991	47

16. SUPPLEMENTARY NOTATION

17. COSATI CODES		
FIELD	GROUP	SUB-GROUP
06	04	
06	10	

18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
Temperature Regulation; Cold; Core Temperature; Mild Hypothermia; Human; Environmental Stress

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

Phase 1 exposed 14 subjects to the neck in 3 water temperatures (T_w) during both rest (R) and exercise (E) conditions for up to 3h; whereas 8 subjects in Phase 2 were exposed to the knee (KN), hip (HI), and chest (CH) in water at 15 and 25 deg C during R and E. In Phase 1 the % Body Fat was 9.5 for the low-fat (L, N=5), 14.8 for the moderate-fat (A, N=5), and 19.6 for the high-fat (H, N=4); subjects were immersed on four occasions (two temperatures X two activities) for durations up to 3h. During R at equivalent thermal strain rectal (T_{re}) and esophageal (T_{es}) temperatures declined similarly in all groups over 3h (delta T_{re}, -1.32, -1.45, and -1.32 deg C; delta Tes, -0.47, -0.43, and -0.60 deg C for L, A, and H, respectively). During exposures at 24 deg C T_{re} and T_{es} dropped moderately in the L group (delta T_{re}, -1.67; delta T_{es}, -0.53 deg C) and modestly in the A group (delta T_{re}, -1.04, delta T_{es}, -0.15 deg C) and H (delta T_{re}, -0.18; delta T_{es}, -0.70 deg C) throughout the 3-h exposure. During E, T_{re} and T_{es} were higher compared to R for all groups in all T_w. Phase 2 showed similar T_{re} values across

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT ☐ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION Unclassified
22a. NAME OF RESPONSIBLE INDIVIDUAL Mrs. Virginia M. Miller	22b. TELEPHONE (Include Area Code) 301-619-7325 22c. OFFICE SYMBOL SGRD-RMI-S

DD Form 1473, JUN 86 Previous editions are obsolete. SECURITY CLASSIFICATION OF THIS PAGE

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Michael M. Irwin — 10 NOV 91

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TABLE OF CONTENTS

INTRODUCTION...2

BODY.. 3

CONCLUSIONS... 34

REFERENCES.. 36

APPENDIX.. 39

INTRODUCTION

Limited information is available as to the time course of Tre during cold-water immersion. The preponderance of literature concerned with the physiological responses has utilized immersion exposures for durations between 20 and 90 min (3, 4, 5, 7, 8, 9, 14, 16). In order to relate this literature to longer exposure times in cold water, one must assume that the drop in Tre beyond the reported final values is linear or at least follows an extrapolation of the pattern observed during the immersion period. In one report, Hayward et al. (5) developed a prediction equation that linearly extrapolated Tre values obtained during a 40 min exposure to a duration that represented a Tre of 30 deg C (operationally defined as "incipient" death (5)).

Clearly, this procedure assumes that the fall in Tre during cold water exposure follows a linear pattern as duration progresses. This assumption of linearity, though supported by observations in very cold water (1), would be questionable in warmer temperatures in light of several studies (2, 6, 11, 15). In reporting the unpublished data of Spealman, Molnar (11) described the linear reduction in Tre up to 60 min of immersion, in water temperatures above 20 deg C, however, Tre leveled off as the duration of immersion progressed. Cannon and Keatinge (2) also observed that individuals were able to stabilize Tre at values below 36 deg C during prolonged immersion. Subsequent work (6) indicated that individuals could eventually stabilize Tre in water as low as 5 deg C.

The present study examined the thermoregulatory adjustments of individuals exposed to cold water for durations up to 3 h. Special consideration was given to the influence of body fat, water temperature, depth of immersion, and level of activity on these adjustments.

BODY

METHODS

PHASE 1

Subjects. Fourteen (14) male subjects with a mean age, height and weight of 25.0 yr, 176.0 cm and 76.6 kg, respectively, were recruited from the college community. Each individual completed an examination which included medical history, physical examination, blood and urine chemistries and resting electrocardiogram and cleared for maximal exercise and cold water immersion by a board-certified emergency medicine physician. All subjects were informed of the nature of the study, as well as the risks and benefits of participation in the testing procedures. Participants were free to withdraw their consent at anytime during the testing. One subject withdrew from a cold water exposure prior to reaching the core-temperature limit established by the protocol. Three subjects did not have esophageal temperature measured, two of which had mild episodes of vaso-vagal syncope during the probe's placement, while one did not attempt the procedure.

The subjects were divided into three groups based on body fatness. Individuals in the low fat group (L) (N=5) averaged 9.5 % body fat, whereas the average (A) and high fat (H) groups averaged 14.8 and 19.6 %, respectively.

Procedures. Two pre-experimental tests were performed by all subjects prior to immersion tests. These included body composition analysis by hydrostatic weighing and peak aerobic power tests in air on both a cycle ergometer and treadmill. During the ergometer test the subject pedals initially at 50 W for 2 min. Exercise intensity is increased 30 W every 2 min until the subject can no longer maintain the 60 rpm pace. During the treadmill test, subjects performed 10 min of walking at 3.2 mph at a 10% elevation as a warmup. This was immediately followed by a continuous, graded protocol to volitional exhaustion where the subject ran at 6 mph at 0% for 2 min followed by increasing elevation of 2.5 % every 2 min.

Following assessment of body fat and peak aerobic power, subjects performed four (4) experimental test. For each test the subject was immersed to the manubrium sternum for a duration of 3 h. The four tests included immersion in two water temperatures with both rest and exercise conditions in each; test were performed on separate days. The water temperatures were 18 and 24 deg C for H (one less fat subject was immersed in 20 rather than 18 deg C), 22 and 24 deg C for A and 24 and 26 deg C for L. Therefore, comparison between groups were made at an equal thermal stress (ST)(24 deg C for H, A and L) and at an equivalent thermal strain (SN)(18 deg C for H, 22 deg C for A and 26 deg C for L). Information was also obtained on nine (9) subjects during both rest and exercise in water at 35 and 33 C, respectively. These four experiments were performed over and above the requirement of the contract and were used as control measures for comparison with the 25 and 15 deg C conditions.

One hour prior to each immersion test subjects arrived at the laboratory dressed in nylon swim suits and were harnassed for temperature and heat-flow measures. Twenty minutes prior to immersion subjects sat quietly in air between 25 and 28 deg C for determination of control values for esophageal (Tes), rectal (Tre) and mean-weighted skin (Mean Tsk) temperatures, mean heat flow (Hc) and oxygen uptake (VO2). During the resting experiments, subjects remained in a seated position in water for a 3-h period. During exercise tests, subjects pedalled an ergometer designed for use in water (12). The subject was seated on a chair directly behind the ergometer such that the legs pedalled in a horizontal plane. Power output adjustments were made during the initial 15 min of exercise so as to achieve the correct exercise intensity for the individual which approximated 35 % of the peak aerobic power obtained on the bicycle test in air. The exercise continued for a 3-h duration. In both still and exercise states the subjects were permitted to keep their arms close to their sides while holding the chair or crossing them over their abdomen. During immersion Mean Tsk, Tre, Tes, Tw, Ta, and Hc were determined and stored every 2 min, whereas VO2 was recorded every min.

