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THE EFFECTS OF ACUTE DEHYDRATION ON THE ENDURANCE OF COLLEGE WRESTLERS

DISSERTATION

Presented in Partial Fulfillment of the Requirements for the Degree Doctor of Philosophy in the Graduate School of the Ohio State University

by

William Albert Floyd, B.Sc., M.A.

The Ohio State University
1968

Approved by

[Signature]
Adviser, Department of Physical Education
To Patty and Amy
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CHAPTER I
INTRODUCTION

Since 1940, the popularity of interscholastic and intercollegiate wrestling has increased at an extremely rapid rate throughout the United States. In the state of Ohio, wrestling has produced the greatest growth percentage of all sports in that over five times as many high schools are wrestling today as were engaged in the sport in 1956-57. The growth has been consistent with between thirty and forty schools adding the sport to their program annually (51). Along with such an increase the quality of performance has also improved so that competition is of high quality and winning is becoming increasingly difficult. To keep pace with the foregoing advances, some coaches and participants have manipulated weight control as a device for securing an advantage over opponents.

Wrestling is somewhat unique in that competition is based on the premise that contestants are evenly matched if their weights are relatively the same. As a result, competition is divided into nine weight classifications in college ranging from 123 lbs. to unlimited, and ten weight classifications in high school ranging from 103 lbs. to
unlimited (44). Many coaches feel that for the following reasons, it is desirable for contestants to lose weight to compete in as low a weight class as possible:

a. To balance the squad's representation in all weight classes.
b. To gain an advantage by wrestling an opponent lighter than oneself.
c. Because everyone does it, therefore, "we have to."
d. Because it really doesn't hurt anyone.

The major problems stem from the fact that the weight losing programs of most contestants are not programs that concentrate on losing body fat over an extended period of time, but which require weight loss by crash diets and/or by "drying out" (dehydration). Contestants may dehydrate to the extent of 15% of body weight depending on the circumstances involved. Dehydration is accomplished by means of strenuous workouts in hot practice rooms while wearing heavy clothing or a rubberized sweat suit specifically designed and manufactured for such purpose, or by the use of sweat boxes, steam baths, complete restriction of fluid intake, and a host of other means invented by each individual wrestler. Then after weighing in, contestants attempt to replace as much body water as possible before competition. In interscholastic wrestling, an hour to an
hour and a half usually elapses between weigh-in time and actual competition. In intercollegiate competition as many as five hours may elapse.

It is the practice of crash dieting and dehydration which has brought criticism from concerned outside groups. Parents, fans, The American Medical Association, and even some contestants and coaches have expressed disapproval. The National Collegiate Athletic Association (the ultimate policy and rule formulating body of amateur wrestling in the United States) has long recognized that the problem exists and a few years ago established rules for interscholastic competition that prohibit the use of any artificial device such as a sweat box or steam bath for losing weight. The NCAA has also recommended that individual high school associations formulate a weight control program which will make every attempt possible to control these unethical practices by member schools. Most states have complied with the recommendation.

The American Medical Association has had great influence in this matter by publishing warnings against such practices and pointing out the possible harmful effects.

Any form of dehydration is self-defeating to a wrestler. Even with a minimal dehydration (eg. sudden loss of 3% body weight), performance can be impaired. The impairment may not be
significant, especially in a brief match, but the effect on the aspiring wrestler's performance potential should concern him. Under tournament conditions, where energy reserves become more significant, premature fatigue from any cause sacrifices the wrestler's acquired talents when they count most.

It is sufficient to attack indiscriminate weight control plans solely on performance impairment hazards, for, if this physiological threat is appreciated, clinically hazardous extremes will not be approached (37).

In general, information describing the effects of exercise on body fluids is meager and only a partial foundation has been built. What remains unknown presents a challenge and opportunity to many specialties in physiological and medical research (17,35).

The sport of wrestling is in dire need of the answers to some pertinent questions. What are the hazards of indiscriminate and excess weight loss? How much can a wrestler lose safely and what are defensible means of losing it? What effect does dehydration followed by rehydration have on the physiological factors that hinder performance and place one's health in jeopardy?

Statement of the Problem

It is the purpose of this study to determine the effects of acute dehydration weight loss on the endurance of collegiate wrestlers. More specifically
the study will attempt to:

1. Determine the effects of dehydration of about 6% body weight on the following physiological variables:
   a. Heart rate
   b. Core temperature
   c. Excess CO₂
   d. O₂ uptake
   e. Exercise weight loss

2. Determine the effects of dehydration of about 6% body weight followed by a rehydration period of one hour on the following physiological factors:
   a. Heart rate
   b. Core temperature
   c. Excess CO₂
   d. O₂ uptake
   e. Exercise weight loss

Significance of the Study

While dehydration plays an important role in the weight classification and physiological functioning during performance of a wrestler, athletes in general should be concerned with the problems of dehydration as related to performance over an extended period of time. A football player may lose up to 6% of his body weight during a
practice session or game on a warm or humid day. Tennis players, bicyclists, and marathon runners are other examples of athletes whose performance may be affected by dehydration (12).

To date, little has been done regarding weight loss due exclusively to dehydration and its effect upon performance, yet this method of weight reduction is universal among wrestlers. Primarily this study is an attempt to gain an understanding of the effects of dehydration weight loss among wrestlers and may therefore contribute toward:

a. Aiding coaches and officials in devising effective criteria for weight control measures.

b. Elevating the dignity of the sport by providing a scientific basis for noting which criticisms leveled at the sport are justifiable.

c. Appealing to coaches and participants on the basis of physiological impairment of performance so that the more serious clinical health hazards resulting from such practices may not be reached.
d. Improving the performance of athletes in general who by the nature of the sport are subjected to prolonged periods of exertion under warm or humid conditions.

**Definition of Terms**

1. **Acute dehydration weight loss** refers to a rapid reduction in weight over a 48 hour period brought about by forced sweating under heavy exercise and a restricted water intake.

2. **Rehydration** refers to the replacing of a percentage of body water lost due to acute dehydration weight loss.

3. **Endurance** is the amount of time it takes to produce a heart rate of 180/minute since at this point the R.Q. exceeds 1, pulse pressure and oxygen pulse are at a maximum, respiratory frequency and minute volume increase along with a drop in alveolar CO₂ tension and blood lactate levels begin to rise sharply.
CHAPTER II
RELATED LITERATURE

Primarily there are two main areas of scientific investigation which are pertinent to this study. One deals with the effects of weight reduction by semi-starvation coupled with dehydration on various selected physiological responses of wrestlers. The other is more concerned with the effects of weight loss purely by dehydration on athletes in general. For the sake of clarity each will be considered separately.

The Effects of Weight Reduction by Semi-Starvation Coupled with Dehydration

In March, 1940, Gillum prepared a questionnaire which he administered to 35 "big ten" wrestlers and all "big ten" wrestling coaches at the Western Conference Tournament held at Purdue University. Each wrestler and coach was asked about making weight, methods used, their feelings on weight reduction and its effects on muscular strength, and staleness. It was discovered that 60% of the wrestlers resorted to unpleasant and often harmful methods of weight reduction. Over 70% claim weight reduction does not effect strength and over 71% did not want to "make weight" and would not if others would refrain from doing so. Many coaches agreed that weight reduction effects strength and if continued week after week predisposes to
staleness. The majority of coaches favor control of weight reduction if everyone would abide by it.

As a supplement, muscular strength of 20 varsity wrestlers was tested on Friday after "making weight" and again on Monday when each was back to normal by use of Rogers Physical Fitness Index. Freshmen not "making weight" served as controls. In each case except one every athlete had a higher average score on Friday than Monday. Therefore, Gillum concluded an individual is stronger physically when below his normal wrestling season weight than at his normal wrestling season weight. The freshman wrestlers showed very little difference in P. F. I. scores (29).

The effect of losing weight by withholding food and dehydration on the responses of five wrestlers was studied by Tuttle in 1943. Eighteen responses involving four main areas (a) Neuro-muscular, (b) Cardio-vascular, (c) Respiratory and (d) Oxygen requirements were measured. The range of weight loss was 3.6% to 4.9% of body weight. Comparison of the data collected after weight loss with those before justifies the conclusion that the weight loss experienced within the limits of this study had no detrimental effect on the physiological responses investigated except that there was a slight increase in heart rate and
a slight decrease in vital capacity. Therefore, it was concluded that a wrestler may safely lose up to 5% body weight without suffering any deleterious effects (52).

The following year, Doscher expressed similar findings with a questionnaire which he sent to college wrestling and boxing coaches throughout the United States. Thirty-two replies were received from all sections of the country. Fifteen coaches expressed the opinion that weight reduction does not adversely affect performance. Fifteen expressed the opinion weight reduction does adversely affect performance. Two coaches were undecided. Of the fifteen who felt performance is adversely effected there was disagreement as to what percent of body weight loss is detrimental. Two even stated the harm was not apparent until 10% of body weight loss was reached. With respect to exactly what elements of the sport are effected there was great disagreement.

Doscher also undertook a short investigation to determine the effect of a brief period of dehydration and reduction of food intake on body weight and certain motor capacity tests. Fifty students were chosen as the experimental group and sixty as control. All were freshmen and sophomores. Each was given a test in pull-ups, dips, standing broad jump, and squat thrusts for one minute. The
The experimental group was then given a restricted diet and water intake for 2½ days. The controls ate and drank normally. The mean body weight lost for the experimental group was 2.4 lbs. The mean weight for the control gained 1 lb. The tests were again administered and no statistical differences were found. Therefore, Doscher expressed an agreement with Tuttle and concluded a certain percentage of body weight may be rapidly lost without affecting performance in physical activity (24). The percentage of rapid weight loss needed to adversely affect performance was not mentioned.

