THE EFFECTS OF RUNNING IN A VAPOR BARRIER SUIT ON WEIGHT LOSS AND OTHER PHYSIOLOGICAL PARAMETERS

by

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ABSTRACT

This study attempted to determine if exercising in a vapor barrier sweatsuit (VBS) caused greater weight loss than exercising in shorts. It was thought that the VBS's effect of augmenting central sweating drive via increased body temperature might be offset by its effect of increasing skin wettedness (known to decrease sweat rate). Eight subjects, four wrestlers and four distance runners, ran on a treadmill at 50% of $\dot{V}O_2$ max for 1 hour under four conditions. These were: running in shorts while normally hydrated; running in a VBS while normally hydrated; running in shorts while dehydrated (2% of body weight); and running in a VBS while dehydrated. HR, T_{re}, and RPE were recorded throughout each run. Blood was drawn before and after each run, and analyzed for minerals and Hct. A leg work capacity test was administered subsequent to each run. A two-way ANOVA was used for statistical analysis. The VBS caused significantly greater weight loss, T_{re} (only in normal hydration), HR and RPE. The leg work capacity test did not show that the VBS caused a greater fatigue. There were no significant blood findings. The VBS did cause a greater weight loss, but at a greater physiological stress which could lead to heat injuries.

CHAPTER 1

INTRODUCTION

Wrestling is a sport that matches individuals of equal weight in competition. This concept of equality, on the basis of weight, is what makes wrestling such an outstanding individual sport. The weight classification system was developed so that there were many weight classes instead of just a few; this allows more wrestlers to select their optimum weight class. Many wrestlers and coaches feel that in order to maximize relative strength a wrestler should drop two-three weight classes below his normal weight. To do this, many wrestlers use unsafe and extreme methods to lose weight (Lopez, 1980).

The weight loss problem is exemplified by the wrestler who weighs 145 pounds and wishes to compete at 126 pounds. In order to reduce to his competition weight the wrestler may lose the first ten pounds through exercise and a weight reducing diet, but quite often the last 9-10 pounds is water lost by dehydration. One common method used by wrestlers to lose this water weight is to run in a vapor barrier suit (VBS), a plastic suit which covers the entire body except the hands, feet and head. This VBS creates a micro-environment around a large part of the body, thereby increasing the temperature within this environment which promotes increased sweating. A major problem may occur after the wrestler has lost 4.7% of his body weight by sweating and may still have a pound or two to lose. At this point the wrestler is substantially dehydrated and his body is attempting to conserve its remaining water, possibly through the antidiuretic hormone (Nadel et al., 1971). The wrestler who then works out in a VBS is doing so with a lower total body water and therefore a decreased cooling capacity. This results in an increase in rectal temperature (Falls and Humphrey, 1976) and an increased chance of incurring heat stress problems under these circumstances. Besides the danger involved, there is also some doubt as to whether there actually is a greater weight loss from sweating with the VBS (Nadel et al., 1971 and 1973).

There are two reasons for the doubt about the VBS's ability to increase total weight loss through sweating. First, the VBS may cause early fatigue and therefore a reduction in duration of sweating. Secondly, the VBS causes an increase in relative humidity as well as temperature within the VBS. Increases in both temperature and humidity have opposing effects on sweat rate (Falls and Humphrey, 1976).

As the temperature within the VBS increases, the sweating will increase in order to keep the body cool, but the sweating mechanism is only effective when the sweat can evaporate. Also, as more sweat evaporates, the micro-environment within the VBS quickly becomes saturated and at this point sweat can no longer evaporate and thus, little cooling takes place. Since the sweat is not evaporating the skin becomes wet. According to Nadel and Stolwijk, 1973, as the skin wettedness increases, the sweat rate decreases; this decrement is known as hidromeiosis. This finding is also supported by the work of other studies, (Brown and Sargent, 1965; and Gonzalez et al., 1974). However, since skin wettedness and the temperature in the VBS both increase so that the net effect is questionable. In other words, does the increased temperature within the VBS influence sweat rate substantially more than the increased skin wettedness?

Two other variables are of major importance to the question of the VBS's ability to increase total weight loss through sweating; these are the level of hydration of the wrestler and the duration of the exercise. According to Nielsen et al., 1971, as hydration levels change, the related variables of temperature and relative humidity and their importance to sweat rate change, (i.e. the relative humidity may become more important in determining sweat rate as dehydration increases). The duration of the exercise also is important in its relation to the onset of hidromeiosis. It may be that during the early stages of exercise the increased temperature within the VBS is a greater determinate of sweat rate than is the relative humidity. But as the exercise continues, relative humidity may become an increasingly greater determinant of sweat rate and may eventually surpass the VBS temperature in importance. And further, it may be that this is the point when the hidromeiotic effect is observed. Because of the importance of the hidromeiotic effect in determining the VBS's effectiveness in increasing weight loss, a further discussion of the cause of hidromeiosis follows.

The cause of hidromeiosis is unknown. There are several theories as to the cause. Most of the theories implicate a peripheral rather than a central phenomenon. Randall and his associates, 1957, proposed that hidromeiosis was the result of hydration of the stratum corneum with resulting mechanical swelling of the keratin ring. Brown and

Sargent, 1965, conducted some studies to test this hypothesis. They found that when the stratum corneum was stripped, the responsiveness of sweat glands were not depressed. They added that while evidence points at mechanical blockage it does not rule out other possibilities such as a disturbance at the receptor site or at the neuroglandular junction. Kerslake, 1972, agrees with Brown and Sargent that their hypothesis could not account for such observations as the exponential decay of sweating with time.

A more logical explanation involves osmotic gradients. Peiss et al., 1970, demonstrated a hidromeiotic effect with the hand when it was placed in water or dilute saline but not so when it was placed in strong saline. Hertig et al., 1961, found a similar effect with whole body immersion in water and 15% saline. Peiss and associates, 1970, have suggested that dried skin promotes sweating because evaporation of sweat leaves the solutes behind and establishes an osmotic gradient that actively pulls sweat out of the duct. Conversely, in wet environments the sweat does not evaporate thereby not allowing osmotic gradients to be established and thus forcing the myo-epithelial cells to do all the work of sweat expulsion. This latter theory is supported by studies from Nadel and Stolwijk, 1973, and Collins and Weiner, 1962. In these studies, the effect of wiping the skin dry was investigated, and it was found that this simple procedure reversed the hidromeiotic effect, by reversing the osmotic gradients.

Falls and Humphrey, 1976, investigated the effects of a VBS on weight loss, and found that a wrestler wearing a VBS lost 30% more weight than when wearing light clothing. However, as they pointed out, the duration of their experimental condition may not have been long enough to elicit the reduction in sweat rate. In their study, the subjects did ten 3-minute exercise periods with a one minute rest between each period followed by two 10-minute sauna exposures. Also, most experiments have used a continuous exercise protocol, so that it is difficult to say what effect the rest periods had in relation to the hidromeiotic effect. Fox et al., 1963, reported a hidromeiotic effect as early as 45 minutes into the experimental condition of thermal stress. Johnson et al., 1944; MacDonald and Wyndham, 1950; and Robinson and Gerking, 1947, all reported a reduction in sweat rate beginning within one hour of exposure to thermal conditions.

According to Sargent, 1962, dehydration may accelerate the decrement in sweat rate. Because of his observation, both normally hydrated and dehydrated subjects were studied in relation to the hidromeiotic effect.

The Problem

The major purpose of this investigation was to study the effects of a VBS on the ability of normally hydrated and dehydrated subjects to lose water weight. A secondary purpose was to investigate the influence of a VBS on work capacity.

It was hypothesized that subjects, both hydrated and dehydrated, who exercise in shorts would have an equal or greater weight loss from sweating than those subjects who exercise in a VBS, and further, it was hypothesized that subjects who exercise for an hour in the VBS would have a greater reduction in leg work capacity compared to those wrestlers who exercise in shorts.

CHAPTER 2

METHODOLOGY

In order to test the hypothesis that exercising in shorts would be as effective as exercising in a vapor barrier suit (VBS) for inducing rapid weight loss in normally hydrated and dehydrated subjects, and that exercising in shorts would cause less fatigue, the following experimental design was used. Eight subjects completed four treatments; each treatment involved running on a treadmill at 50% of $\dot{V}O_2$ max for one hour in each of the following conditions:

1) normally hydrated and in shorts,
2) normally hydrated and in a VBS,
3) dehydrated by 2% of their body weight and in shorts,
4) dehydrated by 2% of their body weight and in a VBS.

The subjects were weighed on a balance, sensitive to 50 gms, before and after each treatment so that the exact weight loss could be determined. After each treatment the subjects completed a leg work capacity test which was designed to estimate the amount of muscular fatigue that was caused by the treatment. In order to determine which treatments were most stressful, three different indicators of stress were monitored and recorded throughout the treatment; these were heart rate, rectal temperature, and ratings of perceived exertion (Borg, 1970). Finally, approximately 12 ml, (two-6 ml vacutainers) of blood were taken both before and after each treatment. The blood was analyzed for four major minerals, (Na^+, Cl^-, Ca^{++}, and Mg^{++}) and hematocrit. Due to a technical error, it was not possible to obtain potassium concentrations.

Subject Characteristics

Eight subjects volunteered to participate in this study. Four subjects were members of the University of Arizona Wrestling Team and four subjects were distance runners who averaged between 40 and 80 miles per week. Their physical characteristics are summarized in Table 1. Wrestlers and runners were used because the experimental protocol was very strenuous and because both groups of athletes were thought to have well developed sweating capacities due to the nature of their training.

The wrestlers in this study were top level collegiate wrestlers from the University of Arizona Varsity Team. Previous investigations have reported similar data on wrestlers for body composition and $\dot{V}O_2$ max (see Table 2). Sinning (1974) found that the mean relative fat percentage of 37 collegiate wrestlers was 8.8. This value is very close to the value of 8.4% found in this study. The mean maximal values for $\dot{V}O_2$ obtained in other investigations were all very close to the mean value found in this study, with the exception of a study by Fahey et al., 1975. They found a mean $\dot{V}O_2$ max for two wrestlers to be 64.0 ml/kg·min. This is a higher max than is normally found in wrestlers, as judged by the three other studies.

The runners in this study represented a fairly wide range of running ability. One subject had run a marathon in two hours and 26½

Table 1. Subject Characteristics.