PHASE 2

Subjects. Eight (8) male subjects with a mean age, height and weight of 25.0 yr, 173.7 cm, 76.6 kg and 15.7 % body fat, respectively, were recruited from the college community. Identical to PHASE 1, each individual completed a medical history, physical examination, blood and urine chemistries and resting electrocardiogram and cleared for maximal exercise and cold water immersion. All subjects were informed of the risks and benefits of participation in the testing procedures. Participants were free to withdraw their consent at anytime during the testing. One subject withdrew from both the still- and exercise-chest tests during the 15 deg C exposure prior to reaching the core-temperature limit established for the protocol. One subject (#3) performed only four tests and withdrew from the study. During this phase of the project five subjects used the esophageal probe and five had muscle temperatures taken.

Procedures. Similar to PHASE 1 of the study, body composition analysis and a peak aerobic power test in air on a cycle ergometer were performed utilizing the protocols as described earlier. However, unlike the horizontal cycling performed in PHASE 1, the peak test and exercise in the experiments were performed in the standard upright position. Following assessment of body fat and peak aerobic power, twelve experiments were systematically administered to each subject. The treatments included immersion at three depths (Knee, Hip and Chest) X two water temperatures (15 and 25 C) X two activities (still and one submaximal exercise intensity). On each occasion the subject would arrive 45 min before the start of the immersion and don nylon swim trunks, insert the rectal probe and have the skin and heat flow harnass affixed to the skin. Following harnassing the subject would insert the esophageal probe at a depth of 0.25 X height ($\pm$ 1 cm). At the completion of the probe insertion the subject sat quietly for a period of 15 min, after which the control-air values were obtained. Muscle temperatures were recorded after the pre-immersion control data and just prior to immersion. Subjects entered the immersion tank by use of ladder and in all conditions the subjects were required to assumed the required position and activity state within a 4-min period. All experimental conditions included immersion for a 2.25-h period with subjects sitting on a bicycle ergometer for the entire time. Following immersion the subjects were deharnassed and rewarmed if the core temperatures were below 35.5 deg C. If muscle temperature measurements were required, then the subjects were immediately placed on a plinth and covered with towels. Post-immersion muscle temperatures were standardized for time and measurements were obtained within 9-min of the completion of the immersion period.

Measurements and Equipment in PHASES 1 and 2

Body composition. Body volume was determined by the technique of hydrostatic weighing. Pulmonary residual lung volume was measured in the bent forward body position just prior to water immersion by the use of an oxygen dilution technique. Body weight in air was measured on a Chatillion scale accurate to the nearest 50 g. Body fat was determined from body density by the use of a formula derived by Siri (13).

Thermal and metabolic assessments. Measurements of Mean Tsk were obtained by the use of a five-point thermocouple harnass, where Mean Tsk was determined by an area-weighting formula as follows: Mean Tsk = 0.22 Tcalf + 0.28 Tthigh + 0.28 Tchest + 0.08 Ttriceps + 0.14 Tforearm. Thermistors (YSI, Ohio) were covered with one layer of tape (Hy-tape, New York). Air and forehead temperatures were also recorded. Tre was recorded by the placement of a probe 10 cm into the rectum and held in place by a 1.1 cm diameter ball attached to the probe. Direct assessment of heat loss was determined by 5 heat flow sensors taped adjacent to the skin thermistors.

Oxygen uptake (VO2) was determined by open-circuit spirometry where the inspired volumes are measured by a Parkinson-Cowen CD-4 gasmeter. Samples of expired air were taken from a seven-liter mixing chamber and analyzed for oxygen (Applied Electrochemistry S-3A) and carbon dioxide (Ametek CD-3A). All volumes were corrected to standard conditions for determination of VO2. Metabolic Rate (M) was calculated from VO2 (18).

Immersion tank and data acquisition. During PHASE 1 of the project subjects were immersed in a 2000 gallon tank of water. Individuals were immersed to a depth of the manubrium sternum. In PHASE 2 a 1500 gallon tank of water was used with the depths of immersion as follows: the Knee (above the patella), the Hip (superior aspect of the iliac crest) and the Chest (shoulders completely covered). In both phases the water was continuously circulated by the use of a pool filter. Temperature was maintained within +/- 0.5 C. All temperature and heat flow data were recorded and stored on a

Hewlett-Packard (HP) 3056 DL Data Acquisition System that included an HP 3421 Data Acquisition/Control Unit and an HP 85 B computer.

Statistical Analysis. Metabolic and thermal data were analyzed, where reported, using a repeated measures design analysis of variance (ANOVA). The 5% level of significance was selected for all analyses. In PHASE 2 the subjects that completed the entire exposures and all measures were used in the analyses.

RESULTS

PHASE 1

Subject Characteristics. The physical characteristics of the subjects are provided in Tables 1 and 2. Table 2A considers the combined group of 14 subjects and the subjects divided into subgroups based on the level of body fat (Table 2B). The three levels of fatness included low (L) fat (< 12 % body fat), average (A) fat (between 12 and 17 %) and high (H) fat (>17%).

Table 1. Physical Characteristics of the Subjects in Phase 1.

S #	Age	Weight	Height	%Body Fat
1	27.5	69.9	173.9	16.6
2	21.9	75.5	179.7	9.6
3	19.8	56.2	153.7	6.2
4	23.9	70.0	172.1	13.8
5	25.0	82.4	184.2	9.2
6	30.0	69.8	175.3	11.6
7	25.0	77.4	183.0	17.8
8	36.1	72.9	172.1	14.8
9	18.6	71.3	166.4	14.3
10	22.7	73.1	173.9	11.1
11	22.7	86.6	184.8	14.3
12	25.0	97.9	189.0	21.4
13	28.5	93.8	185.4	19.4
14	22.8	75.9	170.8	19.6

Maximal metabolic and cardiovascular responses of the L, A, and H groups to treadmill exercise are reported in Table 3. The L group's maximal oxygen uptake averaged 4.6 l/min which represented 62.1 ml/min per kg of body weight. In contrast to L, both the A and H groups averaged about 4.3 l/min with the relative-to-body weight maximal oxygen uptakes of 57.0 and 49.1 ml/kg*min for A and H, respectively. Maximal pulmonary ventilation, respiratory exchange ratio (R) and heart rate were within normal limits for all subjects.

Table 4 illustrates the maximal metabolic and cardiorespiratory responses of the groups to bicycle ergometer exercise. Despite the somewhat lower values on the bicycle ergometer compared with treadmill for all groups, the contrasts between groups during cycling were similar to those observed during treadmill exercise with responses of L slightly higher than both A and H groups.

Table 2A. Mean values of the subjects represented as a combined group (A)

	(A) All Subjects Combined			
	Age	Weight	Height	%Body Fat
$\bar{X}$	25.0	76.6	176.0	14.3

Table 2B. Mean values of the subjects divided into three groups of Low, Average and High Body Fat.

		Age	Weight	Height	%Body Fat
Low Fat Group	$\bar{X}$	23.9	71.4	173.4	9.5
	Ss:	2, 3, 5, 6, 10;		N = 5	
Average Fat Group	$\bar{X}$	25.8	74.1	173.9	14.8
	Ss:	1, 4, 8, 9, 11;		N = 5	
High Fat Group	$\bar{X}$	25.3	86.2	182.1	19.6
	Ss:	7, 12, 13, 14;		N = 4	

Table 3. Maximal metabolic and cardiorespiratory responses of the low, average and high body fat groups to treadmill exercise .