Over a seven day period three college wrestlers lost 5.65%, 6.44% and 7.02% respectively of body weight by semi-starvation and dehydration in an experiment conducted by Edwards in 1951. A fourth subject was used as a control. Measurements were taken in strength by use of push-ups, pull-ups and hand dynamometer, endurance as measured by exhaustion runs on a treadmill, blood pressure, blood lactate, and basal metabolism. Recordings were made at (a) the beginning of weight loss (b) the end of the fourth day and (c) the end of the seventh day. Measurements of blood pressure, blood lactate, and basal metabolism were inconclusive and could not be properly interpreted. Therefore, no general statement could be made either for or against the use of semi-starvation
and dehydration as a means of losing weight to enable an individual to wrestle in a lower weight. However, Edward's study is pertinent in that endurance was effected by severe semi-starvation and dehydration being decreased an average of 30% as measured by the exhaustion runs on the treadmill. The fourth subject (control) actually increased his time after 7 days. Strength was again found to be unaffected (25).

Shortly after, however, Byron conducted a study contradictory to Edward's findings with reference to endurance. The purpose of the study was to determine the effects of weight reduction on strength and muscular endurance of a group of 7 wrestlers. An adaptation of the Carlson Fatigue Test was used to measure cardio-respiratory endurance. Muscular endurance was determined by the ability to repeatedly flex a body segment against resistance. By restriction of water and food intake the group lost a mean weight of 5%, the upper limit of weight loss being 11.04%. Measurements taken before and after dehydration revealed no significant differences. Byron concluded a weight loss of 5% had no detrimental effect on strength, muscular or cardio-respiratory endurance (19).

Schuster, in 1954, also verified the findings of Byron in a study to ascertain the effects of rapid weight
loss on endurance and performance of wrestlers. Twenty subjects were divided into two groups of ten each. Both groups were subjected to push-ups, squat thrusts, miles ridden on a bicycle ergometer, points scored in actual competition, and evaluation of performance by a jury of experts. The ten subjects in the experimental group were then asked to lose 10 pounds per man in seven days by restriction of food and water intake and exercise. Again both groups were subjected to the previous measurements.

No significant differences were found between the measurements before and after the dehydration period. In the opinion of the judges weight loss had no effect on wrestling performance. Therefore, it was concluded that conditioned wrestlers may safely lose 7% body weight in a seven day period without affecting performance (49).

In 1957, Taylor further substantiated previous findings with an investigation of the effects of caloric restriction on performance capacity as measured by hard physical work. Data were collected under the following conditions: (a) 3,100 cal/day for the entire experiment constituted the control group of 6 men, (b) 580 cal/day for twelve days constituted an experimental group of 6 men and (c) 1,010 cal/day for twenty-four days constituted
an experimental group of 13 men. Except for the control group all ate a diet of pure carbohydrates and 4.5 gm. of NaCl daily during the period of caloric restriction. Assigned work requiring 1,200 cal/day was performed by each subject in both experiments. The 580 cal/day group prevented ketosis and demonstrable liver damage but failed to maintain adequate work blood sugar levels. The capacity to perform aerobic and anerobic work tasks was well maintained but pulmonary ventilation during work, the O2 debt and pulse rate responses to a fixed task indicated some deterioration. The 1,010 cal/day group maintained satisfactory work blood sugar levels and there was no evidence of poor physiological response to the stress of work. No important change occurred in grip strength or in the maximum oxygen uptake per kilogram of body weight in either experiment. However, the total maximum oxygen intake declined slowly in both experiments. Data from other experiments in the Minnesota lab was pooled to show that a marked deterioration in both maximum oxygen uptake and strength as measured by the hand dynamometer took place between a weight loss of 10% and 16%. It is concluded that when sufficient calories and NaCl in the presence of an adequate vitamin intake are provided to prevent ketosis, dehydration and hypoglycemia under conditions of moderate energy output, performance capacity
is well maintained up to a weight loss of 10% of original body weight (50).

There are several similar studies which concur with the previous findings. For example, during an entire wrestling season, Nichols administered a battery of tests in five main areas of (a) balance, (b) reaction time, (c) strength, (d) power and (e) endurance, to two groups of wrestlers. The control group practiced no weight control measures. The experimental group lost from 3 to 18 lbs. or 1.67 to 11.11% body weight with a mean weight loss of 16.29 lbs. or 6.78% of body weight. No significant differences were found within the variables measured (43). It is interesting to note, however, that the main criteria on which endurance was based was post exercise heart rate recovery for one minute following a five minute step test.

In 1959, Alitz attempted to ascertain the effects of participation in a high school wrestling program on physical status. Strength and anthropometric measurements were taken on 18 high school wrestlers, some of which were controlling their weight to wrestle while others were not. The youngsters were observed from the beginning of the season until three months after its close. Those who controlled weight and those who did not made normal
gains in weight and strength. The only difference being that the young athletes controlling their weight complained that they seemed to catch colds more easily (5).

Similarly, Nelson studied ninety-nine 10th, 11th, and 12th grade wrestlers by use of the Wetzel Grid with the purpose of determining growth differences between wrestlers practicing weight control and those not. No distinct differences were found although there was an indication that those not dieting tended to make a slight gain in height (42).

In 1960, James organized a testing program whereby he administered the Carlson-Fatigue Curve Test on Monday and again after the final practice of the week to 20 high school wrestlers, half of which were dieting to control weight and the other half were not. The measurements were taken each week for an entire season. There were no significant differences. Also, measurements of (a) pulse rate and (b) systolic and diastolic blood pressures were taken immediately after the completion of an interscholastic bout. These measurements also indicated no significant differences (33).

Then finally, Englund undertook a study to see if efficiency of wrestlers was effected by rapid and extreme weight loss. His testing device was an adapted Harvard
Step Test of 36 steps/minute on a 12 inch step. Sixty-six wrestlers were studied at the beginning and at the end of the week for a three week period. The subjects in the experimental group lost a mean weight of 4%. A heart rate recovery index was established at the beginning and the end of each of the three week periods. No significant differences were revealed in physical efficiency between 4.4% mean weight loss and normal body weight. Also, a rank difference correlation showed no significant relationship between physical efficiency and the percentage of weight lost (27).

Primarily, the previous studies have dealt with weight loss of wrestlers by restriction of both caloric and water intake as may be preferred by the subject. The amount of time available for weight loss influencing the proportion of one to the other. Only little has been done with weight loss among wrestlers whereby caloric and water intake have been uniformly restricted or controlled. The data, therefore, reflects the interaction of two primary factors, namely, dehydration coupled with reduced caloric intake.

In 1965, however, Hanson undertook a study whereby caloric intake was the media of weight loss and no dehydration occurred. Seven Ohio State University students and
one high school senior were used as subjects. All were placed on low caloric diet for three weeks. Weight loss, oxygen consumption, blood lactate levels, heart rate and rectal temperature were measured both before weight reduction and after. Subjects lost from 9 to 18 lbs. No statistical differences were found in oxygen consumption, heart rate or rectal temperature. Blood lactate levels, however, were significantly higher after the weight reduction period. Therefore, the author concludes a 5.3 to 8.8% gradual reduction of weight does not appear to unfavorably influence the physical parameters measured. Advantages of this method of weight reduction over dehydration are noted in maintenance of heart rate and the ability to complete an established maximal work load (30).

The Effects of Weight Reduction by Dehydration

Rock after dehydrating ten college wrestlers for 40 hours and then running them on a bicycle ergometer found no significant effect upon maximal oxygen uptake or heart rate. However, 7 or 10 subjects had a reduced maximal oxygen uptake following dehydration. Also, core temperatures showed no significant change with dehydration, but more difference than can be attributed to chance was observed. Exercise sweat loss was significantly affected by dehydration (13).
Further substantiating Bock's work, Elfenbaum dehydrated three college wrestlers 3.98%, 6.63% and 9.26% body weight respectively and subjected them to runs on a bicycle ergometer while dehydrated. The variables under investigation were (1) strength, (2) maximum oxygen uptake, (3) heart rate, (4) central core temperature and (5) exercise weight loss. No statistical computations were made since only three subjects were used. However, generally strength was unaffected up to 6.63% weight loss. Maximum oxygen consumption/minute decreased. At submaximal work loads oxygen consumption was unaffected. Heart rate was distinctly affected by dehydration weight loss during rest, exercise, and recovery being elevated proportionately with work load and percentage of weight reduction. Core temperature was distinctly elevated as a result of weight reduction during rest, exercise and recovery. Exercise weight loss was greater for two subjects during control conditions than experimental. Therefore, it was concluded that rapid weight reduction primarily due to dehydration is most inadvisable as a method for "making weight." The stress on the cardiovascular system as a result of dehydration reduces efficiency and is physiologically indefensible. Reduction beyond 3.98% of original body weight by dehydration is questionable in terms of the hazards involved (26).
From the three previous studies it would appear that the effects of rapid weight reduction due to dehydration are a very serious threat to the physiological factors contributing to optimum performance.

Nadal and Associates in 1941, undertook one of the first significant studies to determine the effects of dehydration on hematocrit concentration. Two subjects were used in that one was placed on a salt restricted diet for six days yet water intake was adequate. The other underwent complete restriction of water but adequate salt. In the first experiment, the hematocrit and plasma concentration showed a gradual and continuous increase. Toward the end of the dehydration period, the subject became weak and apathetic. Systolic blood pressure fell to 85 mmHg. He became faint on assuming an upright posture and preferred to lie flat in bed. There was pronounced loss of appetite. In the second experiment, thirst became acute and voice was weak and high pitch. Near the end of the 5th day, it was necessary to give the subject water to facilitate eating his food. Both subjects showed reduction in blood volume - 21% and 22% respectively. Thus, Nadal and Associates conclude with the following:

It seems reasonable to conclude, therefore, that serious depletion of extracellular electrolyte causes a decrease in the volume of extracellular
fluid, both interstitial fluid and plasma. This leads eventually to peripheral circulatory failure, but before this stage is reached a progressive hemoconcentration can be observed.

One often hears the statement that in dehydration the plasma volume is protected by the existence of a large amount of fluid in the interstitial reservoir and that no reduction in plasma volume occurs until dehydration is quite advanced. The results of our experiments do not support this concept (41).