Subject	Age Yr	Ht cm	Wt kg	Body Fat %	LBW kg	$\dot{V}O_2$ max ml/kg·min STPD	$\dot{V}E$ BTPS l/min
Wrestlers							
1	19	176	72.8	4.5	69.6	48.3	140.3
2	20	168	66.1	7.9	66.1	57.1	158.9
3	21	178	71.8	6.6	67.1	53.7	154.6
4	21	173	79.6	14.6	67.9	55.7	162.4
$\bar{X}$	20	174	72.6	8.4	67.7	53.7	154.1
S.D.	.96	4.4	5.5	4.4	1.5	3.9	9.7
Runners							
5	24	163	65.8	10.0	58.9	56.3	123.7
6	25	175	63.9	7.4	59.2	66.5	171.4
7	25	173	67.2	10.8	59.9	54.3	135.5
8	24	186	74.1	7.9	68.2	62.7	167.3
$\bar{X}$	25	174	67.8	9.0	61.6	60.0	149.5
S.D.	.38	9.4	4.4	1.6	4.5	5.6	23.5
Combined Group							
$\bar{X}$	22	174	70.2	8.7	64.6	56.8	151.8
S.D.	2.4	6.8	5.3	3.1	4.5	5.6	16.8

Table 2. Comparison of the Physical Characteristics of the Subjects in the Present Study with those in Previous Investigations.

Investigator	N	Age Yr	Ht cm	Wt kg	Body Fat %	LBW kg	$\dot{V}O_2$ max ml/kg·min STPD	$\dot{V}E$ max l/min BTPS
Wrestlers								
Present study	4	20	173	74.0	8.4	67.7	53.7	154.1
Fahey et al. (1975)	2	26	177	81.5	9.8	73.8	64.0	164.8
Gale & Flynn (1974)	17	25	175	73.4	9.8	66.0	54.5	–
Saltin & Astrand (1967)	10	–	–	–	–	–	58.0	–
Sinning (1974)	37	20	174	74.8	8.8	67.9	–	–
Runners								
Present study	4	25	174	70.8	8.7	64.6	59.9	151.8
Farrell et al. (1979)	18	28	180	70.2	9.3	63.7	61.7	154.0
Costill et al. (1973)	16	35	174	63.1	7.9	58.0	66.6	–
Wyndham et al. (1969)		35	176	64.0	–	–	62.4	–

minutes while two other subjects had run three hour marathons. The mean relative fat percentage of 8.7 was between the 9.3% value, found in Farrell's study of 18 runners and the 7.9% value found by Costill et al., 1973, on 16 runners (see Table 2). The mean $\dot{V}O_2$ max of 59.9 ml/kg/min was the lowest of the four studies cited. However, two of the other three studies reported values in the low 60's.

Maximal Oxygen Consumption Determination

Each subject completed a minimum of two $\dot{V}O_2$ max tests on a motor driven treadmill. If the $\dot{V}O_2$ max values were not within 3 ml/kg/min of each other, a third test was conducted. The higher of the two max tests was recorded as the subject's $\dot{V}O_2$ max. The protocol for these tests was designed so that the initial speed and grade of the treadmill required an energy cost well below 50% of the subject's $\dot{V}O_2$ max, after which the grade of the treadmill was increased by 2% every minute until the subject could not continue. Fifty percent of $\dot{V}O_2$ max was determined by dividing the $\dot{V}O_2$ max value by two.

The data for determination of the $\dot{V}O_2$ max were obtained through the use of a Beckman OM-11 oxygen analyzer and a Godart Capnograph carbon dioxide analyzer. Both analyzers were calibrated with a reference gas that had been analyzed by a MicroScholander. Ventilation was measured on the expired side by a Parkinson-Cowan gas meter. A YSI Model 46 Telethermometer with a YSI thermistor was used to measure the expired gas temperature, in order to make gas volume corrections. A potentiometer mounted in the gas meter was connected to a Multi-purpose Channel of a Gilson Polygraph to get a measure of $\dot{V}E$. Minute recordings of $\dot{V}E$,

$\dot{V}O_2$, $\dot{V}CO_2$, and temperature were made throughout the test. A Daniels two-way breathing valve was used for all tests.

Body Composition Determination

Body composition was determined by assessing body density using the hydrostatic weighing method according to the procedures recommended by Behnke and Wilmore (1974). The subject was weighed underwater ten times and the heaviest weight was used as the correct underwater weight if it occurred at least three times. If not, the next heaviest weight was taken as the correct underwater weight if it occurred at least twice. Finally, if neither of the above criteria were met, the third heaviest weight was used. A Chatillon scale (9 kg capacity) was used to measure underwater weight to within ± .01 kg. Residual lung volume was determined by the nitrogen dilution technique (Wilmore, 1969). If two trials differed by more than 100 ml, a third trial was conducted and the two closest trials were averaged. The Siri (1956) equation was used to estimate the relative fat from total body density.

Measurement of Leg Work Capacity

A Cybex II isokinetic testing device (Lumex Inc., New York City) was used to determine the amount of work a subject could perform in 60 seconds. This consisted of maximal knee extensions and flexions at a speed of 180°/sec. The leg which the subject chose initially was used throughout the study. A Digital Work Integrator was used to record the Joules of work performed every 10 seconds and the total work output at the end of 60 seconds. Each subject completed a minimum of six leg work capacity tests. The first two were orientation tests and the other four were post-treatment tests.

Protocol for Determining the Effect of the Vapor Barrier Suit on Weight Loss and Leg Work Capacity

Each subject ran on a motor driven treadmill at 50% of his $\dot{V}O_2$ max for one hour under four different conditions with the treatment order randomly assigned. The four conditions consisted of: 1) running in shorts while normally hydrated; 2) running in a VBS while normally hydrated; 3) running in shorts and in a state of 2% dehydration; and finally, 4) running in a VBS and in a state of 2% dehydration. The 2% dehydration state was induced by having the subject sweat in a dry sauna and/or steam room (the temperature and relative humidity varied) until he reduced his body weight by 2%. This usually required about one hour. Heart rate, rectal temperature, and ratings of perceived exertion were recorded every five minutes during the treadmill run.

The step-by-step procedures were as follows: 1) The subject reported to the Exercise and Sports Sciences Laboratory. On the days when the subject was to undergo a dehydration treatment, the subject and the investigator went to a sauna or steam room. The subject was weighed and then sat nude in the sauna or steam room. Periodically he dried off and weighed. This procedure was continued until the subject lost 2% of his body weight. 2) The subject and the investigator then returned to the laboratory at which time 12 ml (two vacutainers with a 6 ml capacity) of blood were taken from a vein in the antecubital space of the subject (hematocrit was determined immediately after the blood was drawn). 3) The subject was weighed nude on a Hom's Triple Beam Balance to the nearest 50 grams. 4) The subject was then prepared for an exercise EKG, using a CM-5 configuration, (the exploring lead was placed on the left midaxillary line at the level of the 5th and 6th intercostal space, the ground electrode was placed on the right midaxillary line at the same level, and the indifferent electrode was placed on the manubrium). 5) A YSI Model 46 Telethermometer and a YSI rectal thermistor were used to determine rectal temperature. A small (approximately 1 cm in diameter) cork was attached to the rectal thermistor ten cm from the inserted end. The thermistor was inserted so that the cork was situated proximally adjacent to the internal anal sphincter. This was to insure a constant distance from the internal anal sphincter and to help keep the thermistor in place during the run. 6) The subject ran for an hour on a motor driven treadmill, in either shorts, or a VBS and at 50% of his $\dot{V}O_2$ max. Following the run, he immediately removed his clothing, dried off vigorously and completely with a towel, and weighed nude to determine the total weight loss. 7) The leg work capacity test was then administered and lastly, 8) twelve more ml of blood were taken from the subject. During all treatments barometric pressure, T_{db} and T_{wb} were recorded.

Calibrations of Instruments

The treadmill speedometer was calibrated before and during the three month testing period, at each of the running speeds (5, 5½, 6, 6½, 7, 7½, and 8 mph). The length of the treadmill belt was measured and it was determined how long it should take for the belt to make 30 revolutions at each of the different speeds. This was done by marking the treadmill belt and using a stopwatch to determine the amount of time it actually took the belt to make 30 revolutions. This procedure was done several times and was found to be very accurate. The variance of 1-2 tenths of a second could easily be accounted for by errors in the reaction time in turning off the stopwatch.

Prior to each leg work capacity test the Cybex II was calibrated by applying a known torque in Newton-meters to the lever arm, set at 90°, for a period of 60 seconds. The Digital Work Integrator was adjusted so it read the appropriate number of KJ ± 20, or a maximum error of 0.3%. During the 60 second leg work capacity test, the work output for each 10 second interval was recorded in order to observe where the fatigue became paramount.

The CD-4 gas meter was calibrated by pumping a known amount of air through it at flow rates of 30, 60, and 120 l/min. This involved pumping 30, 60, or 120 liters of air into a meteorological balloon with the one-liter syringe, which was then pulsed through the CD-4 at the same flow rates. A correction factor was calculated for each flow rate; however, the correction factor for the 120 l/min flow rate was used because it was between the 50% $\dot{V}_E$ and maximal $\dot{V}_E$ of the eight subjects. It was found that the CD-4 slightly overestimated the actual flow rate and so a correction factor of 0.9668 was used to compensate for this.

The rectal thermistor was calibrated by placing it in water along with two mercury thermometers. The water temperature was then increased by adding hot water to the pre-existing water. The temperature was progressively raised by one tenth of a degree centigrade from 36.0°C to 41.0°C. At every tenth of a degree, the rectal thermistor was checked against the mercury thermometers. The water was then allowed to cool from 41.0°C to 36.0°C. And again the thermistor was checked against the two thermometers every tenth of a degree centigrade and found to verify the previous values. The rectal thermistor was found to be 0.7°C below the mercury thermometers at all temperatures measured. Therefore, all of the recorded temperatures were corrected by adding 0.7°C to them.

Blood Analyses

Two 6-ml vacutainers of blood were drawn before and after each treatment. One of the vacutainers had no additives, and the other was heparinized. Hematocrit was determined immediately after each blood draw using blood taken from the non-heparinized tube. The blood was refrigerated overnight and centrifuged at 3000 rpm for ten minutes the next day. The serum from the non-heparinized blood sample was drawn off, placed in a marked vial and frozen. It was later analyzed for Na^{+}, Cl^{-}, Ca^{++}, and Mg^{++}. The Cl^{-} was analyzed by the potentiometric titration method (Schales et al., 1941). The Na^{++}, Ca^{++}, and Mg^{++} were analyzed by Atomic-Absorption Spectrophotometry as described by Paschen and Fuchs, 1971. Due to difficulties in obtaining the aldosterone assays, the heparinized vacutainer was not used.