Group	Low	Average	High
Maximal Oxygen Uptake	4.60	4.31	4.32
(l/min)	.20	.40	.24
Maximal Oxygen Uptake	62.1	57.0	49.1
(ml/kg*min)	5.6	4.4	3.6
Maximal Heart Rate	201	195	199
(beat/min)	9	5	17
Maximal Pulmonary Ventilation	154.9	146.6	150.9
(l/min,BTPS)	15.7	26.6	20.7
Maximal R	1.15	1.12	1.19
	.05	.14	.01

values are means and standard deviations

Table 4. Maximal metabolic and cardiorespiratory responses of the low, average and high body fat groups to bicycle ergometer exercise.

Group >	Low	Average	High
Maximal Oxygen Uptake (l/min)	3.98 .69	3.68 .49	3.68 .29
Maximal Oxygen Uptake (ml/kg*min)	55.4 2.6	51.9 6.2	43.2 3.1
Maximal Heart Rate (beat/min)	188 8	188 9	191 16
Maximal Pulmonary Ventilation (l/min,BTPS)	152.7 21.6	143.9 12.3	150.9 20.8
Maximal R	1.19 .21	1.10 .15	1.10 .09

values are means and standard deviations

Table 5 shows the oxygen uptake values across time during resting conditions in water at temperatures that provide equivalent thermal strain (SN) and equal thermal stress (ST) to the L, A and H groups. Compared to pre-immersion values the still oxygen uptake values were somewhat higher during immersion in the SN condition, though the increase was consistent among the differing body fat groups. During the ST condition the oxygen uptake values increased proportional to the level of body fatness of each group. That is, minimal changes in oxygen uptake were seen in the H group during immersion compared with the air-control condition, whereas there was a noted two to three fold increase in rate above the level established by the pre-immersion condition in L.

Table 5A. Oxygen uptake values during rest in water at equivalent thermal strain for low, average, and high body fat groups.

	Tw	N	PRE	30	60	90	120	150	180
LOW	26	5	.33	.54	.67	.74	.70	.62	.73
			.08	.27	.14	.14	.13	.06	.25
						*	*	*	*
AVERAGE	22	5	.30	.43	.66	.66	.76	.78	.77
			.05	.13	.19	.08	.10	.11	.09
									*
HIGH	18	4	.38	.58	.82	.69	.99	.76	.78
			.07	.13	.07	.08	.23	.04	.09

values are means and standard deviations; Tw is water temperature;
* N=N-1

Table 5B. Oxygen uptake values during rest in water at equivalent equal thermal stress for low, average, and high body fat groups.

	Tw	N	PRE	30	60	90	120	150	180
							*	*	*
LOW	24	5	.32	.62	.70	.85	.96	.85	.84
			.06	.17	.21	.14	.23	.10	.17
						*	*	*	*
AVERAGE	24	5	.33	.53	.60	.76	.72	.64	.55
			.05	.13	.16	.13	.12	.10	.06
HIGH	24	4	.32	.36	.52	.57	.54	.61	.56
			.02	.03	.15	.08	.06	.08	.07

values are means and sd; Tw is water temperature; * N=N-1

Table 6 illustrates the oxygen uptake values during exercise in water during SN and ST conditions. During exercise in water oxygen uptake values were higher than pre-immersion rest values for all three groups. The values approximated 1.4 lO2/min for each group across time in the ST condition. Similar results were evident during exposure of all groups to water at 24 deg

C; though for the L group, there was a slight increase in the rate of oxygen usage across the three hour immersion period.

Table 6. Oxygen uptake values during exercise in water at equivalent thermal strain (A) and equal thermal stress (B) for low, average, and high body fat groups.

A

	Tw	N	PRE	30	60	90	120	150	180
LOW	26	5	.33	1.33	1.38	1.42	1.52	1.33	1.36
			.04	.25	.19	.18	.37	.2	.18
AVERAGE	22	5	.32	1.39	1.48	1.56	1.52	1.54	1.46
			.02	.21	.16	.30	.19	.22	.20
HIGH	18	4	.36	1.37	1.44	1.44	1.49	1.42	1.52
			.04	.15	.11	.03	.04	.10	.16

B

	Tw	N	PRE	30	60	90	120	150	180
LOW	24	5	.32	1.43	1.56	1.55	1.62	1.65	1.75
			.06	.18	.27	.22	.27	.33	.40
AVERAGE	24	5	.34	1.42	1.42	1.46	1.50	1.43	1.51
			.08	.22	.26	.23	.16	.23	.23
HIGH	24	4	.31	1.34	1.38	1.32	1.38	1.32	1.42
			.01	.16	.21	.24	.18	.09	.08

values are means and sd; Tw is water temperature; * N = N-1

Pulmonary ventilation during resting conditions is shown in Table 7. Prior to immersion in the SN condition the ventilation was approximately 9.0 l/min for all subjects., During immersion the ventilation increased slightly during the first 30 min and reached levels of 1.5 to 2 times the pre-immersion values during <u>mins</u> 60 to 180. During the ST condition the pulmonary ventilation the pre-immersion values for all groups were approximately 8.5 l/min. During immersion the ventilation was increased in all groups though the magnitude of increase was indirectly related to the level of body fatness with the greatest increase observed in the L group and the least increase in H.

Table 7. Pulmonary ventilation values during rest in water at equivalent thermal strain (A) and equal thermal stress (B) for low, average, and high body fat groups.

					A				
	Tw	N	PRE	30	60	90	120	150	180
LOW	26	5	8.14	10.38	12.7	15.94	13.79	13.59	14.24
			1.54	4.14	2.66	3.18	2.49	1.94	3.60
						*	*	*	*
AVERAGE	22	5	8.71	11.02	16.04	15.74	15.67	18.86	16.42
			1.62	2.53	5.37	3.95	1.84	4.01	3.24
HIGH	18	4	9.64	12.58	16.27	14.05	20.17	15.22	15.6
			.52	3.74	.48	2.40	6.66	.90	2.26
					B				
	Tw	N	PRE	30	60	90	120	150	180
							*	*	*
LOW	24	5	8.38	12.29	14.66	17.83	18.28	15.94	15.72
			1.17	2.77	3.25	1.48	3.42	1.44	3.07
						*	*	*	*
AVERAGE	24	5	8.66	14.12	13.55	16.78	16.32	14.87	14.29
			.89	6.58	2.03	1.20	3.22	1.90	3.50
HIGH	24	4	8.56	7.77	10.84	11.98	11.55	12.67	11.83
			1.18	1.46	3.41	1.26	1.28	1.54	2.00

values are means and standard deviations; Tw is water temperature;
* N = N-1

Table 8 shows the pulmonary responses to exercise during 3-h immersion in ST and SN conditions. Pre-immersion values were approximately 9 l/min during ST and increased to levels between 26 and 31 l/min during exercise. These values were maintained during the 180 min of immersion. In the exercise and SN condition the pulmonary ventilations were similar to ST with values ranging from 28 - 34 l/min throughout the immersion period with the higher values recorded by the L group.

Table 8. Pulmonary ventilation values during exercise in water at equivalent thermal strain (A) and equal thermal stress (B) for low, average, and high body fat groups.