In 1947, Adolph and Associates published the results of extensive research concerning work in the desert. It is interesting to note that their works strongly substantiate those of Nadal. The following is a summary of findings pertinent to this study:

129 soldiers were used as subjects on endurance hikes in the desert. One group of 59 drank water ab libitum. 70 were restricted to no water intake. A great difference in endurance was evident in that only one of the fifty-nine with water could not complete the hike, while eleven in the group without water were clearly exhausted. These tests were discontinued when about a third of the subjects without water had dropped out because of exhaustion or other causes.

Similarly, in tests on laboratory personnel, 15 cases of exhaustion during walking were observed. In
every case, water had been withheld while another group
given adequate water on the same hike showed no exhaus-
tion.

The following is a summary of the deterioration
of physiological factors preceding exhaustion of one man
while walking in the desert for four hours without water.
At the completion of the 4th hour, his body weight loss
was 5.5%. Rectal temperature was over 101° F and rose in
relation to the pulse rate which reached over 120 beats/
minute. He could not walk or stand, and was near fainting.
Sweating was profuse and breathing difficult. He had
difficulty speaking and felt tingling in the upper extre-
mities. On other days just as warm and with water, the
same subject was able to walk farther without becoming ex-
hausted or without significant increases in heart rate or
body temperature. Thus, it was concluded that clearly it
was the deficit of body water which predisposed him to
exhaustion.

On five subjects who exercised in a hot room
nine pairs of determinations yielded the following results.
There is an evident relation between dehydration and
reduction of plasma volume. It appears that the fraction
by which the plasma is reduced is about 2.4 times that
by which the total body water is reduced. Therefore,
with dehydration of about 6% body weight the plasma loses about 15% of its initial volume. Expressed as a proportional loss; i.e., percent plasma/percent total body water loss, the ratio is about 5:2, indicating that percentage wise more water is lost from plasma than from the remaining fluid volumes. The red blood cells also lose some water, thus, the circulating blood volume is reduced and circulatory deficiency ensues. The elevation of heart rate is due to circulatory strain.

In another study somewhat like the above, one man was exercised in a hot room with restricted water intake and compared to the same conditions with water. A marked increase in exercise and resting pulse rate was evident with dehydration.

On another occasion, four experiments were performed whereby two subjects performed half-hour rides on a bicycle at a constant load of 190 kilogram-meters/minute. The subjects were then dehydrated and asked to perform identical work loads. During the dehydration experiments, the working pulse rate increased until the point was reached where the subjects could not maintain the pace. Therefore, dehydration alone accelerates the pulse and exhaustion ensues.
On another desert hike, subjects were dehydrated and compared to those who drank freely. The hike was performed at 3 to 4 m.p.h. with an air temperature of 100°F. Rectal temperatures rose about 0.55°F for every one percent of body weight lost by depletion of water content (1).

Thus, it is quite evident that even a fractional weight loss due to dehydration adversely affects the physiological factors involved in the ability to maintain a work load for an extended period of time.

In 1956, Monagle and associates further substantiated Adolph's work with findings somewhat similar with a reference to body temperature as it is affected by dehydration. Twelve soldiers were exercised on a treadmill for one hour at 3.5 m.p.h. at a 10% grade before, during, and after a period of dehydration and calorie restriction. The men lived and worked in an environment of 78°F and 65% relative humidity. Water intake during the experimental period was 900 cc for one group of six men and 1,800 cc for another group of six. All men received 1,000 cal/day of pure carbohydrates and used 1,200 calories for the treadmill work daily. In group 1 (900 cc), there was a continuous increase in rectal temperature at the end of one hour work until, after five days of water
restriction, the average was 1.6°C higher than before water restriction. In group 2 (1,800 cc), only a small increase of 0.6°C over the value before water restriction was found on the third day and by the sixth day this value returned to prestarvation levels. Administration of water ab libitum to group 1 brought temperatures back to the prestarvation levels and produced no important change in group 2. Therefore, it was concluded that the water deficit in group 2 was insufficient to produce a persistent alteration in thermoregulation as observed in group 1 (38).

Accepting the fact that dehydration limits man's ability to perform work largely because of impaired cardiovascular function, Buskirk and associates designed a study to determine if acclimatization or conditioning, or both, would ameliorate the impairment of ability to work when dehydrated. Three groups of five men each were used. All men were dehydrated 5.5% overnight in the heat of 115°F on two different occasions, labeled D1 and D2. Three weeks elapsed between D1 and D2. During the three weeks, one group was acclimatized and physically conditioned. The second group was conditioned only and the third group remained sedentary. Although pulse rates in all groups were elevated with dehydration the acclimatized and
conditioned group, and the conditioned group, showed lower differences than the sedentary group between D₁ and D₂. Although rectal temperatures increased with dehydration there were no significant differences in rectal temperatures between D₁ and D₂ in any group. Dehydration was also associated with decrement in maximum oxygen uptake in all groups, but the conditioned men maintained a higher maximal oxygen uptake than the sedentary group between D₁ and D₂. Thus, physical conditioning was associated with enhanced work performance during dehydration whereas acclimatization to heat did not appreciably supplement this effect (15).

The following month, Beetham and Buskirk published additional information on the previous study. Primarily, their findings support those of Adolph's in that resting heart rates were significantly elevated with dehydration and after four minutes of standing the mean pulse rate increased four beats/minute before dehydration as compared to 14 beats/minute after. Two of the 14 subjects became apprehensive, pale and faint, while standing after dehydration (8).

In 1961, Blyth and Burt studied the effects of water balance on the ability to perform in high
temperatures by subjecting 18 non-athletes to exhaustion runs on a treadmill under three experimental conditions of normal water balance, dehydration, and superhydration. All three runs were performed at 120°F. Performance time in the dehydrated state was significantly reduced while there was no real difference between superhydrated and normal conditions. However, with a subgroup of eleven athletes exhaustion time on the treadmill under superhydrated conditions was significantly greater over normal conditions. Thus, one may conclude that there is definite advantage to the ingestion of water before work in the heat and one may do so with no detrimental effects of stomach sickness and nausea (11).

An experimental study by Blank substantiates this conclusion as 33 collegiate track and field men were divided into three groups and then subjected to 27 individual 220 yard time trials. One group consumed no liquid with an hour preceding the runs. Another group consumed a pint of water five minutes prior to trials and a third group consumed water freely five minutes before the run. No significant differences were found, thus, the null hypothesis regarding the ill effect of water ingestion upon performance was rejected (10).
A quote by Adolph further substantiates the point.

Some men like to tank up in anticipation of impending water restriction. Tradition is against such a practice, on the supposition that overloading the stomach with water either just before or just after is harmful. Since we found neither to be the case to any significant extent, we believe that predrinking in appropriate circumstances should be encouraged. Only half of any water suddenly drunk in excess of bodily needs is excreted after an hour and a half; in the desert, most of the excess has been removed by sweating within that time, so that only a small part of it is excreted instead of being used economically in sweat formation (2).

Saltin used ten subjects to perform standard exercise tests at two submaximal and one maximal load both before and 90 minutes after dehydration of between 1.7 - 4.6 Kg. caused by (1) a thermal, (2) a metabolic and (3) a combined thermal and metabolic heat load applied for 2½ to 4 hours. The work was performed sitting on a Krogh Bicycle Ergometer and all loads were constant. During submaximal loads no change was evident in oxygen uptake after dehydration, however, heart rates were significantly higher with a mean difference of 13 beats/minute. Blood lactates were lower. With maximal loads there were no significant changes in oxygen uptake and heart rate, however, work times decreased markedly from 6 to 4 minutes. Blood lactates also were markedly decreased (47).
Saltin also studied circulatory responses of four subjects under a similar protocol to the above. Circulatory data were measured at rest and during exercise at two submaximal and one maximal load. The decrease in body weight due to dehydration was accompanied by a reduction in plasma volume up to 25%. After dehydration, the hemodynamic response to work in a sitting position at the submaximal loads was a decrease in stroke volume and an associated increase in heart rate so that cardiac output remained almost unaltered. Both changes were significantly correlated to the reduction in body weight and plasma volume (45).

In 1966, Craig undertook a study to examine the effects of dehydration when exhausting muscular work was performed in a warm environment. Nine men walked on a treadmill to exhaustion at 3.5 m.p.h. on a gradually increasing incline. The room was 46°C dry bulb and 23°C wet bulb. Runs took place before and after a six hour period of dehydration at rest. Dehydration resulted in 4.3% body weight lost as compared to 1.9% with water. Walking time with dehydration was reduced 48% whereby it decreased under normal conditions 22%. Maximal oxygen consumption was also reduced by 27% during dehydration, only 10% under normal conditions. However, reduction in walking
time was better correlated with an increase in rectal temperature (0.84), a decrease in fraction of CO₂ in expired air during work (0.82), and increase in heart rate in standing before work (0.82) than with dehydration (0.63). It was concluded that impairment of performance was attributed to circulatory inadequacy elsewhere than in working muscles (20).

**Summation of Related Literature**

There is an appreciable amount of research studies appearing as masters theses that supports weight reduction by semi-starvation coupled with dehydration to the extent of 10% weight loss without the impairment of selected physiological factors that effect performance. On the other hand, it has been demonstrated that weight loss due to dehydration of as little as 3% of original body weight can and does impair the ability to perform work for an extended period of time.

It appears that one of the answers to the conflict in evidence is the extent of water deprivation undergone by the subjects (36). For example, moderate water deficit causes an increase in pulse rate, an elevation of rectal temperature and in some cases, ventilation rate, and a reduction of circulating blood plasma volume with eventual exhaustion as a result of circulatory inadequacy. Whereas, semi-starvation results in a reduction of heart rate, a
decline in blood pressure and a decrease in total metabolism. Therefore, differences in the relative amounts of fasting and dehydration will definitely yield differences in results.