Statistical Analysis

A two-way mixed design ANOVA was used to detect any differences that existed between exercising in the VBS and exercising in shorts and to detect any differences that existed between the wrestlers and the runners. This statistic was necessary because there were repeated measures for each subject, (i.e. each subject had a value for the shorts trial and the VBS trials). Each parameter required 2 two-way ANOVAs. One was used for the normal hydration conditions and one was used for the 2% dehydration conditions. Originally it was planned to use a three-way ANOVA so that the two hydration conditions could be compared, but in the dehydration conditions the subjects started the run with higher rectal temperatures, heart rates, and ratings of perceived exertion (see Chapter 3, Tables 4, 5, and 6). The analysis was therefore split up into 2 two-way ANOVAs.

The same statistical tests (i.e. 2 two-way ANOVAs) were used on the blood data, however the statistic was not designed to detect differences between pre and post exercise values. It was desirable to determine if there were any differences between these values so that any significant hemoconcentration that occurred would be found. It was therefore decided to do a dependent t-test on the pre and post exercise values for each of the blood parameters, under each of the four conditions.

Doing two statistical tests on the same data violates one of the assumptions that probability testing is based on (i.e. obtaining two sets of results on one set of data). This results in what is referred to as alpha slippage (Kirk, 1968). This means that if two statistical tests are applied on the same data and are found to be significant at a specific level (e.g. $p < .01$), this level is actually increased. According to Kirk, to determine the actual level of significance, the alpha level that the test is found to be significant at should be multiplied by the number of tests that are performed on the data. For example, if the alpha level is found to be .01 for one statistical test, but two tests are performed, then the actual level of significance would be .02. In the present study, two statistical tests were done on all blood data. Therefore the level of significance was multiplied by two and was reported in this study accounting for alpha slippage.

CHAPTER 3

RESULTS

This chapter presents the findings of the present investigation which involved running subjects at 50% of their $\dot{V}O_2$ max for an hour in conditions of normal hydration and two percent dehydration while wearing either shorts or a vapor barrier suit (VBS). The effects of the four treatments on the measured physiological parameters are presented in Tables 3 through 12 within this chapter.

Weight Loss

The main purpose of the vapor barrier suit (VBS) as used by wrestlers is to rapidly lose water weight. The major hypothesis in this study was that the VBS would not cause a significantly greater weight loss than wearing shorts during exercise. Refer to Table 3 for the weight loss data.

Normal Hydration

In the normal hydration state, both wrestlers and runners lost more weight while exercising in the VBS than when exercising in shorts ($p < .005$). The actual mean weight losses under normal hydration conditions were 1.12 kg with shorts and 1.53 kg with a VBS. This represents a 0.41 kg or 36.6% greater weight loss during exercise while wearing a VBS compared to exercise while wearing shorts.

Table 3. The Effects of the Four Treatments on Weight Loss (kg) during the 60 Minute Treadmill Run.

Subject	SN	VN	SD	VD
Wrestlers				
1	.90	1.15	.85	1.0
2	1.15	1.65	.70	1.55
3	1.05	1.35	1.10	1.25
4	1.05	1.35	1.20	1.40
$\bar{X}$	1.04	1.38	.96	1.30
S.D.	.10	.21	.23	.24
Runners				
5	1.68	2.16	1.39	2.30
6	.95	1.35	1.20	1.40
7	1.18	1.33	1.00	1.68
8	1.00	1.93	1.21	1.50
$\bar{X}$	1.20	1.70	1.20	1.72
S.D.	.33	.42	.16	.40
Combined Group				
$\bar{X}$	1.12	1.53*	1.08	1.51**
S.D.	.25	.35	.22	.38

SN - Running while wearing shorts and normally hydrated
VN - Running while wearing a VBS and normally hydrated
SD - Running while wearing shorts and dehydrated by 2% of body weight
VD - Running while wearing a VBS and dehydrated by 2% of body weight

* Significantly different than SN, $p < .05$
** Significantly different than SD, $p < .05$

Another interesting finding, although not statistically significant, was the greater weight loss found in runners in comparison to the wrestlers. The runners lost .16 and .32 kg more weight than did the wrestlers during the shorts and VBS treatments respectively.

Dehydration

During the dehydration trials, the weight loss was again greater with the VBS ($p < .025$). The actual mean weight losses under dehydration conditions were 1.08 kg while wearing shorts and 1.51 kg while wearing the VBS. This represented a 39.8% greater weight loss during exercise while wearing a VBS compared to exercise while wearing shorts. The actual difference was .43 kg.

It was also found that in the dehydration trials the runners lost more weight than did the wrestlers, ($p < .10$). The runners lost .24 and .42 kg more weight than did the wrestlers in the shorts and VBS trials respectively. This finding was also observed in the normal hydration trials, although the difference found was not significant. Some possible explanations for this finding are discussed in the next chapter.

Heart Rate

The importance of heart rate as an indicator of physical stress has often been illustrated by its uses in cardiac rehabilitation, research in exercise physiology, and as a measure for prescribing aerobic exercise. Heart rate and workload are known to relate to each other in a linear fashion. It is on this basis that it was used in the present investigation to determine if wearing the VBS was more strenuous than performing the same exercise in shorts. Refer to Table 4 for the

Table 4. The Effects of the Four Treatments on Heart Rate (bpm) during the 60 Minute Treadmill Run.

Subject	SN		VN		SD		VD	
	Initial	Final	Initial	Final	Initial	Final	Initial	Final
Wrestlers								
1	130	145	132	156	132	160	132	150
2	134	145	138	180	159	163	165	185
3	124	142	124	145	135	145	143	161
4	123	137	128	151	126	142	132	166
$\bar{X}$	129	142	131	158	138	158	143	166
S.D.	5	4	6	15	15	11	16	15
Runners								
5	151	142	132	168	150	165	145	177
6	115	125	128	135	126	130	119	142
7	130	132	118	128	138	135	118	149
8	119	120	118	132	110	129	128	154
$\bar{X}$	129	130	124	141	131	140	128	156
S.D.	16	10	7	18	17	17	13	15
Combined Group								
$\bar{X}$	128	136	130	149*	135	146	135	161**
S.D.	11	10	7	18	15	15	16	15

SN - Running while wearing shorts and normally hydrated
VN - Running while wearing a VBS and normally hydrated
SD - Running while wearing shorts and dehydrated by 2% of body weight
VD - Running while wearing a VBS and dehydrated by 2% of body weight

*Significantly different from SN(final), $p < .05$
**Significantly different from SD(final), $p < .05$

heart rate data. Also see Figure 1 for an illustration of the effects of the treatments on heart rate.

Normal Hydration

Under conditions of normal hydration, the VBS was found to cause a significantly higher heart rate than did the same treatment performed in shorts, ($p < .05$). The mean difference between the final heart rates in the shorts treatment and the VBS treatment was 13 bpm; the VBS caused on the average a 9.9% increase in heart rate. Because the heart rate increased one can conclude that the VBS significantly increased the strenuousness of the activity used in this case.

Another interesting finding, although probably not suprising, was the difference in the average final heart rates between runners and wrestlers. The runners had lower final mean heart rates in both the shorts and VBS treatments. Initially, (i.e. after 5 minutes into the treatments) the two groups differed by less than 3 bpm. At the end of the normal hydration treatments the wrestlers had an average final heart rate (taken during the last 5 minutes of the run) that was 15 bpm higher than that of the runners. The wrestlers' heart rates, therefore, increased 12 bpm more than the runners' heart rates did over the duration of the hour run.

Dehydration

In the dehydration treatments, the VBS was again found to cause a significantly higher heart rate than did the shorts, ($p < .025$). The mean difference between the final heart rates found in the shorts and VBS treatments was 14 bpm. This represents a 9.9% increase in heart

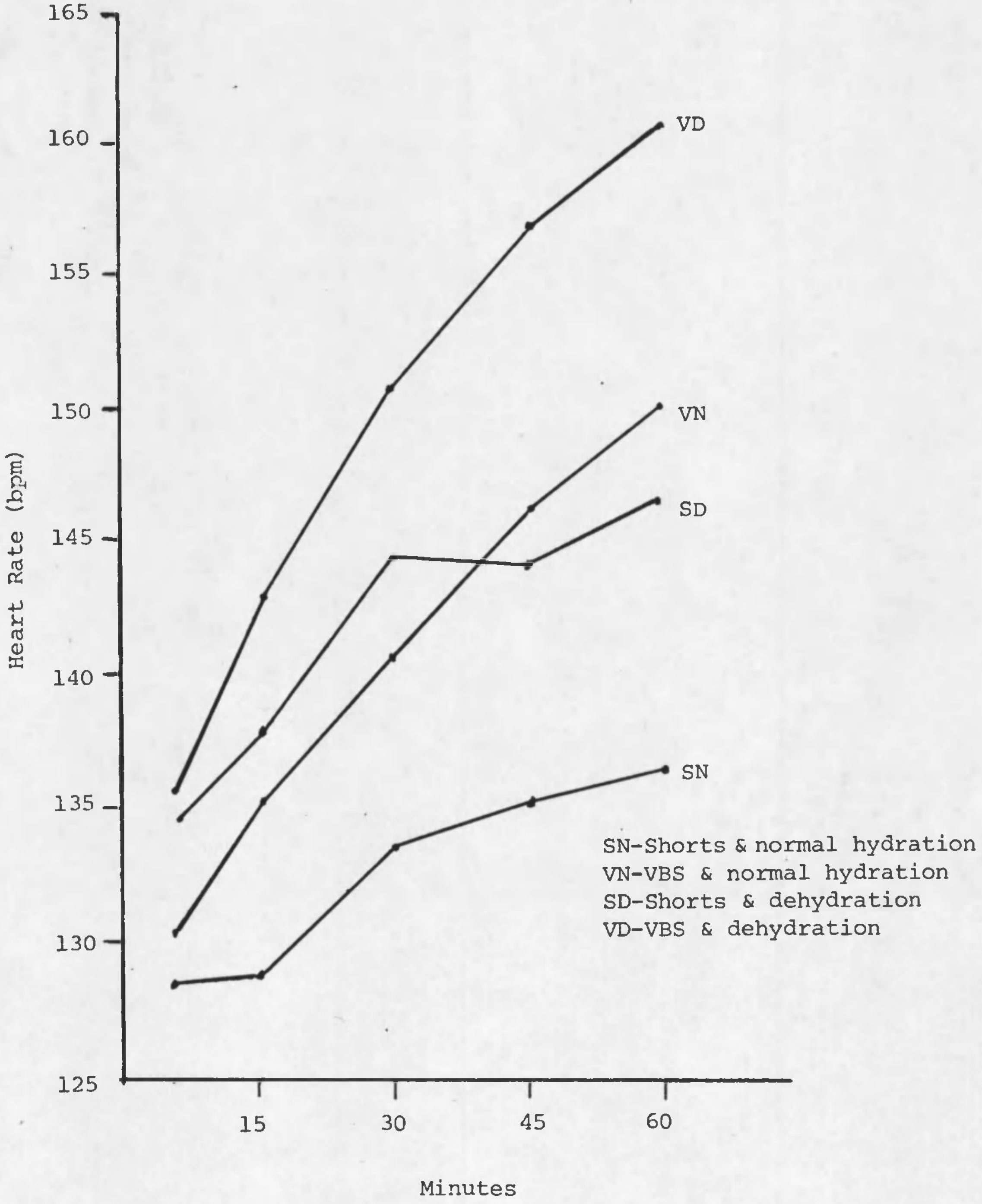

Figure 1. The Effects of the Four Treatments on Heart Rate during the 60 Minute Treadmill Run.

rate that was caused by the VBS. The VBS's effect on increasing the strenuousness of the hour run in normally hydrated conditions was also true for dehydrated conditions.