A

	Tw	N	PRE	30	60	90	120	150	180
LOW	26	5	8.50	26.49	27.06	28.30	31.14	26.54	26.76
			0.14	2.27	2.69	4.46	8.57	3.79	3.86
AVERAGE	22	5	8.19	28.82	29.06	31.33	30.46	30.20	29.15
			0.66	6.07	5.29	5.91	5.36	5.00	5.24
HIGH	18	4	10.50	31.40	30.35	30.98	30.12	28.36	29.33
			0.19	2.61	4.36	1.39	2.34	3.24	3.30

B

	Tw	N	PRE	30	60	90	120	150	180
LOW	24	5	8.06	29.22	30.40	31.28	32.02	32.28	34.05
			1.39	4.69	5.95	5.79	7.25	8.16	8.75
AVERAGE	24	5	9.61	30.45	29.79	29.65	30.03	29.02	30.20
			2.73	5.48	6.82	5.38	4.52	4.39	4.60
HIGH	24	4	8.84	28.38	29.34	28.36	28.58	27.60	28.98
			1.26	5.10	5.30	6.14	5.20	2.30	3.92

values are means and standard deviations; Tw is water temperature;
* N = N-1

Rectal temperature values during rest in SN and ST conditions are shown in Table 9. Prior to immersion in the SN condition Tre values were approximately 37.1 deg C and declined in all groups throughout 3 h of immersion. Similar declines in Tre were noted between the groups throughout

Table 9. Rectal temperature values during rest in water at equivalent thermal strain (A) and equal thermal stress (B) for low, average, and high body fat groups.

					A				
	Tw	N	PRE	30	60	90	120	150	180
LOW	26	5	37.11	36.88	36.35	36.16	36.01	35.84	35.79
			.17	.15	.26	.37	.29	.27	.35
							*	*	*
AVERAGE	22	5	37.12	36.67	36.10	35.74	35.70	35.63	35.57
			.11	.41	.62	.55	.3	.16	.16
									*
HIGH	18	4	37.08	36.88	36.35	35.98	35.72	35.30	35.86
			.27	.26	.48	.65	.83	1.00	.34
					B				
	Tw	N	PRE	30	60	90	120	150	180
							*	*	*
LOW	24	5	37.09	36.89	36.43	36.03	35.75	35.55	35.42
			.22	.24	.32	.32	.42	.49	.64
						*	*	*	*
AVERAGE	24	5	37.11	36.76	36.26	36.26	36.16	36.13	36.07
			.33	.30	.50	.14	.06	.16	.23
HIGH	24	4	37.22	37.00	36.70	36.38	36.17	36.10	36.04
			.16	.12	.10	.13	.25	.28	.31

values are means and standard deviations; Tw is water temperature;
* is N = N-1

the exposure period. Tre declined in all groups over the immersion period (delta Tre, - 1.32, -1.45, and -1.32 deg C for L, A and H subjects, respectively). During ST conditions Tre dropped moderately in the L (delta Tre, -1.67 deg C) and A (delta Tre, -1.04 deg C) groups and modestly in the H group (delta Tre, -0.18 deg C) throughout the 3-h exposure. The decline in Tre was non-linear with the major decline in core temperatures occurring within first 2.0-2.5 h of immersion followed by a stabilization thereafter.

Table 10. Rectal temperature values during exercise in water at equivalent thermal strain (A) and equal thermal stress (B) for low, average, and high body fat groups.

	Tw	N	PRE	30	60	90	120	150	180
A									
LOW	26	5	37.03	36.88	36.82	36.56	36.85	36.84	36.82
			.21	.33	.51	.73	.58	.56	.52
AVERAGE	22	5	37.18	36.78	36.66	36.6	36.57	36.47	36.50
			.32	.26	.22	.29	.37	.46	.67
HIGH	18	4	37.03	37.27	37.21	36.97	36.86	36.72	36.58
			.08	.17	.11	.21	.20	.32	.45
B									
	Tw	N	PRE	30	60	90	120	150	180
LOW	24	5	37.05	36.70	36.57	36.60	36.72	36.65	36.63
			.08	.20	.26	.42	.67	.74	.68
AVERAGE	24	5	37.00	36.56	36.64	36.63	36.72	36.75	36.77
			.19	.38	.40	.43	.49	.54	.60
HIGH	24	4	37.03	37.26	37.38	37.34	37.25	37.24	37.25
			.10	.15	.38	.48	.48	.42	.39

values are means and standard deviations; Tw is water temperature;
* is N = N-1

During exercise Tre values were higher compared to rest for all groups in all Tw (Table 10). During the SN condition the Tre responses were not the same for all groups. In the L group Tre declined modestly during the first 30 min and remained at about 36.8 deg C for 2.5 h. Tre responses of the A

Table 11. Esophageal temperature values during rest in water at equivalent thermal strain (A) and equal thermal stress (B) for low, average, and high body fat groups.

	Tw	N	PRE	30	60	90	120	150	180
A									
LOW	26	5	36.88	36.8	36.54	36.42	36.4	36.38	36.41
			.22	.29	.34	.20	.15	.15	.28
AVERAGE	22	3	36.70	36.86	36.50	36.40	36.30	36.28	36.27
			.21	.16	.24	.03	.21	.18	.18
HIGH	18	3	36.76	36.87	36.51	36.36	36.15	36.16	* 36.36
			.17	.18	.12	.10	.23	.28	.21
B									
	Tw	N	PRE	30	60	90	120	150	180
LOW	24	5	38.83	36.87	36.33	36.09	36.25	36.31	36.30
			.22	.3	.42	.49	.37	.35	.36
AVERAGE	24	3	36.71	36.68	36.51	36.35	36.53	36.43	36.56
			.22	.27	.23	.18	.16	.25	.17
HIGH	24	4	36.81	36.81	36.41	36.16	36.04	36.18	36.11
			.06	.08	.10	.10	.26	.20	.28

values are means and standard deviations; Tw is water temperature;
* is N = N-1

group followed a similar pattern though the stabilized temperature was 36.5 deg C, somewhat lower than the L group. In contrast to these responses the H group demonstrated a slight increase throughout the first h of immersion followed by a consistent decline throughout the last 2 h, dropping to 36.58

deg C by the end of the exposure. It appeared that equivalence in thermal strains was not achieved in the present study during exercise conditions. During ST the responses of the L and A groups appeared to be similar. Tre declined during the first 30 min, followed by Tre stabilization throughout the remainder of the exposure. The H group showed an increase in Tre during the first 30 min and the Tre remained elevated for the final 2.5 h.

Table 11 shows the Tes responses during rest. In the SN condition Tes declined in all groups over the immersion period (delta Tes, -0.47, -0.43, and -0.40 deg C for L, A and H subjects, respectively). During the ST condition Tes dropped modestly in L (delta Tes, -0.53 deg C), A (delta Tes, -0.15 deg C) and H (delta Tes -0.70 deg C) throughout the 3-h exposure. The decline in Tes was also not linear with the major decline occurring within first 1.0-1.5 h of immersion followed thereafter by stabilization. During exercise Tes values were higher compared to rest for all groups in all Tw (cf. Tables 9 and 10). Minimal changes in Tes were noted across time. The differences observed between Tre and Tes at rest were not evident when no change or a slight increase in core temperatures was observed.

Table 12. Esophageal temperature values during exercise in water at equivalent thermal strain (A) and equal thermal stress (B) for low, average, and high body fat groups.