Another important factor that becomes obvious is that the effects of dehydration are much more severe than those of semi-starvation (40,31). Yet, rapid weight reduction which occurs over a period of from 24 to 48 hours is primarily weight loss due to dehydration since virtually no body fat can be lost in such a short period of time. Unfortunately, weight loss as it is now being practiced by wrestlers is primarily weight loss within 48 hours and, therefore, subjects the contestant to the worst possible harmful effects to the physiological factors controlling performance.

Thus, additional research designed to isolate semi-starvation as opposed to dehydration is of an urgent need.

Secondly, there is scant evidence revealing the degree to which one may or may not condition or acclimatize oneself to dehydration. This is to say that more work is needed to clarify the ill effects of rapid weight loss among wrestlers as opposed to athletes in general.

Lastly, there is an urgent need for information which reveals the effects of dehydration weight loss on a
wrestler's ability to perform work for an extended period of time. Testing measures which are of long duration which place stress on the physiological factors enabling one to sustain work for extended periods of time are of critical value to the contestant who must compete two and three times/day for successive days in tournament competition.

Perhaps the following statement will suffice:

Exercise changes the dynamic body-fluid equilibrium. A single bout of work or athletic event may induce changes that are relatively transitory or long-lasting. In general, information describing both acute and chronic shifts in the body fluids with exercise is meager. Reliance must be placed on measurements that are in most cases rather indirect and frequency inadequate (18).
CHAPTER III
METHODS AND PROCEDURES

In order to determine the effects of acute dehydration weight loss on the endurance of college wrestlers, subjects were subjected to the Balke Treadmill Test, under two experimental conditions and one control.

The Balke Treadmill Test is a test of endurance as measured in terms of the duration of exercise required to produce a heart rate of 180 beats/minute (T180) (34). The test consists of having a subject walk on a motor driven treadmill at a constant speed of 3.5 m.p.h. while the grade is increased 1% per minute. Heart rate is recorded each minute of the test (6).

Bedecki and Nagle studied the Balke test and compared the results with all-out runs on the treadmill and found the correlation to be 0.85. Therefore, one may conclude it to be a valid test in measuring circulatory-respiratory capacity under variable exercise stress conditions (7).

Subjects

The subjects for this study were nine Ohio State University freshmen wrestlers competing for a position on
the freshman team and 1 varsity wrestler. All men had been practicing two months prior to the study and continued training for competition throughout its duration. Subjects ranged in weight from 123 lbs. to 192 lbs., in height from 5'6" to 6'0", and in age from 18 to 25. All subjects had wrestling experience in high school. One competed in the service and one had three years varsity experience. These data appear in Table 1.

**TABLE 1**

<table>
<thead>
<tr>
<th>Subject</th>
<th>Age</th>
<th>Height</th>
<th>Weight</th>
<th>Wrestling Experience</th>
</tr>
</thead>
<tbody>
<tr>
<td>J.B.</td>
<td>18</td>
<td>5'9&quot;</td>
<td>155</td>
<td>H.S. &amp;</td>
</tr>
<tr>
<td>T.C.</td>
<td>22</td>
<td>5'7&quot;</td>
<td>149</td>
<td>H.S.</td>
</tr>
<tr>
<td>R.C.</td>
<td>18</td>
<td>5'8&quot;</td>
<td>134</td>
<td>H.S.</td>
</tr>
<tr>
<td>C.K.</td>
<td>18</td>
<td>5'6&quot;</td>
<td>132</td>
<td>H.S.</td>
</tr>
<tr>
<td>G.M.</td>
<td>18</td>
<td>5'8&quot;</td>
<td>164</td>
<td>H.S.</td>
</tr>
<tr>
<td>T.H.</td>
<td>19</td>
<td>5'6&quot;</td>
<td>123</td>
<td>H.S.</td>
</tr>
<tr>
<td>V.S.</td>
<td>25</td>
<td>6'0&quot;</td>
<td>193</td>
<td>H.S. &amp; service</td>
</tr>
<tr>
<td>D.V.</td>
<td>19</td>
<td>5'10½&quot;</td>
<td>170</td>
<td>H.S.</td>
</tr>
<tr>
<td>D.Y.</td>
<td>20</td>
<td>5'9½&quot;</td>
<td>142</td>
<td>H.S.</td>
</tr>
<tr>
<td>R.Y.</td>
<td>21</td>
<td>5'6½&quot;</td>
<td>144</td>
<td>H.S. &amp; college</td>
</tr>
</tbody>
</table>
Dehydration

Subjects were asked on four different occasions to lose weight by dehydration over a period of 24 to 48 hours. The dehydration procedure was accomplished by: (1) exercise in a hot room using heavy clothing during a regularly scheduled practice session; (2) abstinence from fluid intake; and (3) by the use of an electrically heated sweat box, steam baths, or any combination of the above. Subjects were encouraged to continue food intake as near normal as possible.

Procedures

The subjects were tested by use of the Balke Treadmill Test under two experimental conditions and one control. Two tests were made under each of the three conditions in order to obtain a mean score for the physiological variables measured. Reliability between the two trials for T180 under each conditions was established in that for the two trials under control conditions \( r = .92 \). For the two trials under dehydrated conditions \( r = .60 \), and for the two trials under rehydrated conditions \( r = .85 \).

Control Condition

The control condition consisted of testing each subject at his normal body weight on two different occasions
to obtain mean scores for the physiological variables measured (1c).

Experiment #2D Condition

Experiment #2D condition consisted of dehydrating the ten subjects over a 24 to 48 hour period by the processes described above. The subjects were tested on two different occasions in the dehydrated state to obtain mean scores. The mean range of weight loss for the two different occasions was from 5.97% to 8.5% of original body weight. The mean percentage of dehydration for the ten subjects was 6.71% of original body weight.

Experiment #3R Condition

Experiment #3R condition consisted of dehydrating the ten subjects over a 24 to 48 hour period exactly the same as described in Experiment #2D. This dehydration procedure was also performed on two different occasions to obtain a mean score. The mean range of weight loss was from 5.92% to 8.31% with a mean for the ten subjects again being 6.71% of original body weight. However, before the subjects were tested each was given one hour to rehydrate to satiety. The range of rehydration was from .85 Kgs. to 1.62 Kgs. with a mean of 1.08 Kgs. After the rehydration period subjects were tested immediately.
Normal body weight was established for each subject by recording their weight each night before practice two weeks prior to the study. A mean weight was then used as the normal body weight and the percentage dehydration figured on this amount. The percentage of weight lost by dehydration and the amount of rehydration by each subject appears in Table 2.

**TABLE 2**

**MEAN WEIGHT LOSS FOR 1C, 2D AND 3R CONDITIONS IN KGS.**

<table>
<thead>
<tr>
<th>Subjects</th>
<th>1C</th>
<th>2D</th>
<th>2D%</th>
<th>3R</th>
<th>3R%</th>
<th>Rehydration</th>
</tr>
</thead>
<tbody>
<tr>
<td>J.B.</td>
<td>70.20</td>
<td>64.21</td>
<td>8.5%</td>
<td>64.36</td>
<td>8.31%</td>
<td>.96</td>
</tr>
<tr>
<td>T.C.</td>
<td>67.70</td>
<td>63.28</td>
<td>6.5%</td>
<td>63.19</td>
<td>6.7%</td>
<td>.85</td>
</tr>
<tr>
<td>R.C.</td>
<td>60.58</td>
<td>56.01</td>
<td>7.5%</td>
<td>56.01</td>
<td>7.5%</td>
<td>1.62</td>
</tr>
<tr>
<td>C.K.</td>
<td>59.96</td>
<td>56.35</td>
<td>6.0%</td>
<td>56.41</td>
<td>5.92%</td>
<td>1.20</td>
</tr>
<tr>
<td>G.M.</td>
<td>74.12</td>
<td>68.92</td>
<td>7.01%</td>
<td>68.84</td>
<td>7.12%</td>
<td>1.28</td>
</tr>
<tr>
<td>T.M.</td>
<td>55.47</td>
<td>51.81</td>
<td>6.59%</td>
<td>51.56</td>
<td>7.04%</td>
<td>.94</td>
</tr>
<tr>
<td>V.S.</td>
<td>87.17</td>
<td>81.89</td>
<td>6.5%</td>
<td>81.98</td>
<td>5.95%</td>
<td>.88</td>
</tr>
<tr>
<td>B.V.</td>
<td>77.12</td>
<td>72.13</td>
<td>6.47%</td>
<td>72.19</td>
<td>6.39%</td>
<td>.91</td>
</tr>
<tr>
<td>D.Y.</td>
<td>64.61</td>
<td>60.69</td>
<td>6.06%</td>
<td>60.64</td>
<td>6.14%</td>
<td>.98</td>
</tr>
<tr>
<td>R.Y.</td>
<td>64.89</td>
<td>61.01</td>
<td>5.97%</td>
<td>60.98</td>
<td>6.02%</td>
<td>1.09</td>
</tr>
</tbody>
</table>

Mean for 68.18Kgs, 63.63Kgs, 6.71 63.62Kgs, 6.71% 1.08 10 subjects

S.D. 8.89Kgs, 8.37Kgs, 8.42Kgs, 0.23
Orientation

Subjects were brought to the laboratory prior to testing and practiced the test in order to familiarize themselves with procedures and skills involved in walking on the treadmill. Orientation was also provided for the use of the thermister, heart rate measuring devices, the use of the breathing apparatus, and for establishing a schedule for testing. Conditions were rotated by use of a latin square. Table 3 shows the arrangement.