Rectal Temperature

Rectal temperature is a good indicator of how well the body is maintaining temperature homeostasis. In hot or humid environments or during a prolonged bout of exercise the rectal temperature may increase dramatically. In this study, rectal temperature was used to determine if exercising in a VBS resulted in a higher body temperature than exercising in shorts. See Figure 2 for an illustration of the effects of the four treatments on rectal temperature. Also refer to Table 5 for the data on rectal temperature.

Normal Hydration

In the normal hydration treatments, the rectal temperatures were found to be significantly higher during exercise while wearing the VBS than when wearing shorts, ($p < .05$). The final mean rectal temperatures were 38.2°C for the VBS trial and 38.2°C for the shorts trial, for a difference of .3°C.

Another very interesting and statistically significant difference found in the normal hydration trials was the higher rectal temperature in the wrestlers compared to the rectal temperature of the runners, ($p < .005$). The wrestlers had a mean rectal temperature of 38.1°C in the shorts trial compared to a mean rectal temperature of 37.9°C for the runners. This is a difference of .2°C In the VBS trial, the wrestlers had a mean rectal temperature of 38 0°C, compared to

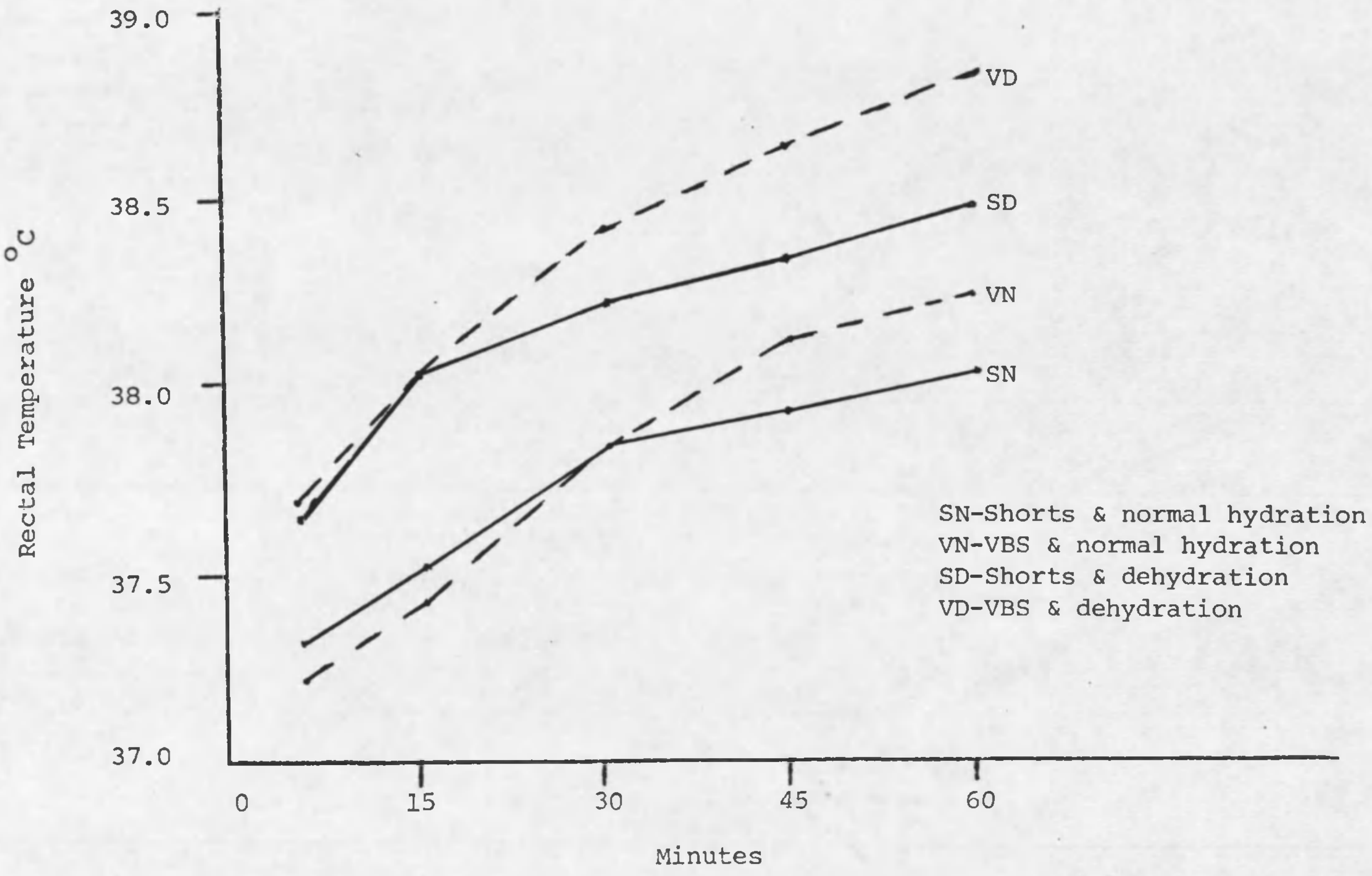

Figure 2. The Effects of the Four Treatments on Rectal Temperature during the 60 Minute Treadmill Run.

Table 5. The Effects of the Four Treatments on Rectal Temperature (^{o}C) during the 60 Minute Treadmill Run.

Subject	SN		VN		SD		VD	
	Initial	Final	Initial	Final	Initial	Final	Initial	Final
Wrestlers								
1	37.0	38.2	37.1	38.5	37.5	38.2	37.3	38.0
2	37.3	38.1	37.4	38.3	38.0	39.0	38.0	39.4
3	37.2	38.1	37.0	38.5	37.7	38.6	37.6	39.0
4	37.3	37.9	37.6	38.6	37.7	38.5	37.7	38.9
$\bar{X}$	37.2*	38.1*	37.3	38.5	37.7	38.6	37.7	38.3
S.D.	.1	.1	.3	.1	.2	.3	.3	.6
Runners								
5	37.3	37.7	37.2	38.0	37.4	38.3	37.8	38.8
6	37.1	38.0	37.0	38.0	37.5	38.6	37.7	38.3
7	37.4	38.2	37.7	37.9	37.7	38.5	37.1	38.7
8	37.1	37.5	37.2	37.9	37.6	38.0	38.1	39.3
$\bar{X}$	37.2*	37.9*	37.1	38.0	38.0	38.4	38.0	39.0
S.D.	.2	.3	.1	.1	.1	.3	.4	.4
Combined Group								
$\bar{X}$	37.2	38.0	37.3	38.2*	37.6	38.5	37.7	38.8
S.D.	.2	.3	.3	.3	.2	.3	.3	.5

SN - Running while wearing shorts and normally hydrated
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VD - Running while wearing a VBS and dehydrated by 2% of body weight

*The average of $SN_{\bar{X}}$ + $VN_{\bar{X}}$ was significantly different between the wrestlers and the runners

**Significantly different from SN(Final), $p < .05$

for the runners. The wrestlers were on the average $.5^{\circ}C$ warmer than the runners at the end of the VBS trial.

Dehydration

There were no statistically significant differences found in the rectal temperatures of the dehydration trials. However, the trends were the same as those seen in the normal hydration trials. That is, that exercise in the VBS was associated with a higher mean rectal temperature, compared to exercise in the shorts, in both wrestlers and runners. The wrestlers also had higher mean rectal temperature than did the runners. Although the trends were the same, the differences were smaller.

Ratings of Perceived Exertion

Ratings of perceived exertion (RPE) are subjective numerical ratings of how hard the subject feels he is working (see Borg Scale, in Appendix A). RPE was used in this study to detect any differences between treatments in the degree of difficulty that the subjects perceived (see Table 6 and Figure 3). The statistical results of the RPE data were identical to that which was found with heart rates.

Normal Hydration

In the normal hydration trials, the RPE was higher for the VBS treatment than it was for the shorts treatment ($p < .05$). The mean for the shorts treatment was 12.1 , which is 1.9 units below the mean of 13.9 for the VBS treatment. Descriptively the difference ranged from one unit above "Fairly Light", to one unit above "Fairly Hard".

Table 6. The Effects of the Four Treatments on Ratings of Perceived Exertion (RPE - Borg Scale) during the 60 Minute Treadmill Run.