A

	Tw	N	PRE	30	60	90	120	150	180
LOW	26	5	36.74	36.99	36.80	36.82	36.92	36.91	36.87
			.18	.20	.33	.44	.42	.44	.43
AVERAGE	22	3	36.76	36.89	36.87	36.75	36.78	36.83	36.77
			.18	.06	.36	.55	.61	.53	.55
HIGH	18	3	36.67	37.32	37.05	36.86	36.85	36.69	36.53
			.07	.31	.26	.20	.18	.19	.32

B

	Tw	N	PRE	30	60	90	120	150	180
LOW	24	5	36.84	36.87	36.86	36.85	36.90	36.90	36.89
			.14	.37	.39	.45	.60	.65	.71
AVERAGE	24	3	36.71	36.68	36.51	36.35	36.53	36.43	36.56
			.22	.27	.23	.18	.16	.25	.17
HIGH	24	3	36.68	37.29	37.18	37.16	37.10	37.21	37.26
			.07	.08	.14	.22	.28	.25	.22

values are means and standard deviations; Tw is water temperature;
* is N = N-1

Values of Mean Tsk and Hf during rest and exercise for the groups are reported in the Appendix.

PHASE 2

Subjects. The subjects are described in Table 13. The group varies in age from 20 to 38 years and this large a range is due to the difficulty in recruitment of subject for this phase of the project. Prospective subjects felt that the nature of the experiment was too harsh for their participation. In addition the use of reusable needles presented recruitment difficulties with the expressed concern of infection. Despite the difficulties and nearly two years of effort, seven subjects performed all twelve experimental treatments. Subject # 3 participated in four of the tests and did not complete the study. His data were included in the results.

Table 13. Physical Characteristics of the Subjects in Phase 2.

	Subject	Age	Height	Weight	% Body Fat
	1	24	185.6	88.2	15.5
	2	21	179.7	86.2	11.4
	3	27	177.8	73.5	25.5
	4	23	158.1	64.5	15.1
	5	24	167.0	67.2	19.3
	6	22	165.0	72.3	14.5
	7	20	169.6	69.6	11.2
	8	38	186.7	77.2	13.0
N = 8	$\bar{X}$	25	173.7	74.8	15.7

The exercise, performed on a standard cycle ergometer immersed in the water, required that the knee exit the water when the pedal and crank were positioned in the up side of the stroke. In this position the calf was partially removed from the water. On the down stroke the knee was completely immersed.

<u>Exercise in 25 deg C Water</u>. The thermal responses of the subjects during leg exercise in 25 deg C water are reported in Tables 14- 16 . Results with knee immersion are presented in Table 14. Despite the immersion of the calf in 15 deg C, mean-weighted heat flow (Hc) values and both rectal (Tre) and esophageal (Tes) temperatures did not significantly differ over 2 h of exercise, though there appeared to be some upward trend in all three measures as time progressed. This is in contrast to the adjustments in mean-weighted skin temperature (Mean Tsk) which dropped significantly over time and reached 30.23 deg C after 2h. Final Hc, Tre and Tes averaged 99 W/m2, 37.50 deg C and 37.31 deg C, respectively.

Table 14. Exercising thermal responses during immersion to the knee in water at 25 deg C.

Exercise/Knee 25 deg C

	Time	Pre	30	60	90	120		
Mean-Weighted Heat Flow (W/m2)	Mean	67	89	91	93	99	P =	.061
	SD	11	23	23	23	30		
Mean-Weighted Skin Temperature (deg C)	Mean	31.42	30.57	30.83	30.61	30.23	P <	.001
	SD	.84	.95	1.06	1.06	1.12		
Rectal Temp (deg C)	Mean	37.22	37.32	37.51	37.42	37.5	P =	.116
	SD	.29	.42	.36	.31	.33		
Esophageal Temp (deg C)	Mean	36.95	37.07	37.32	37.28	37.31	P =	.062
	SD	.29	.53	.32	.21	.26		

Subjects exercised in water at 25 deg C while immersed to the hip (Table 15). During this exposure and activity level Hc significantly increased over time while Mean Tsk, Tre and Tre all decreased ($P < 0.05$) over the course of the 2-h period. The final Hc (122 W/m2) was twice as high as the pre-immersion value (50 W/m2). The increase heat loss was noted in values of Mean Tsk, reduced from 31.72 deg C about 29 deg C, and both Tre and Tes. Final Tre and Tes were similar to each other and averaged 36.82 and 36.75 deg C, respectively.

Table 15. Exercising thermal responses during immersion to the hip in water at 25 deg C.

Exercise/Hip 25 C

	Time	Pre	30	60	90	120		
Mean-Weighted Heat Flow (W/m2)	Mean	60	140	140	136	122	P <	.001
	SD	9	34	23	21	18		
Mean-Weighted Skin Temperature (deg C)	Mean	31.72	28.76	29.00	28.95	29.21	P <	.001
	SD	.69	.55	.63	.48	.80		
Rectal Temp (deg C)	Mean	37.06	37.05	37.02	36.90	36.82	P =	.025
	SD	.14	.33	.29	.26	.29		
Esophageal Temp (deg C)	Mean	36.55	36.95	36.92	36.84	36.75	P <	.01
	SD	.25	.22	.29	.32	.25		

Results of the subjects immersed to the chest are shown in Table 16. Hc increased a factor of four from the pre-immersion value 56 W/m2 during the initial 30 min of immersion (197 W/m2) and remained elevated throughout the exposure, averaging approximately 180 W/m2. The Mean Tsk values were lowered early in the exposure (Pre: 31.98 deg C; <u>min</u> 30: 25.61 deg C) and tracked water temperature throughout the experiment. Adjustments of Tre and Tes similar over time with a gradual but statistically significant reduction in values (Final Tre: 36.45 deg C; Final Tes: 36.32 deg C).

Table 16. Exercising thermal responses during immersion to the chest in water at 25 deg C.

Exercise/Chest 25 C

	Time	Pre	30	60	90	120		
Mean-Weighted Heat Flow (W/m2)	Mean	56	197	181	179	171	P <	.001
	SD	8	42	46	53	42		
Mean-Weighted Skin Temperature (deg C)	Mean	31.98	25.61	25.45	25.52	25.42	P <	.001
	SD	.76	.33	.26	.22	.31		
Rectal Temp (deg C)	Mean	37.23	36.92	36.67	36.53	36.45	P <	.001
	SD	.18	.42	.51	.55	.59		
Esophageal Temp (deg C)	Mean	36.54	36.69	36.39	36.35	36.32	P <	.001
	SD	.10	.07	.24	.21	.18		

Rest in 25 deg C Water. Subjects were asked to sit in water with minimal voluntary movements. This permitted the analysis of the thermal adjustments during still conditions. The average values of the subjects during KN immersion are reported in Table 17. As indicated, Hc values were significantly elevated during the early period of immersion. Though slight, the 30-min value (82 W/m2) was higher than both the pre-immersion value (60 W/m2) and the values reported during the last 1h of immersion (mean: $\simeq$ 62 W/m2). The increase in Hc was attributed to the large increase in heat flow of the calf (Hcalf) during the early phase of the test. Later in the experiment, Hcalf return to the values reported during the pre-immersion condition. The Mean Tsk values were reduced slightly compared to control and were approximately 30.6 deg C throughout the test. Despite the similar Hc values throughout the immersion period both Tre and Tes values drifted downward over time (delta Tre, post-pre: -0.38; delta Tes, post-pre: -0.16 C deg).