**TABLE 3**

**ROTATION OF CONDITIONS**  
(Performed twice for mean score)

<table>
<thead>
<tr>
<th>SUBJECT</th>
<th>1st Test</th>
<th>2nd Test</th>
<th>3rd Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1C</td>
<td>2D</td>
<td>3R</td>
</tr>
<tr>
<td>2</td>
<td>1C</td>
<td>2D</td>
<td>3R</td>
</tr>
<tr>
<td>3</td>
<td>1C</td>
<td>2D</td>
<td>3R</td>
</tr>
<tr>
<td>4</td>
<td>1C</td>
<td>2D</td>
<td>3R</td>
</tr>
<tr>
<td>5</td>
<td>1C</td>
<td>2D</td>
<td>3R</td>
</tr>
<tr>
<td>6</td>
<td>1C</td>
<td>3R</td>
<td>2D</td>
</tr>
<tr>
<td>7</td>
<td>1C</td>
<td>3R</td>
<td>2D</td>
</tr>
<tr>
<td>8</td>
<td>1C</td>
<td>3R</td>
<td>2D</td>
</tr>
<tr>
<td>9</td>
<td>1C</td>
<td>3R</td>
<td>2D</td>
</tr>
<tr>
<td>10</td>
<td>1C</td>
<td>3R</td>
<td>2D</td>
</tr>
</tbody>
</table>
On the day a subject was scheduled for testing, he would arrive at the laboratory about 15 minutes prior to the testing time and was weighed nude and dry. The thermister was then inserted and taped in place. The electrode strap and electrodes were placed on the subject's chest while the mouth piece was secured in place and connected to the spirometer. The subjects wore a standard uniform of wrestling tights, over tights or briefs, and wrestling shoes and socks. As preparation was completed, the subject mounted the treadmill to one side of the belt while the speed and grade were adjusted to begin testing. At the subject's will, he mounted the treadmill and stop watches were started simultaneously. At the conclusion of the testing, the treadmill was turned off and the subject stood to the side as all equipment was removed and cleaned. The subject was again weighed nude and dry.

Methods

Five physiological factors were measured in order to study the effects of acute dehydration weight loss on the endurance of college wrestlers - 1. heart rate 2. core temperature 3. exercise weight loss 4. excess CO₂ and 5. O₂ uptake.

Heart Rate

Heart rate was monitored by the use of a electrocardiograph manufactured by the Cambridge Instrument
Company. Two surface electrodes were placed on the front of the subject's chest and two on the back of the chest and held in place by chest straps. Electrode leads were then attached and the opposite end plugged into the electrocardiograph. Heart rate was recorded at the end of each minute while walking on the treadmill by a fifteen second count from 30 seconds to 45 and multiplied by 4. When the subject's heart rate reached 180 beats/minute, the test was terminated. The subject's score was thus recorded in terms of the number of minutes for the heart rate to reach 180 beats/minute.

**Core Temperature**

Core temperatures were recorded by a Yellow Springs Instrument Company thermister which is specifically designed for such purpose. The thermister was inserted four inches into the rectum and securely taped to the buttocks by the use of surgical tape. The jack end of the thermister was then looped around the subject's supporter and plugged into a telemetering device which records temperatures to .1°C. Core temperatures were recorded each minute while walking on the treadmill.

**Exercise Weight Loss**

Exercise weight loss was measured by weighing the subject nude and dry immediately before and after the
exercise period. The amount of sweating during the exercise period determined the exercise weight loss.

**Excess CO₂ Production and O₂ Uptake**

While walking on the treadmill, subjects breathed through a mouth piece which permitted inhalation of room air and exhalation into a spirometer. The mouth piece was held in place by a chest plate strapped around the subject's chest. A nose plug was used to insure proper exhalation into the mouth piece. The mouth piece was connected by a rubber hose to a Warren and Collins chain-compensated 120 liter capacity spirometer. Expired air was collected for thirty seconds in the spirometer the last half of every fifth minute of exercise until the exercise was terminated. Before each collection the spirometer was washed three times with the subject's expired air. The meter stick was read before and after each 30 second collection and recorded. The temperature of the spirometer was also recorded after each collection. Samples of the expired air were then taken from the spirometer in bladder bags and the percent concentration of oxygen and carbon dioxide were analyzed by the use of a Beckman Model B-2 Oxygen Analyzer and a Beckman Model L-1 Carbon Dioxide Medical Gas Analyzer. Both analyzers were zeroed and spanned immediately prior to the testing of each subject.
O₂ consumption in ml/minute was determined by the following steps:

a - V̇EATPS  
- Bell factor x distance traveled

b - Correction factor
- $\left( \frac{\text{BP} - \text{WVP}}{760} \right) \left( \frac{273}{273 + Ts} \right)$

c - V̇ESTPD
- V̇E.TPS x correction factor

d - Nitrogen factor
- $\frac{1.000}{1.000}$ - total expired air
- $\text{total room air}$

e - V̇ISTPD
- V̇ESTPD x nitrogen factor

f - $\dot{V}O_2$
- V̇ISTPD x Rm. Air O₂% - V̇ESTPD x expired O₂% x 2 (collections were for 30 seconds)

For the calculation of excess CO₂ two reference metabolism R.Q.'s may be used, 0.75 or 0.83 respectively. Thus, excess CO₂ = total CO₂ minus 0.75 x O₂ (or 0.83 x O₂). The value 0.75 is preferable since at lower work loads the excess CO₂ will show a positive value. Calculations based on 0.83 will yield no excess CO₂ production at low work loads even though small amounts of lactate are being formed (32).
CHAPTER IV
ANALYSIS OF DATA

The purpose of this study was to determine the effects of acute dehydration weight loss on the endurance of college wrestlers. The physiological factors measured were 1. heart rate 2. core temperature 3. exercise weight loss 4. excess CO₂ and 5. O₂ uptake. Three conditions were used, two experimental and one control with ten subjects performing under all three conditions.

Statistical Procedures

The null hypothesis was established at the .05 and .01 levels of confidence for differences among the three conditions with respect to the four physiological variables measured. Thus, the hypothesis that no real differences would occur between the means of 1. heart rate 2. core temperature 3. exercise weight loss 4. Excess CO₂ production and 5. oxygen uptake, under the following conditions was formulated: (a) control condition (1C) (b) mean dehydration weight loss of 6.71% of original body weight (2D) and (c) mean dehydration weight loss of 6.71% of original body weight followed by a one hour period of rehydration (3R). The "t" test for significant differences between means was the statistical procedure employed in this study.
Heart Rate

A significant difference in heart rate was found to exist between the mean times taken for the heart rate to reach 180 (T180) among all three conditions. The mean time for the heart rate to reach 180 beats/minute for the ten subjects in 1C condition was 20.75 minutes. For 2D condition the mean T180 was 17.35 minutes, and for 3R condition the mean T180 was 19.20 minutes. Statistical analysis for differences between means by use of the "t" test showed a "t" of 5.95 between 1C and 2D conditions. This difference exceeded the .001 level of confidence. A "t" of 3.019 was found between the 1C and 3R condition, which exceeded the .025 level of confidence. Between 2D and 3R conditions the difference was also significant with a "t" of 3.799 which exceeded the .005 level of confidence. Thus, the null hypothesis for differences among the mean scores of heart rate under the three conditions was rejected. These data are summarized in Table 4. These differences indicate that, endurance as measured by T180, was severely reduced by a mean dehydration weight loss of 6.71% and was greatly reduced by dehydration (to the same extent) followed by one hour of rehydration.
Core Temperature

Results of core temperature means between groups showed statistically significant results. However, the "t" between 1C and 2D conditions was 1.26 which did not approach the .05 level of confidence. Core temperatures for the 2D condition were only 0.10°C higher than the means for the controls.

A significant difference was found to exist between 1C condition and 3R being lower under 3R conditions. A significant difference was also found to exist between 2D and 3R conditions being lower for 3R. The "t" between 1C and 3R was 2.454 which was significant beyond the .05 level. The mean core temperatures for 3R were 0.12°C lower than core temperatures for the control group.

When mean core temperatures for 3R were compared to 2D, the 3R mean temperatures were .22°C lower than 2D. The "t" ratio between 3R and 1C was 2.774 which was significant beyond the .025 level of confidence. Thus, the null hypothesis was rejected. These data appear in Table 5 and show that a mean dehydration weight loss of 6.71% did not change core temperatures to any great extent yet, when rehydration followed the 6.71% dehydration procedure, core temperatures were lowered below what would be expected normal for the given amount of exercise.
## TABLE 4