Subject	SN		VN		SD		VD	
	Initial	Final	Initial	Final	Initial	Final	Initial	Final
Wrestlers								
1	6	6	9	9	6	6	6	6
2	6	13	7	14	7	16	7	18
3	9	15	7	15	10	16	12	18
4	7	14.5	7	19	7	15	12	19
$\bar{X}$	7.0	12.5	7.5	14.3	7.5	13.3	9.3	15.3
S.D.	1.4	4.2	1.0	4.1	1.7	4.9	3.2	6.2
Runners								
5	10	14	10	16	10	16	12	17
6	11.5	12	11.5	12.5	11	12.8	11.5	13
7	8	11	7	15	7	14	7	15
8	11	11	11	11	11	14	11	14
$\bar{X}$	10.1	12.0	9.9	12.6	9.75	14.2	10.4	14.8
S.D.	1.5	1.4	2.0	2.3	1.9	1.3	2.3	1.7
Combined Group								
$\bar{X}$	8.6	12.1	8.7	13.9*	8.6	13.7	9.8	15.0**
S.D.	2.2	2.9	1.9	3.1	2.1	3.3	2.6	4.2

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VD - Running while wearing a VBS and dehydrated by 2% of body weight

*Significantly different from SN(Post), $p < .05$
**Significantly different from SD(Post), $p < .05$

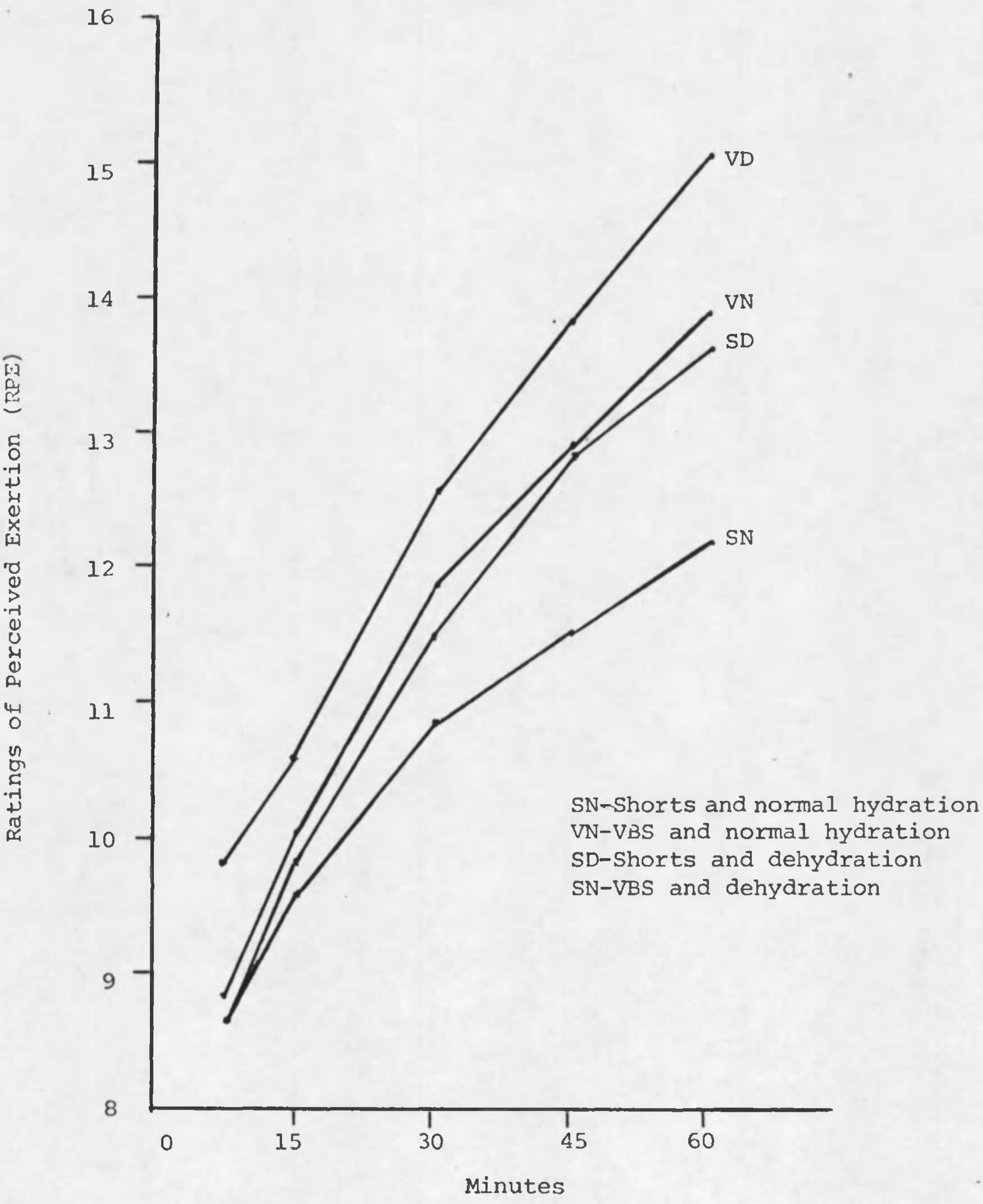

Figure 3. The Effects of the Four Treatments on RPE during the 60 Minute Treadmill Run.

The final mean RPE for the wrestlers was higher than the mean RPE for the runners. This was true for both the VBS and shorts treatments. Although the difference was larger in the VBS treatment, neither of the differences were significant.

Dehydration

As in the normal hydration treatments, the RPE was higher in the VBS treatment compared to the shorts treatment ($p < .05$). The mean RPE was 14.1 (one unit above "Somewhat Hard") in the shorts treatment and it was 15.0 (equivalent to "Hard") in the VBS treatment. The difference here was .9 units.

The runners' mean RPE was higher than the wrestlers' mean RPE in the shorts treatment. This is the only treatment of the four that the wrestlers did not rate higher than did the runners.

Leg Work Capacity Test

It was hypothesized that the leg work capacity test would show that the VBS caused a greater fatigue in the subject. Statistically, it did not. The statistical results did, however, demonstrate that the wrestlers were able to do a significantly greater amount of work than the runners were able to do, in all four conditions. Even when the total amount of work was divided by the subjects body weight to correct for the wrestlers' greater weight, the wrestlers' still did more work (see Tables 7 and 8).

Table 7. Leg Work Capacity Test (KJ/min)

Subjects	SN	VN	SD	VD
Wrestlers				
1	3660	3690	3690	3710
2	4300	4330	4030	4230
3	3260	3730	4010	3670
4	4190	4100	4390	4210
$\bar{X}$	3853	3963	4030*	3955*
S.D.	484	307	286	307
Runners				
5	3680	3180	3560	3250
6	3450	3350	3600	3350
7	2730	2180	3010	2340
8	3820	3630	3180	3670
$\bar{X}$	3420	3085	3338*	3153*
S.D.	485	631	289	570
Combined Group				
$\bar{X}$	3636	3524	3684	3554
S.D.	504	657	456	603

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SD - Running while wearing shorts and dehydrated by 2% of body weight
VD - Running while wearing a VBS and dehydrated by 2% of body weight

*The average of $SN_{\bar{X}}$ + $VN_{\bar{X}}$ was significantly different between the wrestlers and the runners.

Table 8. Leg Work Capacity Test (KJ/kg·min).

Subject	SN	VN	SD	VD
Wrestlers				
1	50.3	50.7	50.7	51.0
2	65.1	65.5	61.0	64.0
3	45.4	52.0	55.9	51.1
4	52.6	51.5	55.2	52.9
$\bar{X}$	53.3	54.9	55.7	54.8
S.D.	8.4	7.1	4.2	6.2
Runners				
5	55.9	48.3	54.1	49.4
6	54.0	52.4	56.3	52.4
7	40.6	32.4	44.8	34.8
8	51.6	49.0	42.9	49.5
$\bar{X}$	50.5	45.5	49.5	46.5
S.D.	6.8	8.9	6.7	7.9
t	.522	1.65*	1.57*	1.63*

*Significant at .10 level

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VD - Running while wearing a VBS and dehydrated by 2% of body weight

Normal Hydration

Under normal hydration conditions it was found that the wrestlers were able to produce more work, (measured in KJ/min) per minute, than were the runners ($p < .10$). This is not a surprising result since the wrestlers had a greater amount of lean body weight and did more weight training than the runners did. The means for the shorts trials were 3853 and 3420 KJ/min for the wrestlers and runners, respectively. The means for the VBS trials were 3963 KJ/min for the wrestlers and 3085 KJ/min for the runners. In the normal hydration treatments the wrestlers produced on the average, 655 KJ/min more than the runners did. This amounts to a 20% greater amount of work produced by the wrestlers.

The runners produced more work after exercise in shorts than after the exercise in a VBS which was expected. However, the wrestlers performed better after the VBS trial. This was not expected and is difficult to understand. This unusual result led to a statistically significant interaction term ($p < .05$), between type of subject (runner or wrestler) and type of clothing (shorts vs. VBS) worn during the treatments. The interpretation of this interaction effect is this: the runners performed less on the leg work capacity test after the VBS was worn during the treatment than after a treatment performed with shorts; whereas the wrestlers performed better on the leg work capacity test after the VBS treatment. This significant interaction term was found only in the normal hydration conditions.

Dehydration

It was found that the wrestlers performed better than did the runners on the leg work capacity test, in this case, under dehydration conditions ($p < .025$). The wrestlers had a mean of 4030 KJ/min after the shorts treatment while the runners had a mean of only 3340 KJ/min after the same treatment. The wrestlers also produced more work in the VBS treatment than did the runners with a mean of 3960 KJ/min compared with 3150 KJ/min. The wrestlers produced on the average, 576 KJ/min, or 8.9% more work than the runners.

The runners and wrestlers both did better after performing in shorts than they did after performing in a VBS. However, the differences between the wrestlers' means (shorts - VBS) was very small, only .074 KJ/min. This is equivalent to a 1.8% difference.

An analysis of the six 10-second segments in the leg work capacity test revealed fatigue curves that were characteristic of runners and wrestlers. This is, that endurance athletes such as runners usually have a higher resistance to fatigue and a lower capacity for large force contractions than do non-endurance athletes such as the wrestlers (see Figure 4). In the first ten seconds of the leg work capacity test, the wrestlers performed 32% more work than the runners did. However, in the last ten seconds the wrestlers performed 11% less work than the runners did (see Figure 4).