Table 17. Resting thermal responses during immersion to the knee in water at 25 deg C.

Rest/Knee 25 C

	Time	Pre	30	60	90	120		
Mean-Weighted Heat	Mean	60	82	67	60	59	P <	.001
Flow (W/m2)	SD	8	8	10	12	10		
Mean-Weighted Skin	Mean	31.78	30.66	30.71	30.68	30.59	P <	.001
Temperature (deg C)	SD	.73	.46	.65	.64	.62		
Rectal Temp (deg C)	Mean	37.15	37.11	37.02	36.86	36.77	P <	.001
	SD	.24	.24	.20	.24	.27		
Esophageal Temp	Mean	36.74	36.86	36.84	36.68	36.58	P <	.01
(deg C)	SD	.29	.29	.20	.19	.22		

Immersion to the HI resulted in significant thermal adjustments as noted in all thermal measures (Table 18). The increase in Hc appeared more pronounced than during KN with the Hc value doubling during the initial 30 min (pre: 61W/m2; min 30: 114W/m2) and remaining elevated throughout the immersion, averaging about 80W/m2. Partly as a result of the increased heat loss, the Tre decreased over time (Tre: pre 37.09,post 36.28 deg C). Despite the reduction in Tre, the chest core, as evinced by changes in Tes, was unaffected (Tes: pre 36.53, post 36.25 deg C; P> 0.05).

CH immersion resulted in significant skin and core cooling (Table 19). Values of Hc across time of exposure were dramatic with a 3.5-fold increase in Hc during the first 30 min of exposure (161W/m2) compared with control-air values (48W/m2) and a maintained of high heat loss throughout the experiment (average of min60-120: 120W/m2). Values of Tre and Tes both decreased over time with the more noticeable cooling in the rectum (Tre pre,post: 36.97, 36.01; Tes pre,post: 36.52, 36.18 deg C).

Table 18. Resting thermal responses during immersion to the hip in water at 25 deg C.

Rest/Hip 25 C

Mean-Weighted Heat Flow (W/m2)	Mean	61	114	89	80	80	P <	.001
	SD	9	14	5	4	4		
Mean-Weighted Skin Temperature (deg C)	Mean	31.87	29.05	28.81	28.61	28.53	P <	.001
	SD	.78	.50	.60	.72	.81		
Rectal Temp (deg C)	Mean	37.09	36.98	36.69	36.44	36.28	P <	.001
	SD	.27	.22	.15	.25	.23		
Esophageal Temp (deg C)	Mean	36.53	36.73	36.55	36.38	36.25	P =	.073
	SD	.11	.28	.35	.31	.36		

Table 19. Resting thermal responses during immersion to the chest in water at 25 deg C.

Rest/Chest 25 C

	Time	Pre	30	60	90	120		
Mean-Weighted Heat Flow (W/m2)	Mean	48	161	125	122	112	P <	.001
	SD	10	49	19	19	24		
Mean-Weighted Skin Temperature (deg C)	Mean	32.09	26.00	26.13	25.94	25.89	P <	.001
	SD	.90	.87	.74	.59	.41		
Rectal Temp (deg C)	Mean	36.97	36.72	36.45	36.20	36.01	P <	.001
	SD	.17	.33	.24	.23	.28		
Esophageal Temp (deg C)	Mean	36.52	36.57	36.42	36.21	36.18	P <	.01
	SD	.22	.26	.21	.21	.29		

Exercise in 15 deg C. Table 20 shows Hc, Mean Tsk, Tre and Tes response during exercise in cold water. Much like the results obtained in 25 deg C water, Hc was increased after exposure and remained elevated throughout, although the relative increase above control values (200 % increase) and the absolute Hc (≃ 140W/m2) appeared greater in 15 compared with 25 deg C water. The affect of exercise heat input and Hc resulted in similar core temperature responses throughout the experiment. Tre and Tes remained near pre-immersion values (delta Tre, post-pre: 0.17; delta Tes, post-pre: 0.24 C deg). Mean Tsk was reduced ≃3 deg C (pre - average min 30-60) with the lower legs exposed to 15 deg C water.

Table 20. Exercising thermal responses during immersion to the knee in water at 15 deg C.

Exercise/Knee/ 15 C

	Time	Pre	30	60	90	120		
Mean-Weighted Heat Flow (W/m2)	Mean	70	145	140	138	132	P <	.001
	SD	23	57	32	52	22		
Mean-Weighted Skin Temperature (deg C)	Mean	31.54	27.71	28.17	28.08	28.13	P <	.001
	SD	.71	.82	.69	1.44	1.55		
Rectal Temp (deg C)	Mean	37.2	37.14	37.29	37.3	37.37	P <	.01
	SD	.15	.25	.36	.33	.29		
Esophageal Temp (deg C)	Mean	36.91	37.02	37.15	37.13	37.15	P <	.05
	SD	.26	.35	.15	.32	.21		

Table 21 shows a 600% increase in Hc (305W/m2) above control-air values (56W/m2) during the first 30 min of HI exposure to cold water. This increase was somewhat maintained (260W/m2) throughout the test. The increased exercising-heat liberation was not able to offset the increased heat loss, and core temperatures were reduced throughout the exposure. As was the case in 25 deg C water, the more dramatic cooling took place in the rectal area (delta

Tre, post-pre: -0.90 C deg) compared with the chest core (delta Tes, post-pre: -0.46 C deg). The core temperatures appeared to stabilize at at 60min.

Care must be taken in examining the results presented during CH exposure in cold water (Table 22). As pointed out in the statistical analysis section, the individuals completing the exposure are represented in these results. Therefore, Table presents the results 3 of the 7 subjects participating in this experimental condition. Therefore, only those individuals who are able to adjust physiologically to this condition are shown here. Of the remaining 4 subjects, one of which voluntarily removed himself from the exposure at 37 min and 3 lasted between 53 and 92min. These results, though not considered in this report, are significant and will form the basis for a paper to be submitted to the open literature for publication.

Table 21. Exercising thermal responses during immersion to the hip in water at 15 deg C.

Exercise/Hip/ 15 C

	Time	Pre	30	60	90	120		
Mean-weighted Heat	Mean	56	305	275	261	250	P <	.001
Flow (W/m2)	SD	14	100	94	100	103		
Mean-weighted Skin	Mean	32.16	24.71	24.31	24.60	24.63	P <	.001
Temperature (deg C)	SD	.62	1.56	1.79	1.5	1.44		
Rectal Temp (deg C)	Mean	37.11	36.86	36.5	36.25	36.21	P <	.001
	SD	.35	.36	.49	.40	.39		
Esophageal Temp	Mean	36.65	36.49	36.24	36.24	36.19	P <	.01
(deg C)	SD	.19	.36	.30	.40	.46		

Considering this situation, one can observe that the subjects tolerate to exercise in cold water showed high Hc values and progressively decreasing core temperatures. Although not analyzed for this report, a careful examination of the rates of rectal and chest core temperature cooling should provide valuable information about the factors regulating core temperature maintainence during exercise in water. Without a careful examination, only a limited descriptive approach can be used here. As such, it appears that these 3 tolerate individuals show core cooling that begins to approach a stabilized core temperature during the last h of immersion. In fact the drop of core temperature during the last 30 (delta Tre, min 90-120: 0.20; delta Tes, min 90-120: 0.14 C deg) appears less than the drop seen between min 30-60 (delta Tre, min 30-60: 0.64; delta Tes, min 30-60: 0.33 C deg).