MEAN HEART RATE SCORES TO 180/MIN. AT 5 MIN. INTERVALS

<table>
<thead>
<tr>
<th>Subjects</th>
<th>5'</th>
<th>10'</th>
<th>15'</th>
<th>20'</th>
<th>25'</th>
<th>T180</th>
<th>5'</th>
<th>10'</th>
<th>15'</th>
<th>20'</th>
<th>T180</th>
<th>5'</th>
<th>10'</th>
<th>15'</th>
<th>20'</th>
<th>T180</th>
</tr>
</thead>
<tbody>
<tr>
<td>J.B.</td>
<td>102</td>
<td>124</td>
<td>152</td>
<td>172</td>
<td>---</td>
<td>22.0'</td>
<td>86</td>
<td>114</td>
<td>154</td>
<td>176</td>
<td>21.0'</td>
<td>94</td>
<td>124</td>
<td>156</td>
<td>176</td>
<td>---</td>
</tr>
<tr>
<td>R.C.</td>
<td>128</td>
<td>152</td>
<td>172</td>
<td>---</td>
<td>---</td>
<td>13.5'</td>
<td>128</td>
<td>158</td>
<td>176</td>
<td>---</td>
<td>16.0'</td>
<td>130</td>
<td>152</td>
<td>172</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>T.C.</td>
<td>118</td>
<td>142</td>
<td>166</td>
<td>---</td>
<td>---</td>
<td>18.0'</td>
<td>130</td>
<td>160</td>
<td>176</td>
<td>---</td>
<td>15.0'</td>
<td>116</td>
<td>144</td>
<td>174</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>C.K.</td>
<td>128</td>
<td>144</td>
<td>164</td>
<td>176</td>
<td>---</td>
<td>21.5'</td>
<td>122</td>
<td>146</td>
<td>166</td>
<td>---</td>
<td>19.0'</td>
<td>122</td>
<td>142</td>
<td>164</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>G.M.</td>
<td>114</td>
<td>136</td>
<td>162</td>
<td>174</td>
<td>---</td>
<td>21.5'</td>
<td>126</td>
<td>160</td>
<td>180</td>
<td>---</td>
<td>15.5'</td>
<td>122</td>
<td>154</td>
<td>170</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>T.M.</td>
<td>108</td>
<td>138</td>
<td>162</td>
<td>---</td>
<td>---</td>
<td>19.5'</td>
<td>110</td>
<td>148</td>
<td>172</td>
<td>---</td>
<td>17.5'</td>
<td>112</td>
<td>142</td>
<td>168</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>V.S.</td>
<td>118</td>
<td>140</td>
<td>116</td>
<td>---</td>
<td>---</td>
<td>19.0'</td>
<td>134</td>
<td>162</td>
<td>---</td>
<td>---</td>
<td>14.5'</td>
<td>130</td>
<td>156</td>
<td>174</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>B.V.</td>
<td>118</td>
<td>140</td>
<td>164</td>
<td>178</td>
<td>---</td>
<td>20.5'</td>
<td>126</td>
<td>158</td>
<td>174</td>
<td>---</td>
<td>16.5'</td>
<td>130</td>
<td>158</td>
<td>172</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>D.Y.</td>
<td>120</td>
<td>150</td>
<td>170</td>
<td>---</td>
<td>---</td>
<td>19.5'</td>
<td>122</td>
<td>150</td>
<td>172</td>
<td>---</td>
<td>17.5'</td>
<td>103</td>
<td>136</td>
<td>164</td>
<td>178</td>
<td>---</td>
</tr>
<tr>
<td>R.Y.</td>
<td>98</td>
<td>114</td>
<td>136</td>
<td>158</td>
<td>172</td>
<td>27.5'</td>
<td>104</td>
<td>134</td>
<td>156</td>
<td>174</td>
<td>21.0'</td>
<td>96</td>
<td>114</td>
<td>138</td>
<td>162</td>
<td>174</td>
</tr>
<tr>
<td>Mean H.R.</td>
<td>115.2</td>
<td>138</td>
<td>161.4</td>
<td>175.8</td>
<td>--</td>
<td>20.75'</td>
<td>118.8</td>
<td>148.3</td>
<td>170.6</td>
<td>--</td>
<td>17.35'</td>
<td>116</td>
<td>142.2</td>
<td>165.2</td>
<td>177.6</td>
<td>--</td>
</tr>
</tbody>
</table>

\[
\begin{align*}
\text{t} & = 5.95 \\
\text{t} & = 3.79 \\
\text{t} & = 3.019
\end{align*}
\]

- .05 = 2.26
- .025 = 2.68
- .010 = 3.25
- .005 = 3.69
- .001 = 4.78
Exercise Weight Loss

Exercise weight loss due to sweating was significantly affected when 1C condition was compared to 2D and when 2D was compared to 3R. The ten subjects during control measures lost a mean weight of .372 Kgs. due to sweating during exercise and only .185 Kgs. during exercise when dehydrated 6.71% of body weight. The "t" ratio between these conditions was 5.377 which was significant well beyond the .001 level of confidence. Also, when the ten subjects were allowed to rehydrate after the 6.71% dehydrated period exercise weight loss was .109 Kgs. greater than in the dehydrated state. The "t" between 3R and 2D was 4.779 which was significant beyond the .005 level. Thus, for differences between the mean scores of the ten subjects under various conditions with regard to exercise weight loss the null hypothesis was rejected.

However, no significant differences were demonstrated between the means of control and 3R conditions. When subjects were allowed to rehydrate after the 6.71% dehydration period the weight loss due to sweating did not significantly change. In this study, a great deal less weight was lost due to sweating when dehydrated than when normal or when rehydration followed the dehydration procedure. The mean exercise weight loss for each subject for each condition is summarized in Table 6.
### Table 5

**Mean Core Temperature at 1180**

<table>
<thead>
<tr>
<th>Subjects</th>
<th>1C</th>
<th>2D</th>
<th>3R</th>
</tr>
</thead>
<tbody>
<tr>
<td>J.B.</td>
<td>38.00</td>
<td>38.08</td>
<td>38.08</td>
</tr>
<tr>
<td>T.C.</td>
<td>37.88</td>
<td>37.85</td>
<td>37.55</td>
</tr>
<tr>
<td>R.C.</td>
<td>37.93</td>
<td>38.05</td>
<td>37.83</td>
</tr>
<tr>
<td>C.K.</td>
<td>38.10</td>
<td>38.03</td>
<td>38.00</td>
</tr>
<tr>
<td>G.M.</td>
<td>38.08</td>
<td>38.65</td>
<td>37.93</td>
</tr>
<tr>
<td>T.M.</td>
<td>37.75</td>
<td>37.90</td>
<td>37.5</td>
</tr>
<tr>
<td>V.S.</td>
<td>37.78</td>
<td>37.80</td>
<td>37.85</td>
</tr>
<tr>
<td>B.V.</td>
<td>37.88</td>
<td>38.35</td>
<td>37.95</td>
</tr>
<tr>
<td>D.Y.</td>
<td>38.08</td>
<td>38.00</td>
<td>37.75</td>
</tr>
<tr>
<td>R.Y.</td>
<td>38.43</td>
<td>38.25</td>
<td>38.33</td>
</tr>
</tbody>
</table>

**Group**

<table>
<thead>
<tr>
<th>Mean</th>
<th>37.99</th>
<th>38.09</th>
<th>37.87</th>
</tr>
</thead>
</table>

| m    | .0592 | .0773 | .0733 |

### Table 6

**Mean Exercise Weight Loss in Kgs. For Each Condition**

<table>
<thead>
<tr>
<th>Subjects</th>
<th>1C</th>
<th>2D</th>
<th>3R</th>
</tr>
</thead>
<tbody>
<tr>
<td>J.B.</td>
<td>.341</td>
<td>.199</td>
<td>.256</td>
</tr>
<tr>
<td>T.C.</td>
<td>.312</td>
<td>.142</td>
<td>.227</td>
</tr>
<tr>
<td>R.C.</td>
<td>.341</td>
<td>.199</td>
<td>.227</td>
</tr>
<tr>
<td>C.K.</td>
<td>.454</td>
<td>.028</td>
<td>.199</td>
</tr>
<tr>
<td>G.M.</td>
<td>.454</td>
<td>.114</td>
<td>.227</td>
</tr>
<tr>
<td>T.M.</td>
<td>.312</td>
<td>.170</td>
<td>.284</td>
</tr>
<tr>
<td>V.S.</td>
<td>.284</td>
<td>.170</td>
<td>.398</td>
</tr>
<tr>
<td>B.V.</td>
<td>.394</td>
<td>.227</td>
<td>.341</td>
</tr>
<tr>
<td>D.Y.</td>
<td>.483</td>
<td>.312</td>
<td>.312</td>
</tr>
<tr>
<td>R.Y.</td>
<td>.341</td>
<td>.284</td>
<td>.483</td>
</tr>
</tbody>
</table>

**Group**

<table>
<thead>
<tr>
<th>Mean</th>
<th>.372</th>
<th>.185</th>
<th>.295</th>
</tr>
</thead>
</table>

| m    | .0207 | .0221 | .0728 |
**O₂ Consumption**

Subjects walked on the treadmill at a constant speed of 3.5 mph and a grade increase of 1% each minute. Exhaled gases were collected and analyzed at five minute intervals.

At each interval, no significant differences were found to exist between the mean scores of the ten subjects for oxygen consumption under any of the three conditions tested. Differences between the mean scores of the three conditions was small and the "t" ratios between 1C and 2D, 1C and 3R, 2D and 3R were 1.45, 1.73 and .950 respectively. Thus, the null hypothesis was accepted. A summary of these data appear in Table 7.

**Excess CO₂ Production**

The mean scores for the ten subjects for excess CO₂ production were statistically significant at each 5 minute interval among all three conditions tested.