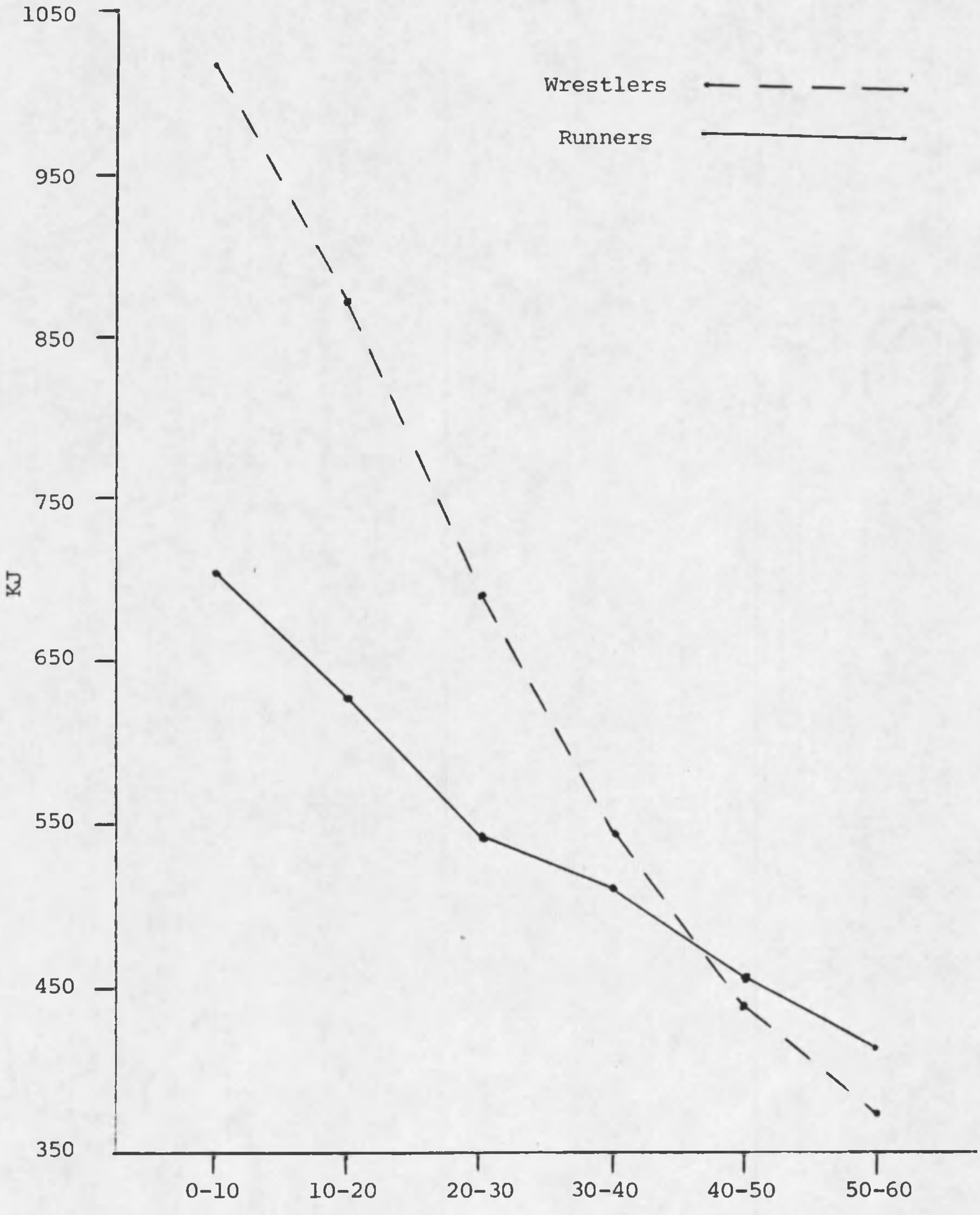

Figure 4. Sixty Second Muscular Fatigue Curve for Wrestlers and Runners.

Blood Analyses

There were no statistically significant differences found in any of the blood parameters measured. However, the statistical tests used to analyze the blood results were not designed to determine any differences in pre and post exercise values. Therefore, a dependent t-test was used in addition to the two-way ANOVA, to determine if any significant hemoconcentration resulted from the treatments.

Post exercise hematocrit and plasma sodium were both found to be significantly larger than the pre exercise values ($p < .02$, corrected for alpha slippage), in the shorts, normal hydration treatments. There was also a larger post than pre exercise hematocrit in the VBS, dehydration treatment ($p < .05$, corrected for alpha slippage). None of the other 20 t-tests were found to differ significantly, (see Tables 9, 10, 11 and 12).

Table 9. Effects of the Four Treatments on Plasma Chloride (mEq/L) during the 60 Minute Treadmill Run.

Subject		SN	Δ	VN	Δ	SD	Δ	VD	Δ
Wrestlers									
1	Pre	106.54		106.54		110.05		113.25	
	Post	104.21	-2.33	107.71	1.17	112.15	2.10	110.93	-2.32
2	Pre	105.35		107.95		107.95		109.58	
	Post	105.81	.46	104.68	-3.27	107.48	- .47	108.88	- .70
3	Pre	105.38		102.34		103.27		114.02	
	Post	103.27	-2.11	101.87	- .47	104.21	.94	108.41	-5.61
4	Pre	103.43		107.01		107.67		109.35	
	Post	106.54	3.11	110.28	3.27	109.30	1.63	108.65	- .70
$\Delta\bar{X}_W$			- .22		.18		1.05		-2.33
S.D.			2.55		2.76		1.12		2.31
Runners									
5	Pre	110.52		104.21		112.79		105.61	
	Post	112.15	1.63	110.28	6.07	110.93	-1.83	111.45	4.16
6	Pre	106.04		112.55		115.58		110.00	
	Post	108.60	2.56	111.86	- .69	117.21	1.63	108.83	-1.17
7	Pre	109.35		107.25		108.18		107.95	
	Post	109.11	- .24	107.71	.51	110.28	2.1	110.05	2.1
8	Pre	104.68		106.08		111.45		111.92	
	Post	105.38	.70	109.82	3.74	115.42	3.97	111.92	0
$\Delta\bar{X}_R$			1.16		2.41		1.47		1.27
S.D.			1.20		3.08		2.42		2.35

SN - Running while wearing shorts and normally hydrated
VN - Running while wearing a VBS and normally hydrated
SD - Running while wearing shorts and dehydrated by 2% of body weight
VD - Running while wearing a VBS and dehydrated by 2% of body weight

Table 10. The Effects of the Four Treatments on Plasma Magnesium (mEq/L) during the 60 Minute Treadmill Run.

Subject		SN	Δ	VN	Δ	SD	Δ	VD	Δ
Wrestlers									
1	Pre	124		116		106		122	
	Post	122	-2	118	2	106	0	112	-10
2	Pre	122		118		114		118	
	Post	128	6	120	2	112	-2	122	4
3	Pre	124		120		106		122	
	Post	124	0	120	0	114	8	128	6
4	Pre	122		124		132		108	
	Post	126	4	134	10	128	-4	116	8
$\Delta \bar{X}_W$			2.0		3.5		.5		2.0
S.D.			3.7		4.5		5.3		8.2
Runners									
5	Pre	118		116		122		118	
	Post	128	10	116	0	124	2	124	6
6	Pre	124		108		128		118	
	Post	130	6	114	6	134	6	120	2
7	Pre	118		122		124		120	
	Post	124	6	124	2	124	0	120	0
8	Pre	114		120		92		100	
	Post	118	4	114	-6	108	16	120	20
$\Delta \bar{X}_R$			6.5		.5		6.0		7.0
S.D.			2.5		5.0		7.1		9.0

SN - Running while wearing shorts and normally hydrated
VN - Running while wearing a VBS and normally hydrated
SD - Running while wearing shorts and dehydrated by 2% of body weight
VD - Running while wearing a VBS and dehydrated by 2% of body weight

Table 11. The Effects of the Four Treatments on Plasma Magnesium (MEq/L) during the 60 Minute Treadmill Run.

Subject		SN	Δ	VN	Δ	SD	Δ	VD	Δ
Wrestlers									
1	Pre	1.4		1.45		1.38		1.5	
	Post	1.20	-.2	1.30	-.15	1.45	.07	1.25	-.25
2	Pre	1.35		1.55		1.45		1.3	
	Post	1.45	.1	1.45	-.10	1.43	-.02	1.2	-.10
3	Pre	1.40		1.20		1.05		1.33	
	Post	1.40	.0	1.15	-.05	1.08	.03	1.30	-.03
4	Pre	1.30		1.18		1.35		1.58	
	Post	1.30	.0	1.25	.07	1.45	.10	1.45	-.13
$\Delta \bar{X}_W$			-.03		-.06		.05		-.13
S.D.			.13		.09		.05		.09
Runners									
5	Pre	1.25		1.33		1.65		1.45	
	Post	1.25	.0	1.20	-.13	1.53	.12	1.40	-.05
6	Pre	1.2		1.35		1.38		1.4	
	Post	1.2	.0	1.4	.05	1.40	.02	1.3	-.10
7	Pre	1.28		1.4		1.30		1.43	
	Post	1.23	-.05	1.35	-.05	1.08	-.22	1.43	.00
8	Pre	1.4		1.28		0.90		1.33	
	Post	1.33	-.07	1.20	-.08	1.08	.18	1.40	.07
$\Delta \bar{X}_R$			-.03		.05		.03		.02
S.D.			.04		.08		.18		.07

SN - Running while wearing shorts and normally hydrated
VN - Running while wearing a VBS and normally hydrated
SD - Running while wearing shorts and dehydrated by 2% of body weight
VS - Running while wearing a VBS and dehydrated by 2% of body weight

Table 12. The Effects of the Four Treatments on Plasma Calcium (mEq/L) during the 60 Minute Treadmill Run.

Subject		SN	Δ	VN	Δ	SD	Δ	VD	Δ
Wrestlers									
1	Pre	3.1		2.9		2.9		3.0	
	Post	2.9	-.2	2.6	-.3	3.0	.1	2.5	-.5
2	Pre	2.6		2.9		2.9		3.0	
	Post	2.8	.2	3.3	.4	2.9	0	3.1	.1
3	Pre	2.9		3.2		3.1		3.4	
	Post	3.2	.3	3.2	0	3.3	.2	3.4	0
4	Pre	2.9		3.1		2.9		3.1	
	Post	3.0	.1	3.3	.2	3.1	.2	3.5	.4
$\Delta \bar{X}_W$			.10		.08		.13		.0
S.D.			.12		.30		.10		.37
Runners									
5	Pre	2.8		2.9		3.0		3.0	
	Post	2.8	0	2.9	0	3.0	0	3.1	.1
6	Pre	2.8		2.6		3.1		2.7	
	Post	2.9	.1	2.7	.1	3.2	.1	2.6	-.1
7	Pre	2.8		2.8		2.9		3.0	
	Post	2.8	0	2.9	.1	2.4	-.5	3.0	0
8	Pre	2.9		2.6		1.9		2.7	
	Post	2.9	0	2.7	.1	2.1	.2	3.0	.3
$\Delta \bar{X}_R$			.03		.08		-.05		.08
S.D.			.05		.05		.31		.17

SN - Running while wearing shorts and normally hydrated
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SD - Running while wearing shorts and dehydrated by 2% of body weight
VN - Running while wearing a VBS and dehydrated by 2% of body weight

CHAPTER 4

DISCUSSION

The main purpose of this study was to determine whether running in a vapor barrier suit (VBS) caused greater weight loss than running in shorts. The hypothesis that the VBS would not cause a greater weight loss was based on the VBS's effect in increasing both skin wettedness and the central drive for sweating via increased skin and core temperature which have been previously shown to have opposing effects on sweat rate (Nadel and Stolwijk, 1973). A discussion of the interrelation of these two factors is important in understanding the implications of the results of this study.