Table 22. Exercising thermal responses during immersion to the chest in water at 15 deg C.

Exercise/Chest 15 C								
	Time	Pre	30	60	90	120		
Mean-weighted Heat Flow (W/m2)	Mean	57	315	315	313	312	P <	.001
	SD	15	62	67	46	55		
Mean-weighted Skin Temperature (deg C)	Mean	31.97	16.33	16.13	16.13	16.00	P <	.001
	SD	.84	.27	.32	.15	.24		
Rectal Temp (deg C)	Mean	37.28	36.62	35.98	35.77	35.57	P <	.001
	SD	.98	.18	.08	.16	.19		
Esophageal Temp (deg C)	Mean	36.70	36.28	35.95	35.84	35.70	P <	.01
	SD	.39	.64	.47	.31	.38		

Resting in 15 deg C Water. During KN exposure Hc values were elevated above the control-air values throughout immersion (Table 23). Despite the limited body surface exposed to the cold water, Tre tended to be reduced throughout immersion. It should be noted that this appeared to be a result of the early increase in Hcalf for all subjects, and the tendency of one subject

(#7) to loose heat from the calf throughout the exposure. In this individual Tre was reduced to 35.88 deg C at the end of the exposure, whereas all other subjects either showed no change or less than a 0.2 C deg drop in Tre, pre to post. It should be pointed out that this subject cooled faster than most in all conditions.

Table 23. Resting thermal responses during immersion to the knee in water at 15 deg C.

Rest/Knee 15 C

	Time	Pre	30	60	90	120		
Mean-weighted Heat Flow (W/m2)	Mean	59	140	101	87	81	P <	.001
	SD	12	43	22	12	15		
Mean-Weighted Skin Temperature (deg C)	Mean	31.61	27.88	27.41	26.91	26.89	P <	.001
	SD	1.16	.84	1.09	1.19	1.47		
Rectal Temp (deg C)	Mean	37.16	37.16	36.98	36.89	36.71	P <	.01
	SD	.17	.21	.32	.16	.29		
Esophageal Temp (deg C)	Mean	36.71	36.97	36.98	36.69	36.63	P =	.14
	SD	.41	.27	.17	.25	.14		

All subjects completed the Hi exposure and responses of the group are included in Table 24. There was a 300% increase in Hc at min 30 (212W/m2) compared with control values (71W/m2), though as time progressed Hc was only 70% above the pre-immersion value at min 120 (120W/m2). Tre was significantly lower at min 120 (35.95 deg C) compared with the control value (37.36 deg C). Tes values appeared to be substantially less than Tre during the control period and this is primarily due to the inclusion of the high Trc value for S #7, who did not use an esophageal probe and is therefore not represented in the Tes data. Although the subjects were able to complete the exposure without difficulty, it appears that the Tre was approaching a stabilized value. This may have significant ramifications on survival in cold water.

Table 24. Resting thermal responses during immersion to the hip in water at 15 deg C.

Rest/Hip 15 C

	Time	Pre	30	60	90	120		
Mean-Weighted Heat Flow (W/m2)	Mean	71	212	155	130	120	P <	.001
	SD	21	46	29	34	19		
Mean-Weighted Skin Temperature (deg C)	Mean	31.57	23.65	22.98	23.16	23.28	P <	.001
	SD	.53	.73	1.33	1.28	.96		
Rectal Temp (deg C)	Mean	37.36	37.17	36.83	36.37	35.95	P <	.001
	SD	.28	.32	.40	.52	.68		
Esophageal Temp (deg C)	Mean	36.41	36.73	36.53	36.22	35.93	P <	.01
	SD	.09	.24	.16	.38	.31		

Similar to the reductions in core temperature observed during E in 15 deg C/ CH condition were the Tre and Tes responses during R. Table 25 shows the Hc, Mean Tsk, Tre and Tes. Hc at min 30 (264 W/m2) was 5 times greater than Hc during the control period (58 W/m2) and remained elevated throughout the immersion, averaging approximately 185 W/m2 at min 60, 90 and 120. There were significant reductions in Mean Tsk (pre-post: 14.94 C deg), Tre (pre-post: 1.72 C deg), and Tes (pre-post: 0.80 C deg). The Tes values appeared to stabilize after the first h of immersion, while Tre continued to decrease during the final 30 min of immersion. Similar to the difference observed in Phase 1, Tes appeared somewhat higher than the Tre at 2 h of immersion with the difference of 0.50 deg C observed for the group, though the difference is minimized by excluding four subjects not completing the immersion. In fact of the four subjects not finishing the experiment one removed himself from the test while the remaining three reach the core temperature criterion for mandatory withdrawal. Of these all three had Tes-Tre differences ranging from 0.67 to 1.35 deg C.

Table 25. Resting thermal responses during immersion to the chest in water at 15 deg C.

Rest/Chest 15 C

	Time	Pre	30	60	90	120		
Mean-Weighted Heat	Mean	58	264	203	172	185	P <	.001
Flow (W/m2)	SD	21	35	23	16	13		
Mean-Weighted Skin	Mean	31.38	16.80	16.38	16.42	16.44	P <	.001
Temperature (deg C)	SD	.78	.44	.29	.33	.40		
Rectal Temp (deg C)	Mean	36.99	36.47	35.56	35.43	35.27	P <	.001
	SD	.10	.14	.61	.50	.47		
Esophageal Temp	Mean	36.49	36.49	35.79	35.64	35.68	P <	.001
(deg C)	SD	.25	.37	.25	.30	.09		

Table 26 illustrates the muscle temperature responses to immersion in 15 and 25 deq C during rest and exercise. The muscle temperatures prior to immersion were consistent at approximately 33 - 34 deg C. However, the post-immersion value varied with the experimental condition. The coldest temperatures were observed in the non-exercising muscles during immersion in the 15 deg C water. For example, the deltoid muscle temperature averaged about 26 deg C following chest immersion during both rest and exercise conditions. The highest temperatures were seen within the exercising muscles during immersion in 25 C. The temperature of the vastus lateralis averaged about 34 deg C following 2.25 h of exercise in 25 deg C water.

Table 26. Deltoid and Vastus Lateralis muscle temperatures during rest and exercise during immersion to the hip and chest in water at 15 and 25 C.

		Rest				Exercise			
		Deltoid		Vastus		Deltoid		Vastus	
		Pre	Post	Pre	Post	Pre	Post	Pre	Post
15 deg C	Chest	33.14 5	26.36 5	33.47 5	31.55 4	32.18 5	26.08 5	33.88 4	32.90 5
	Hip	33.57 4	33.38 4	33.55 4	27.79 4	33.09 3	32.17 3	33.68 3	33.15 3
25 deg C	Chest	33.90 3	30.10 3	33.26 3	31.54 3	33.19 4	28.85 4	31.41 4	33.80 4
	Hip	32.97 4	33.34 4	33.04 4	30.88 4	33.78 3	32.36 3	33.62 3	34.36 3

Values are means and N

CONCLUSIONS

The factors that contribute to the variation in core temperature response during cold-water immersion include body composition (9,10), water temperature (16), type and level of activity (17), and gender (9,10). Limited information is available, however, as to the thermoregulatory response in relation to the duration of exposure. Most studies have utilized immersion exposures for durations up to 90 min (3,4,5,7,8,9,14,16). Presently, the available literature has not adequately detailed the metabolic and thermal adjustments of individuals exposed to longer immersion times in cool and cold water. Hayward et al. (5) using very cold water linearly extrapolated Tre values obtained during a 40 min exposure to the point when Tre dropped to 30 deg C. This approach assumes that the fall in Tre during exposure follows a linear pattern as duration progresses. This assumption of linearity, though supported in very cold water (1), would be questionable in warmer temperatures in light of several studies (2,6,11,15).