**5 Minute Interval.** At the 5 minute interval the difference between 1C and 2D conditions was statistically significant beyond the .001 level. The difference between the 1C and 3R condition was significant beyond the .005 level, and between 2D and 3R the difference was significant beyond the .01 level.
<table>
<thead>
<tr>
<th>Subjects</th>
<th>5'</th>
<th>10'</th>
<th>15'</th>
<th>20'</th>
<th>25'</th>
<th>5'</th>
<th>10'</th>
<th>15'</th>
<th>20'</th>
<th>25'</th>
<th>5'</th>
<th>10'</th>
<th>15'</th>
<th>20'</th>
<th>25'</th>
</tr>
</thead>
<tbody>
<tr>
<td>J.E.</td>
<td>1.38</td>
<td>2.03</td>
<td>2.77</td>
<td>3.63</td>
<td>----</td>
<td>1.48</td>
<td>2.04</td>
<td>2.79</td>
<td>3.25</td>
<td>----</td>
<td>1.40</td>
<td>2.00</td>
<td>2.85</td>
<td>3.13</td>
<td>----</td>
</tr>
<tr>
<td>T.C.</td>
<td>1.45</td>
<td>1.89</td>
<td>2.50</td>
<td>----</td>
<td>----</td>
<td>1.48</td>
<td>2.00</td>
<td>2.38</td>
<td>----</td>
<td>----</td>
<td>1.55</td>
<td>1.94</td>
<td>2.61</td>
<td>----</td>
<td>----</td>
</tr>
<tr>
<td>R.C.</td>
<td>1.40</td>
<td>1.75</td>
<td>2.19</td>
<td>----</td>
<td>----</td>
<td>1.35</td>
<td>1.77</td>
<td>2.21</td>
<td>----</td>
<td>----</td>
<td>1.56</td>
<td>1.82</td>
<td>2.10</td>
<td>----</td>
<td>----</td>
</tr>
<tr>
<td>C.K.</td>
<td>1.37</td>
<td>1.60</td>
<td>2.10</td>
<td>2.66</td>
<td>----</td>
<td>1.35</td>
<td>1.83</td>
<td>2.24</td>
<td>----</td>
<td>----</td>
<td>1.38</td>
<td>1.83</td>
<td>2.12</td>
<td>2.38</td>
<td>----</td>
</tr>
<tr>
<td>G.M.</td>
<td>1.61</td>
<td>2.90</td>
<td>2.61</td>
<td>2.23</td>
<td>----</td>
<td>1.63</td>
<td>2.18</td>
<td>2.17</td>
<td>----</td>
<td>----</td>
<td>1.85</td>
<td>2.10</td>
<td>2.64</td>
<td>----</td>
<td>----</td>
</tr>
<tr>
<td>T.M.</td>
<td>1.25</td>
<td>1.70</td>
<td>2.17</td>
<td>2.61</td>
<td>----</td>
<td>1.28</td>
<td>1.86</td>
<td>2.15</td>
<td>----</td>
<td>----</td>
<td>1.34</td>
<td>1.87</td>
<td>2.19</td>
<td>3.00</td>
<td>----</td>
</tr>
<tr>
<td>V.S.</td>
<td>1.62</td>
<td>2.36</td>
<td>2.78</td>
<td>3.07</td>
<td>----</td>
<td>1.67</td>
<td>2.58</td>
<td>3.22</td>
<td>----</td>
<td>----</td>
<td>1.83</td>
<td>2.31</td>
<td>3.08</td>
<td>----</td>
<td>----</td>
</tr>
<tr>
<td>L.V.</td>
<td>1.59</td>
<td>2.39</td>
<td>3.27</td>
<td>3.86</td>
<td>----</td>
<td>1.68</td>
<td>2.11</td>
<td>2.72</td>
<td>----</td>
<td>----</td>
<td>1.64</td>
<td>2.48</td>
<td>3.11</td>
<td>----</td>
<td>----</td>
</tr>
<tr>
<td>D.Y.</td>
<td>1.39</td>
<td>1.90</td>
<td>2.43</td>
<td>3.26</td>
<td>----</td>
<td>1.51</td>
<td>2.07</td>
<td>2.36</td>
<td>----</td>
<td>----</td>
<td>1.35</td>
<td>1.89</td>
<td>2.28</td>
<td>2.58</td>
<td>----</td>
</tr>
<tr>
<td>R.Y.</td>
<td>1.54</td>
<td>1.89</td>
<td>2.41</td>
<td>3.11</td>
<td>3.81</td>
<td>1.45</td>
<td>1.69</td>
<td>2.28</td>
<td>2.78</td>
<td>----</td>
<td>1.38</td>
<td>1.64</td>
<td>2.22</td>
<td>3.03</td>
<td>3.53</td>
</tr>
</tbody>
</table>

Mean 1.46 1.96 2.52 ---- 1.49 2.01 2.45 ---- 1.53 1.99 2.52 ---- ----
10 Minute Interval. At the 10 minute interval of walking on the treadmill excess CO₂ production was statistically significant between the 1C and 2D conditions, and the 1C and 3R conditions beyond the .001 level. Between the 2D and 3R conditions the significance was beyond the .005 level.

15 Minute Interval. For the 15 minute interval of walking the difference between 1C and 2D conditions was statistically significant beyond the .05 level of confidence. For mean scores between 1C and 2D conditions the differences were significant beyond the .005 level and for means between 2D and 3R conditions the differences were not significant. Thus, the null hypothesis was rejected.

These differences reveal that a great deal less excess CO₂ was produced at each interval when subjects were dehydrated 6.71% of their original body weight and also when they were allowed to rehydrate after the dehydration procedure. It also shows that excess CO₂ production was less when dehydrated 6.71% than when subjects were allowed to rehydrate for one hour after the dehydration procedure. Thus, the amount of excess CO₂ produced was least during dehydrated conditions, during rehydration after dehydration excess CO₂ closer approached the control condition where it was greatest. A summary appears in Table 8.
<table>
<thead>
<tr>
<th>Subjects</th>
<th>5'</th>
<th>10'</th>
<th>15'</th>
<th>20'</th>
<th>25'</th>
<th>5'</th>
<th>10'</th>
<th>15'</th>
<th>20'</th>
<th>25'</th>
<th>5'</th>
<th>10'</th>
<th>15'</th>
<th>20'</th>
<th>25'</th>
</tr>
</thead>
<tbody>
<tr>
<td>J.B.</td>
<td>.108</td>
<td>.194</td>
<td>.407</td>
<td>.736</td>
<td>----</td>
<td>-.077</td>
<td>.013</td>
<td>.213</td>
<td>.492</td>
<td>----</td>
<td>.072</td>
<td>.183</td>
<td>.353</td>
<td>.595</td>
<td>----</td>
</tr>
<tr>
<td>T.C.</td>
<td>.120</td>
<td>.191</td>
<td>.404</td>
<td>.926</td>
<td>----</td>
<td>-.118</td>
<td>-.046</td>
<td>.043</td>
<td>----</td>
<td>----</td>
<td>-.074</td>
<td>-.028</td>
<td>.073</td>
<td>----</td>
<td>----</td>
</tr>
<tr>
<td>R.C.</td>
<td>.088</td>
<td>.225</td>
<td>.384</td>
<td>.614</td>
<td>----</td>
<td>-.119</td>
<td>-.051</td>
<td>.126</td>
<td>----</td>
<td>----</td>
<td>-.125</td>
<td>.089</td>
<td>.171</td>
<td>----</td>
<td>----</td>
</tr>
<tr>
<td>C.K.</td>
<td>.081</td>
<td>.382</td>
<td>.402</td>
<td>.607</td>
<td>----</td>
<td>-.103</td>
<td>-.063</td>
<td>.044</td>
<td>.212</td>
<td>----</td>
<td>.000</td>
<td>.143</td>
<td>.269</td>
<td>.413</td>
<td>----</td>
</tr>
<tr>
<td>G.M.</td>
<td>.112</td>
<td>.291</td>
<td>.394</td>
<td>.712</td>
<td>----</td>
<td>-.024</td>
<td>.003</td>
<td>.700</td>
<td>----</td>
<td>----</td>
<td>.095</td>
<td>.174</td>
<td>.340</td>
<td>----</td>
<td>----</td>
</tr>
<tr>
<td>T.M.</td>
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<td>.162</td>
<td>.393</td>
<td>.660</td>
<td>----</td>
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<td>-.087</td>
<td>.069</td>
<td>----</td>
<td>----</td>
<td>-.055</td>
<td>-.010</td>
<td>.071</td>
<td>.357</td>
<td>----</td>
</tr>
<tr>
<td>V.S.</td>
<td>.138</td>
<td>.355</td>
<td>.476</td>
<td>1.018</td>
<td>----</td>
<td>.033</td>
<td>.203</td>
<td>.403</td>
<td>----</td>
<td>----</td>
<td>.113</td>
<td>.240</td>
<td>.481</td>
<td>----</td>
<td>----</td>
</tr>
<tr>
<td>B.V.</td>
<td>.076</td>
<td>.258</td>
<td>.513</td>
<td>1.102</td>
<td>----</td>
<td>-.156</td>
<td>-.013</td>
<td>.218</td>
<td>----</td>
<td>----</td>
<td>-.011</td>
<td>.067</td>
<td>.305</td>
<td>----</td>
<td>----</td>
</tr>
<tr>
<td>D.Y.</td>
<td>.080</td>
<td>.215</td>
<td>.393</td>
<td>.745</td>
<td>----</td>
<td>-.073</td>
<td>-.050</td>
<td>.139</td>
<td>----</td>
<td>----</td>
<td>-.078</td>
<td>-.034</td>
<td>.091</td>
<td>.275</td>
<td>----</td>
</tr>
<tr>
<td>R.Y.</td>
<td>.143</td>
<td>.207</td>
<td>.390</td>
<td>.600</td>
<td>.967</td>
<td>----</td>
<td>-.078</td>
<td>-.052</td>
<td>.045</td>
<td>.138</td>
<td>----</td>
<td>.051</td>
<td>.137</td>
<td>.265</td>
<td>.505</td>
</tr>
</tbody>
</table>

Mean: .105 .248 .416 .772 .967 -.091 -.014 .223 .281 ---- -.001 .096 .242 .429 .675
Discussion

The 6.71% dehydration procedure in this study has produced statistically significant differences in the mean scores of ten subjects. A brief discussion of the effects of dehydration on the variables measured follows:

Heart Rate

The effects of dehydration are most clearly evident in the serious impairment of cardiovascular functioning (3). With even a slight reduction in the normal amount of body water the volume of circulating blood plasma decreases, thus, placing a greater strain on the heart and blood vessels. The stress is identified by a decrease in stroke volume which requires a compensatory increase in pulse rate to maintain an adequate cardiac output (46). Thus, the strain on the heart and blood vessels is increased and, if dehydration continues, the subject experiences great deficiencies in the ability to maintain exercise levels for prolonged periods of time (16, 9).

The ten subjects in this study clearly experienced an increase in heart rate with dehydration which led to a decrease in the amount of time required to produce a heart rate of 180 beats/minute. In this study the time to
produce a heart rate of 180 beats/minute was taken as a measure of endurance. Figure 1 illustrates the decrease in endurance as a result of the dehydration period.

It is interesting to note that the one hour period of rehydration greatly improved the endurance of the subjects. With a mean dehydration weight loss of 4.55 Kgs., endurance was reduced 16%. With a mean rehydration of 1.08 Kgs. in one hour, endurance improved to 7.5% below normal. However, it should be noted that R.C., a Negro wrestler who had extreme difficulty losing weight by sweating, during the period of rehydration replaced considerably more fluid (1.62 Kgs.) than any of the other subjects. Endurance for R.C. was affected 13.5% by the dehydration weight loss of 4.57 Kgs. However, after replacement of 1.62 Kgs. of fluid in one hour his endurance decreased only 3.7% from normal.