The importance of skin wettedness and its effect on sweat rate is illustrated by Nadel et al., 1971, who proposed the following mathematical relationship to predict whole body sweating.

$$\dot{M}_{sw} = \phi\psi\ \{\alpha'\ (T_{es}-36.7) + \beta'\ (\bar{T}_s-34.0)\}\ e^{(\bar{T}_s-34)/10}$$

$\dot{M}_{sw}$ is sweating rate; ϕ is a function of skin wettedness; ψ is a function of state of acclimation; T_s is esophageal (core) temperature; and $\bar{T}_s$ is mean skin temperature. The summation between the brackets is representative of the central drive for sweating and the exponential is a local skin temperature effect; α' and β' are idealized proportional control constants which are not affected by skin wettedness. α' is approximately ten times that of β', which reflects the much greater influence that internal temperature has on sweat rate.

It is easy to see, by this equation, that the VBS's affect on increasing T_{es} and $\bar{T}_s$ would be expected to increase sweat rate if all other variables were held constant. However, the VBS also increases skin wettedness, ambient temperature and humidity within the VBS, and it causes a decrease in the osmolarity of the sweat on the skin because of the decreased evaporative ability.

The VBS's effect on increasing skin wettedness and its effect on sweating is not as well understood. According to Nadel et al., 1971, the ϕ values should vary inversely with the degree of skin wettedness and range from 0.2 in an extremely wet situation, like that caused by a VBS to 1.0 in a totally dry situation. However, in 1973 Nadel and Stolwijk hypothesized that ϕ was related to a <u>ratio</u> of skin wettedness to central sweating drive and, therefore, skin wettedness could increase along with an equal or greater increment in the central sweating drive and thus the value of ϕ would remain constant or decrease. This was the situation that occurred in the present study; that is, that the VBS increased skin wettedness and central sweating drive. According to Nadel's hypothesis, the central sweating drive in the present study was increased more than skin wettedness. This is evidenced by the greater weight loss which incurred under the VBS trial.

It was not possible to calculate ϕ or $\dot{M}_{sw}$ from the data collected in this study, consequently, Nadel's theory cannot be substantiated or refuted. However, it is possible to state that the mean sweat rate was higher for the VBS condition that it was for the shorts condition. Whether the VBS caused a higher mean sweat rate initially which was then decreased to, or even below the sweat rate of the run in shorts, cannot be determined from the data collected. Therefore, it cannot be discerned whether the VBS caused a significantly greater hidromeiotic effect than did the shorts. The large difference in weight loss may indicate that the sweat rate was higher throughout the VBS run, and no significant hidromeiosis took place.

The effects of dehydration on the sweat rate variables presented in the prediction equation proposed by Nadel are not known (this equation was derived from experiments on normally hydrated subjects). Understanding the relationship between hydration and sweat rate is important in determining the effectiveness of the VBS in inducing quick weight loss via increased sweating. Evidence indicates that changes in the level of hydration do affect the internal temperature to sweating rate relationship (Nielsen et al, 1971). The results of the present study serve to further substantiate this change in internal temperature to sweating relationship. The 2% dehydration trials results in almost identical weight losses as the normal hydration trials, in spite of the higher rectal temperatures at the start of the run ($\bar{X}$ = .48°C higher) and at the finish ($\bar{X}$ = .50°C higher) (see Table 5).

In light of the above information it might seem that increased levels of dehydration would reduce the effectiveness of the VBS in causing increased sweat rate via increased body temperatures. This might be theorized because of the decreased importance of internal temperature in stimulating sweating. The present investigation did not substantiate this theory. Inspection of Table 3 shows that as much weight loss difference resulted between the VBS and shorts in the dehydration trials as it did in the normal hydration trials. A possible explanation for this is the greater increases in rectal temperature caused by the VBS under the dehydration trials. Table 3 shows that the VBS caused an increase in rectal temperature of .34°C over the shorts trials, in the dehydration condition. This is in comparison to a .25°C increase in the VBS trial over the shorts trial in the normal hydration condition.

Although this study did not show a reduced effectiveness of the VBS in causing greater weight loss with dehydration, more research needs to be done in this area. Investigating the VBS's effect at two or three levels of dehydration in addition to normal hydration would be a more definitive study.

It seems clear that the VBS causes a greater weight loss than shorts does, with continuous exercise under normal and 2% dehydration conditions. Falls and Humphrey, 1976, found the same results with a non-continuous exercise protocol followed by two sauna exposures. However, both the present study and the study by Falls and Humphrey found that the VBS also caused higher heart rates and rectal temperatures. These findings indicate that the greater weight loss is at a greater physiological expense and at a greater risk of heat stress or heat stroke, because of the increased rectal temperatures under hydrated conditions.

A comparison of the physiological responses to exercise of the wrestlers and runners revealed some interesting results. The results exemplify the "specificity of training" principle. The runners averaged between 40 and 80 miles per week and the wrestlers lifted weights several hours each week along with their wrestling practice. It is not surprising then, that the runners were able to endure the prolonged running better than the wrestlers did, and that the wrestlers did better in the subsequent leg work capacity test.

A study by Nadel et al., 1974, suggests why the runners experienced greater weight loss and a lower body temperature (rectal temperature). The runners were probably more acclimated than the wrestlers because they trained in the hot, dry environment of Arizona, whereas the wrestlers trained indoors in an ambient temperature that was much less than that of the runners', and without direct sunlight. Data by Nadel et al., 1974, showed that endurance training and/or acclimation resulted in an increased sweating rate at the same set of body temperatures.

Nadel and his colleagues explained the differing effects that training and acclimation had on sweat rate. According to their study, training increased the responsiveness of the sweating mechanism for the same internal temperature increase. Acclimation resulted in a "significant decrease in the sweating threshold. The increased sweating responsiveness is usually attributed to peripheral modifications at the level of the sweat gland, whereas the lowered sweating threshold is generally thought of as a modification that is central in origin. Although the precise mechanisms are not known, it is clear that both training and acclimation aid in maintaining a lowered body core temperature at a given exercise intensity (Nadel et al., 1974). Thus, the runners' lowered body temperature (significant only in the normal hydration trials, ($p < .005$) is explained as well as the greater weight loss (significant only in the dehydration trials, $p < .10$).

The only other significant difference between the wrestlers and the runners was in the leg work capacity test. The wrestlers were able to produce a significantly greater amount of work than the runners were (normal hydration trial, $p < .05$; dehydration trial, $p < .025$). This is not surprising since the training for wrestlers involves weight lifting, and wrestling itself contains many short powerful bursts of energy. This type of training is known to preferentially recruit fast twitch fibers (Gollnick et al., 1973). Fast twitch fibers are characterized by the capacity for a large force of contraction and high fatigueability (Fox, 1979). This profile of a fast twitch muscle is exemplified by the wrestlers in the present study. Figure 4 shows that wrestlers' ability to produce a great amount of force per contraction in the early part of the one minute muscular strength test, but that this ability lessens quickly and in the last 20 seconds the wrestlers actually produced less work than the runners.

The runners displayed a muscular fatigue curve that was characteristic of endurance athletes. Costill and his co-workers (1973) showed that endurance events preferentially recruit slow twitch fibers which fatigue slowly and have a small force of contraction capacity. The runners demonstrated these characteristics by producing 32% less work than the wrestlers did in the first ten seconds, but actually performing 11% more work in the last 10 seconds.

The runners also had a lower final heart rate than the wrestlers did by an average of 13.1 bpm. Although this difference was not significant, it is important. According to research done by Beyegard and Shepard, 1967, the cardiac output is the same at a given oxygen uptake in trained and untrained males. The runners had a higher oxygen uptake during the hour run, since 50% of their $\dot{V}O_2$ max was higher, and therefore they had a higher cardiac output than the wrestlers. With a higher cardiac output and a lower heart rate, the runners must have had a higher stroke volume. Clausen, 1976 and Saltin et al., 1968, have found that an increased stroke volume at submaximal levels of exercise is a result of endurance training. Findings by Zeldis et al., 1978, and Morganoth et al., 1975, of an increased left ventricular cavity in endurance athletes, would explain the mechanism of an increased stroke volume and therefore a decreased heart rate. They also found that there was no increase in the left ventricular cavity of non-endurance athletes, like wrestling, but that instead there was an increase in the left ventricle wall thickness. The lower heart rate may also suggest an enhanced oxygen extraction by the working muscles.

Blood Analyses

There were no statistical differences found in any of the blood parameters measured. Actually this should not be too surprising since all four treatments would be expected to cause similar changes in hematocrit, sodium, chloride, magnesium, and calcium (i.e. increased mEq/l in plasma ions and Hct.) due to plasma volume decreases with exercise dehydration, (Costill and Fink, 1974) and because sweat is hypotonic to other body fluids, (Kozlowski and Saltin, 1964).

The two-way ANOVA was used to detect any difference between the VBS and the shorts, and between the wrestlers and runners. This statistical test was not designed to detect differences between pre and post exercise values. Therefore, a simple dependent t-test was used to detect these differences. The problem of doing two statistical tests on the same data was discussed in Chapter 2.

There were only three significant differences found by the t-test, (20 tests were performed). Pre and post exercise hematocrit and plasma sodium were both found to be significantly different ($p < .02$, after correction for alpha slippage), in the shorts treatment with normal hydration treatments. A difference in pre and post exercise hematocrit in the VBS, dehydration treatment was also found to be significant ($p < .05$, after correction for alpha slippage). It was expected that more of the tests would have had significant pre and post differences. This would have indicated a greater degree of hemoconcentration. Probably the main reason for the low number of significant test differences was measurement error.

The analysis for these three plasma ions were done by flame spectrophotometry. One mixture was made up for the analysis of all three. If the standards were off or if one of the ingredients was contaminated, it might explain why the values for all three were off in the same direction. The values for plasma sodium, calcium, and magnesium were all too low as compared to the values found in the literature, (Costill and Fink, 1974; Kozlowski and Saltin, 1964; and Van Beaumont et al., 1973). Their values ranged from: 140-151 mEq/l for plasma sodium, compared to the values in this study of 92-134 mEq/l;

4.5-5.5 mEq/l for plasma calcium compared to the present study's of 1.9-3.45 mEq/l; and 1.5-3.0 mEq/l for plasma magnesium, compared to .9-1.65 mEq/l for the present study.

The values for plasma chloride were determined by potentiometric titration and were very similar to those found in the literature previously mentioned. Although the values for plasma chloride appeared to be valid, there were no significant differences found by any of the statistical tests used. The values for hematocrit also seems valid, (as judged by the same studies cited previously) with a range of 40-50% packed cell volume to total volume, (uncorrected for trapped plasma). Two of the four dependent t-tests on hematocrit were significant. One of the significant tests was under normal hydration conditions and one was under 2% dehydration conditions.