The present study of the physiological adjustments during prolonged exposures may help clarify thermoregulatory dynamics during cold-water stress. The time course of rectal and esophageal temperature adjustments to exposures to water at temperatures above 18 deg C appears to be non-linear over a 3-h period. In water temperatures that were equivalent in thermal strain on the body (i.e., 18 for H, 22 for A and 26 deg C for L) or equal in the thermal stress provided by the water (i.e., 24 deg C for L, A and H) for all groups, the responses of both the rectal and esophageal temperatures showed a trend toward stabilization of temperatures within the 3-h period. In fact it appears that Tes stabilized at an earlier point in time compared with Tre during all resting conditions in cold water.

The reduction in core temperature during cold-water stress depends on the amount of the surface area that is exposed to the water. The present study involving partial immersion demonstrates that exposure of just the lower legs can lead to depressions in core temperatures. Albeit that the decrease in core temperatures are minimal and the level appears to stabilize, immersion to the hip can still provide a thermal challenge to the thermoregulatory mechanisms responsible for core temperature maintainence. As observed in the present study, immersion at rest to hip depth demonstrates continuous core cooling throughout 2.25 h of exposure and present some individual difficulty as exposure durations are more prolonged.

In addition to the observed stabilization of the core temperatures throughout the three hour period, there appears to be noticeably higher values of the Tes compared with Tre at stabilization. The higher Tes may reflect a greater chest core temperature compared with abdominal core during exposure to cool and cold water. This result was most obvious in the leaner subjects compared with the fatter, and during rest compared with exercise conditions. Based upon the presently available data, it is difficult to determine the underlying physiological and thermoregulatory mechanisms responsible for such adjustments. Additional analyses of the present data and further research are required to determine these mechanisms and the implications of the present findings on survival prediction of man exposed to cold water.

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APPENDIX

Mean weighted skin temperatures during exercise in water at equivalent thermal strain (A) and equal thermal stress (B) for low, average, and high body fat groups.

A

	Tw	PRE	30	60	90	120	150	180
LOW	26	32.4 4	26.6 4	26.4 4	26.5 4	26.5 4	26.4 4	26.4 4
AVERAGE	22	32.4 5	22.6 5	22.8 5	22.6 5	22.6 5	22.6 5	22.8 5
HIGH	18	31.8 3	19.1 3	19.1 3	19.1 3	19.1 3	19.1 3	19.2 2

B

	Tw	PRE	30	60	90	120	150	180
LOW	24	32.0 4	24.7 5	24.6 5	24.5 5	24.7 5	24.5 5	24.6 5
AVERAGE	24	32.0 4	24.4 5	24.4 5	24.4 5	24.4 5	24.4 5	24.5 5
HIGH	24	31.7 4	24.3 4	24.3 4	24.2 4	24.3 4	24.3 4	24.4 3

values are means and N; Tw is water temperature;

Mean weighted heat flow values during exercise in water at equivalent thermal strain (A) and equal thermal stress (B) for low, average, and high body fat groups.

A

	Tw	PRE	30	60	90	120	150	180
LOW	26	53 4	211 4	203 4	198 4	193 4	189 4	174 4
AVERAGE	22	59 5	217 5	186 5	191 5	182 5	174 5	173 4
HIGH	18	60 4	258 4	202 4	199 4	204 4	195 4	185 4

B

	Tw	PRE	30	60	90	120	150	180
LOW	24	56 4	249 5	214 5	213 5	200 5	217 5	212 5
AVERAGE	24	51 3	189 3	181 3	170 3	176 3	199 2	192 2
HIGH	24	58 3	148 3	136 3	137 3	126 3	130 3	97 2

values are means and N; Tw is water cemperature;

Mean weighted skin temperatures during rest in water at equivalent thermal strain (A) and equal thermal stress (B) for low, average, and high body fat groups.

A

	Tw	PRE	30	60	90	120	150	180
LOW	26	32.4 5	26.8 5	26.8 5	26.8 5	26.8 5	26.7 5	26.8 5
AVERAGE	22	31.2 4	23.0 4	22.9 4	22.8 4	22.8 4	23.1 4	23.3 4
HIGH	18	32.1 2	19.3 3	19.2 3	19.4 3	19.5 3	19.8 3	19.7 3

B

	Tw	PRE	30	60	90	120	150	180
LOW	24	32.4 5	25.2 5	25.1 5	24.9 5	24.9 4	24.9 4	24.8 4
AVERAGE	24	31.6 5	24.7 5	24.7 5	24.7 5	24.7 4	24.7 4	24.7 4
HIGH	24	31.6 4	24.9 4	24.6 4	24.5 4	24.6 4	24.6 4	24.6 4

values are means and N; Tw is water temperature;

Mean weighted heat flow values during rest in water at equivalent thermal strain (A) and equal thermal stress (B) for low, average, and high body fat groups.

A

	Tw	PRE	30	60	90	120	150	180
LOW	26	61 5	164 5	167 5	171 5	171 5	162 5	162 5
AVERAGE	22	60 4	190 4	159 4	146 4	148 4	128 4	135 4
HIGH	18	46 2	230 3	228 3	197 3	184 3	183 3	172 2

B

	Tw	PRE	30	60	90	120	150	180
LOW	24	61 5	216 5	205 5	196 5	154 4	151 4	169 3
AVERAGE	24	58 5	160 5	137 5	141 5	129 4	130 4	118 4
HIGH	24	57 4	128 4	124 4	119 4	117 4	116 4	118 4

values are means and N; Tw is water temperature;

Thermal adjustments during exercise in water at 33 C.

	PRE	30	60	90	120	150	180
Skin Temperature (C)	31.6 6	33.2 6	33.1 6	33.1 6	33.1 6	33.1 6	33.1 6
Heat Flow (W/m2)	55 6	105 6	106 6	115 6	105 6	103 6	102 6
Rectal Temperature (C)	36.98 9	36.98 9	37.20 9	37.33 9	37.37 8	37.32 9	37.30 9
Esophageal Temp (C)	36.66 7	36.87 7	36.96 7	37.05 7	36.99 7	37.01 7	37.03 7

Values are means and N.

Thermal adjustments during rest in water at 35 C.

	PRE	30	60	90	120	150	180
Skin Temperature (C)	31.7 5	35.0 5	35.0 5	35.0 5	35.0 4	35.1 4	35.0 4
Heat Flow (W/m2)	55 5	22 6	33 6	33 6	34 5	32 5	36 5
Rectal Temperature (C)	37.02 9	36.72 9	36.68 9	36.69 8	36.73 8	36.79 9	36.83 9
Esophageal Temp (C)	36.67 8	36.50 8	36.51 8	36.48 6	36.62 7	36.67 8	36.69 8

Values are means and N.