It was observed that most of the subjects in this study drank profusely for the first ten to fifteen minutes and were satisfied. However, R.C. drank profusely for the first ten to fifteen minutes and continued the replacement of small amounts of fluid periodically throughout the entire one hour. Thus, if the rehydration period had been extended, and if the other subjects had been forced to replace more fluid than that governed by thirst
alone, the mean endurance of the ten subjects after rehydration might have been improved to an even greater extent.

**Core Temperature**

Along with the detriment to cardiovascular functioning, body temperature usually is adversely effected by dehydration, in that as dehydration increases, rectal temperature rises proportionally (4). When circulation is impaired, a core temperature rise accompanies the inadequacy of the circulatory system to convey the heat from the core to the body shell. This has also been demonstrated by the work of Monagle and Craig in that Monagle et al. found continuous increase in rectal temperatures for one hour's work after dehydration (39). Craig and Cummings correlated a reduction in walking time on a treadmill after dehydration with a rise in rectal temperature to be about 0.84 (21).

The data on the core temperatures of 10 subjects dehydrated 6.71% of body weight in this study did not support the work previously cited. Only 6 of the 10 had an increase in core temperature after dehydration and only one of the six was of any magnitude. Data collected by Bock (14) was also unable to demonstrate a rise in core temperature commensurate with dehydration of college
wrestlers. In the above studies, work was performed for an extended period of time whereas in this study from 13 to 28 minutes was the range of work performance time. Perhaps a work period of longer duration is needed to significantly elevate core temperatures. Perhaps, also, wrestlers experience a certain degree of acclimatization to dehydration which allows a more effective functioning of the body temperature control mechanism.

However, as illustrated in Figure 2, core temperatures for the rehydrated condition were statistically lower than normal or the dehydrated condition. Such findings are unexplainable except that perhaps the water from rehydration was still in the gut which would tend to lower the core temperature because of heat loss by conduction from the core to the unabsorbed water. Especially might this be true if some rehydration occurred relatively close to the scheduled testing time.

**Exercise weight loss**

Figure 2 also illustrates the relationship between conditions with reference to the amount of weight lost due to sweating during exercise. Surely, when the blood plasma volume decreases due to dehydration there is an accompanying loss of body water from interstitial and intracellular spaces to share the deficit (28). Thus, less water is available for sweat production.
Results obtained between the normal conditions and dehydration condition support this concept. Evidently, rehydration greatly replenishes the water deficit to a certain degree as expressed by the data obtained between dehydrated and rehydrated conditions. Subjects in this study drank profusely immediately following the dehydration period. Thus, it would appear that when rehydration occurred enough total body water was replaced to operate the sweating mechanism, although a slight deficit in exercise weight loss still occurred when compared to control conditions.

**Oxygen Consumption**

At comparable times during the tests, no significant differences were found to exist between conditions tested in oxygen uptake. Evidently cardiac output remain sufficient, and percent saturation of the blood adequate, to maintain the levels of demand for oxygen at the tissue level. Owing to the fact that endurance, as measured by T180, was decreased with dehydration it is quite possible that the adjustment made by the circulatory system was a maintenance of cardiac output with increases in heart rate to compensate for a decrease in stroke volume. Thus, the endurance was affected without a change in oxygen uptake at predetermined intervals.
These findings also support those of Saltin who found no significant change in $O_2$ uptake after dehydration but significant changes in heart rate being considerably elevated and a 25% reduction in endurance (48). Craig also reports a reduction in walking time on the treadmill after dehydration with no decrease in $O_2$ uptake (22). A graphic illustration of $O_2$ uptake at five minute intervals under all conditions tested appears in Figure 3.

**Excess CO$_2$ Production**

Figure 4 illustrates that everyone of the ten subjects in this study had a decrease in excess CO$_2$ production at 5 minute intervals during the dehydrated run. These differences are difficult to explain; however, work R.Q. is affected by three basic factors: (a) the type of food utilized during work, (b) the hydrogen ion concentration of the blood, and (c) ventilation rates. Since the mean VESTPD for the ten subjects under all conditions tested did not show great changes (see Fig. 5), it is assumed that the differences in excess CO$_2$ production during the dehydrated state were a result of a decreased hydrogen ion concentration in the blood, which would tend to lower the working R.Q., and an increase in fat metabolism which would have the same effect.
Studies by Craig support the above findings in that after dehydration, a decrease in fraction of CO$_2$ in expired air was correlated 0.82 with a reduction in walking time on the treadmill (23).
FIGURE 2

Mean Core Temp's in °C (N=10)

Mean Ex. HT. Loss in Egs. (N=10)

1C 2D 3R

1C 2D 3R

\[ t=1.26 \quad t=2.77 \]
\[ t=2.45 \]

\[ t=4.80 \quad t=5.33 \]
\[ t=1.88 \]

\[ .05 = 2.26 \]
\[ .025 = 2.69 \]
\[ .01 = 3.25 \]
\[ .005 = 3.70 \]
\[ .001 = 4.78 \]
Figure 4

Excess CO₂ in 1/min.

5 min. intervals
Figure 5

- 1C
- 2D
- 3R

VES/PD in 1/min.

5 min. intervals
CHAPTER V
SUMMARY AND CONCLUSION

Summary

The purpose of this study was to determine the effects of acute dehydration weight loss on the endurance of college wrestlers. More specifically, the study was an attempt to determine the effects of 6% initial body weight loss due to dehydration on heart rate, core temperature, exercise weight loss, excess CO$_2$ production and O$_2$ uptake.

Nine Ohio State University freshmen wrestlers and one varsity wrestler were employed as subjects and were tested by use of the Balke Treadmill Test under two experimental conditions and one control. The Balke Treadmill Test consists of walking on a motor driven treadmill at a constant speed of 3.5 mph with a grade increase of 1% each minute. The test is scored in terms of the time required for heart rate to reach 180 beats/minute (T180).

The ten subjects served as their own controls in that two tests were performed by each subject to establish a mean score for the physiological variables measured under control conditions. Subjects were then asked to dehydrate 6% of original body weight by use of sweat boxes, hard physical exercise during regularly scheduled practice
sessions, steam baths, and abstinence from water over a 24 to 48 hour period. After the dehydration period, subjects were tested immediately. Two tests were performed by each subject in the dehydrated state on two different occasions in order that a mean score might be obtained for the physiological variables measured. The dehydrated condition was labeled 2D. Subjects were then asked again to dehydrate 6% of original body weight by similar means and at the end of the dehydration period were weighed and given one hour to rehydrate to satiety. Subjects were then weighed again and tested. This procedure was also repeated on another occasion in order to obtain a mean score for the physiological variables measured. This experimental condition was labeled 3R.

During each test heart rate was monitored by the use of a Cambridge Instrument Company electrocardiograph for fifteen second during the half minute to the three quarter mark and multiplied by four at each 5 minute interval. When the heart rate of the subject reached 180 beats/minute the test was terminated.

Core temperatures were recorded by the use of a Yellow Springs Instrument Company thermister which is specifically designed for such purpose. The thermister was inserted four inches into the rectum and taped securely
to the buttocks. The opposite end was plugged into the jack of a telemetering device. Core temperatures were recorded each minute of the tests.

Each subject was weighed nude and dry immediately before and after each test. The difference was reported as exercise weight loss.

Excess CO₂ and O₂ uptake were measured by the use of a Warren and Collins chain-compensated 120 liter spirometer. Gases were collected in the spirometer for thirty seconds the last half of the minute at five minute intervals. Samples were taken and analyzed on a Beckman O₂ analyzer. The O₂ uptake was computed by correcting the expired volume of gas to VESTPD. This volume was corrected for the nitrogen factor to give the VISTPD. O₂ consumption was then multiplied by two and reported in ml.

\[ \dot{V}CO_2 \]

was determined by the same method as \( \dot{V}O_2 \).

Excess CO₂ was then figured by subtracting 0.75 x \( \dot{V}O_2 \) from \( \dot{V}CO_2 \).

The "t" test for means was the statistical procedure used to ascertain differences existing between the mean scores of the ten subjects under conditions tested for the physiological variables measured.
Conclusions

Based upon the findings of this study, the following conclusions seem warranted:

Heart Rate

1. Endurance as measured by T130 was significantly decreased by a dehydration weight loss of 6.71% of original body weight.

2. Endurance as measured by T180 was significantly decreased by a dehydration weight loss of 6.71% of original body weight followed by a one hour rehydration period.

3. The one hour rehydration period following 6.71% dehydration weight loss did significantly improve endurance as measured by T130 when compared to the dehydration conditions.

Core Temperature

1. Core temperatures were unaffected by the 6.71% dehydration weight loss.

2. Core temperatures were significantly lower when a one hour rehydration period followed the 6.71% dehydration weight loss when compared to controls.
3. Core temperatures were significantly lower when a one hour rehydration period followed the 6.71% dehydration weight loss when compared to the dehydrated condition. It is suggested that the lower temperatures after rehydration were due to an excessive amount of static water in the gut.

**Exercise Weight Loss**

1. Exercise weight loss was significantly lowered by 6.71% dehydration.

2. When rehydration for one hour followed the 6.71% dehydration weight loss no statistical differences occurred in exercise weight loss when compared to controls.

3. When rehydration for one hour followed the 6.71% dehydration, exercise weight loss was significantly greater than when dehydrated.

**O₂ Uptake**

1. O₂ uptake was unaffected by the 6.71% dehydration weight loss.

2. Rehydration after dehydration did not significantly change O₂ uptake as compared to controls or the dehydrated condition.
Excess CO$_2$ Production

1. Excess CO$_2$ production was significantly lowered by the 6.71% dehydration weight loss at 5, 10 and 15 minute intervals.

2. Excess CO$_2$ production was significantly lowered by a 6.71% dehydration weight loss followed by one hour of rehydration at 5, 10 and 15 minute intervals.

3. When dehydration was followed by one hour of rehydration, excess CO$_2$ production was significantly greater at 5 and 10 minute intervals than when dehydrated. At the 15 minute interval, no difference was found.
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