CHAPTER 5

SUMMARY

Eight subjects, four varsity wrestlers and four long distance runners, were studied in an attempt to determine the effects of a vapor barrier suit (VBS) on weight loss and other physiological parameters. Each subject ran on a motor driven treadmill at 50% of $\dot{V}O_2$ max for one hour under four different conditions. These conditions included running in a VBS while normally hydrated, running in shorts while dehydrated, and running in a VBS while dehydrated. Heart rate, rectal temperature and ratings of perceived exertion were recorded every five minutes throughout each run. Weight loss was determined by weighing the subject prior to and after each treatment. Blood was drawn before and after each run and was analyzed for hematocrit, sodium, chloride, magnesium and calcium. A leg work capacity test was administered subsequent to each treatment.

Contrary to what had been hypothesized, the VBS was associated with a significantly greater weight loss and no significant decrement in leg work capacity. However, the VBS did cause significantly higher heart rates, rectal temperatures (significant difference only between the normal hydration runs) and ratings of perceived exertion. These results point out that the greater weight loss incurred while running in a VBS is accompanied by a greater physiological stress.

Another important finding of this study was that the VBS was as effective in causing a greater weight loss in dehydrated subjects as it was in normally hydrated subjects. Under conditions of normal hydration, exercising in a VBS caused a .41 kg greater weight loss than exercising in shorts. When the subjects were dehydrated this difference was .43 kg. These almost identical weight loss differences indicate that there is not a trend with increasing levels of dehydration for the VBS to become less effective in causing rapid weight loss. However, to substantiate this finding more studies involving exercise in a VBS with greater levels of dehydration need to be conducted. We do know that exercising in a VBS causes greater physiological stress and that in dehydrated subjects this increased physiological stress could become dangerous.

The runners in this study elicited lower rectal temperatures (significant only in the normal hydration conditions), higher weight losses (significant only in the dehydration conditions) and produced significantly lower amounts of work on the leg-work capacity test than did the wrestlers. The runners also had lower heart rates and ratings of perceived exertion however, these differences were not significant. These differences probably indicate that the endurance trained or the more aerobically fit individual is better prepared to handle the additional stress of the VBS.

The blood analysis revealed very little. Because of experimenter error, the values for plasma sodium, magnesium and calcium were questionable. There were no statistically significant differences found in the plasma chloride values. The only statistically significant differences found in hematocrit analyses were in the pre and post treatment values. Even here the results were equivocal with two of the four t-tests revealing insignificant differences.

The results of this study suggest that the VBS causes a greater weight loss and a greater physiological stress in normally hydrated and dehydrated subjects. Furthermore, the VBS is as effective in inducing rapid weight loss in dehydrated subjects as it is in normally hydrated subjects, and finally that higher fit individuals are better equipped to handle the stress imposed by the VBS and dehydration conditions. These findings indicate that extreme caution should be used when exercising in a VBS. Also, that in low fit individuals or in conditions of dehydration the VBS may be contraindicated because of the possibility of sustaining heat injuries.

APPENDIX A

BORG SCALE

Perceived Exertion Scale

6	
7	Very, Very Light
8	
9	Very Light
10	
11	Fairly Light
12	
13	Somewhat Hard
14	
15	Hard
16	
17	Very Hard
18	
19	Very, Very Hard
20	

LIST OF REFERENCES

Behnke, A.R. and J.H. Wilmore. Evaluation and Regulation of Body Build and Composition. Englewood Cliffs, N.J.: Prentice-Hall, Inc., 1974.

Bevegård, B.S. and J.T. Shepard. Regulation of the circulation during exercise in man. Physiol. Rev. 47:178, 1967.

Borg, G.A.V. Perceived exertion as an indicator of somatic stress. Scand. J. Rehab. Med., 2:92-98, 1970.

Brown, W.K. and F. Sargent. Hidromeiosis. Arch. Envir. Health, 11: 442-452, 1965.

Clausen, J.P. Adjustments to dynamic exercise and effect of physical training in normal subjects and in patients with coronary disease. Progr. Cardiovasc. Dis. 18:459, 1976.

Collins, K.J. and J.J. Weiner. Observation on arm-bag suppression of sweating and its relationship to thermal sweat gland "fatigue". J. Physiol. (London). 161:538-556, 1962.

Costill, D.L. and W.J. Fink. Plasma volume changes following exercise and thermal dehydration. J. Appl. Physiol. 37(4):521-525, 1974.

Costill, D.L, P.D. Gollnick, E.D. Jansson, B. Saltin, and E.M. Stein. Glycogen depletion pattern in human muscle fibres during distance running. Acta Physiol. Scand. 89:374-383, 1973.

Fahey, T.D., L. Akka, and R. Ralph. Body composition and $\dot{V}O_2$ max of exceptional weight-trained athletes. J. Appl. Physiol. 39: 559-561, 1975.

Falls, H.B. and L.D. Humphrey. The effect of impermeable clothing on weight loss, heart rate, and core temperature in wrestlers. Res. Quart. 47:630-637, 1976.

Farrell, P.A., J.H. Wilmore, E.F. Coyle, J.E. Billing, and D.L. Costill. Plasma lactate accumulation and distance running performance. Med. Sci. Sports. 11:338-344, 1979.

Fox, E.L., Sports Physiology. Philadelphia, N.J.: W.B. Saunders Co., 1979.

Fox, R.H., R. Goldsmith, D.J. Kidd, and H.E. Lewis. Acclimatization to heat in man by controlled elevation of body temperature. J. Physiol. (London). 166:530-547, 1963.

Gale, J.B. and K.W. Flynn. Maximal oxygen consumption and relative body fat of high-ability wrestlers. Med. Sci. Sports. 6:232-234, 1974.

Gollnick, P.D., R.B. Armstrong, W.L. Sembrowich, R.E. Shephard, and B. Saltin. Glycogen depletion pattern in human skeletal muscle fibers after heavy exercise. J. Appl. Physiol. 34:615-618, 1973.

Gonzalez, R.R., K.B. Pendolf, and A.P. Gagge. Heat acclimation and decline in sweating during humidity transients. J. Appl. Phys. 36(4):419-425, 1974.

Hertig, B.A., M.L. Riedesel, and H.S. Belding. Sweating in hot baths. J. Appl. Physiol. 16:647-651, 1961.

Johnson, R.E., G.C. Pitts, and F.C. Consolazio. Factors influencing chloride concentration in human sweat. Am. J. Physiol. 141:575-589, 1944.

Kerslake, D.M. The Stress of Hot Environments. Cambridge: Univ. Press, 1972.

Kirk, R.E. Experimental Design: Procedures for the Behavioral Sciences. Belmont, Calif: Brooks and Cole Co., 1968.

Kozlowski, S. and B. Saltin. Effect of sweat loss on body fluids. J. Appl. Physiol. 19:1119-1124, 1964.

Lopez, R. Weight loss and diet in wrestling. Phys. Ed. 37:131-139, 1980.

MacDonald, D.K.C. and C.H. Wyndham. Heat transfer in man. J. Appl. Physiol. 3:342-364, 1950.

Morganoth, J., B. Maron, W. Henry, and S. Epstein. Comparative left ventricular dimension in trained athletes. Am. Intern. Med., 82:521-524, 1975.

Nadel, E.R., J.W. Mitchell, and J.A.J. Stolwijk. Control of local and total sweating during exercise transients. Int. J. Biometer. 15(2-4):201-206, 1971.

Nadel, E.R., K.B. Pandolf, M.F. Roberts, and J.A.J. Stolwijk. Mechanisms of thermal acclimation to exercise and heat. J. Appl. Phys. 37(4):515-519, 1974.

Nadel, E.R. and J.A.J. Stolwijk. Effect of skin wettedness on sweat gland response. J. Appl. Physiol. 53:689-694, 1973.

Nielsen, B., G. Hansen, S.O. Jorgensen, and E. Nielsen. Thermoregulation in exercising man during dehydration and hyperhydration with water and saline. Int. J. Biometer. 15:195-200, 1971.

Paschen, K. and C. Fuchs. A new micro-method for Na, K, Ca, and Mg determinations in a single serum dilution by atomic-absorption spectrophotometry. Clin. Chem. Acta., 35:401-408, 1971.

Peiss, C.N., W.C. Randall, and A.B. Hertzman. Hydration of the skin and sweating during thermal transients caused by exercise. J. Appl. Physiol. 28:318-327, 1970.

Randall, W.C. and C.N. Peiss. The relationship between skin hydration and the suppression of sweating. J. Invest. Durm. 28:435-441, 1957.

Robinson, S. and S.D. Gerking. Thermal balance of men working in severe heat. Am. J. Physiol. 149-476-488, 1947.

Saltin, B. and P.O. Åstrand. Maximal oxygen uptake in athletes. J. Appl. Physiol. 23:353-358, 1967.

Saltin, B., B. Blomquist, J.H. Mitchell, R.L. Johnson, Jr., K. Wildenthol, and C.B. Chapman. Response to submaximal and maximal exercise after bed rest and training. Circulation, 38(Suppl. 7), 1968.

Sargent, F. Depression of sweating in man: so-called sweat gland fatigue. In Advances in Biology of Skin. Monatagsa, W., R.A. Ellis, and A.F. Silver, Eds. New York: Pergamon, Vol. 3: pp. 163-212, 1962.

Schales, O. and S.S. Schales. A simple and accurate method for the determination of chloride in biological fluids. J. Biol. Chem. 140:879-883, 1941.

Scholander, P.F. Analyser for accurate estimation of respiratory gases in one-half cubic centimeter samples. J. Biol. Chem. 167: 235-250, 1947.

Sinning, W.E. Body composition assessment of college wrestlers. Med. Sci. Sports, 6:139-145, 1974.

Siri, W.F. Body composition from fluid spaces and density. University of California, Donner Laboratory of Medical Physics Report, March 19, 1956.

Van Beaumont, W., J.C. Strand, J.S. Petrofsky, S.G. Hipskind, and J.E. Greenleaf. Changes in total plasma content of electrolytes and proteins with maximal exercise. J. Appl. Physiol. 34:102-106, 1973.

Wilmore, J.H. A simplified method for the determination of residual lung volume. J. Appl. Physiol. 27:96-100, 1969.

Wyndham, C.H., N.B. Strydom, A.Y. Van Rensburg, and A.J.S. Benade. Physiological requirements for world-class performances in endurance running. S. Afr. Med. J. 43:996-1002, 1969.

Zeldis, S.M., J. Morganroth, and S. Ruben. Cardiac hypertrophy in response to dynamic conditioning in female athletes. J. Appl. Physiol. 44(6):849-852, 1978.