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CANADIAN THESES ON MICROFICHE

THÈSES CANADIENNES SUR MICROFICHE

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TITLE OF THESIS/*TITRE DE LA THÈSE* Aerobic Work Capacity After Mild Dehydration

UNIVERSITY/*UNIVERSITÉ* University of Alberta

DEGREE FOR WHICH THESIS WAS PRESENTED/ *GRADE POUR LEQUEL CETTE THÈSE FUT PRÉSENTÉE* Master of Science

YEAR THIS DEGREE CONFERRED/*ANNÉE D'OBTENTION DE CE GRADE* 1975

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AEROBIC WORK CAPACITY AFTER MILD DEHYDRATION

BY

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A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE.

DEPARTMENT OF PHYSICAL EDUCATION

EDMONTON, ALBERTA

SPRING 1975

THE UNIVERSITY OF ALBERTA

FACULTY OF GRADUATE STUDIES AND RESEARCH

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled "Aerobic Work Capacity After Mild Dehydration" submitted by Daniel Gary Syrotuik in partial fulfillment of the requirements for the degree of Master of Science.

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ACKNOWLEDGEMENTS

The author wishes to express his sincere gratitude to Dr. S. W. Mendryk, Chairman of the thesis committee; and Drs. R. G. Glassford and D. C. Reid, committee members, for their contribution to this study.

Secondly, sincere thanks are extended to Claire Jacobson, whose assistance in the lab was greatly appreciated.

The author would also like to thank the eleven subjects who gave willingly of their time to participate in the stressful testing situations, as they made this study possible.

Finally, thanks go to fellow graduate students Glen Bailey, Phil Gardiner, and Frank Reardon, who acted in an assisting and advisory capacity throughout the study, and to my typist Janice.

ABSTRACT

The main purpose of this research was to investigate how a mild degree of dehydration caused by predominantly thermal heatload, metabolic-thermal heatload and voluntary dietary dehydration influenced an individual's aerobic work capacity and worktime to maximum.

The secondary purpose was to ascertain if a given degree of dehydration would significantly decrease the intravascular fluid or plasma volume of the body by examination of various hematological parameters.

Eleven healthy male university athletes were studied under normal conditions and after dehydration caused by sweating produced 1) by sitting in a heat room at a mean temperature of 135°F for one hour, 2) moderate muscular work in a heat room at a temperature of 92°F for one hour, and 3) by voluntarily reducing fluid intake for a 36 hour period. Body weight, maximum oxygen uptake, worktime to exhaustion, hematocrit ratio, hemaglobin, plasma volume, red blood cell count, and osmolarity were determined before and after the two heat room sessions. Body weight, maximum oxygen uptake and worktime to exhaustion were the only variables reported for the voluntary dietary phase.

The average decrease in body weight was 1.57 kg. (-1.84%), 1.59 kg. (-1.80%), and 1.50 kg. (-1.68%) for

treatments 1, 2, and 3 respectively. Percent body weight lost ranged form 1.13% to 2.87% for acute passive thermal dehydration, 1.27% to 2.85% for acute active thermal dehydration and .24% to 2.7[illegible] for acute dietary dehydration.

Decreases in maximum oxygen consumption and worktime to exhaustion were not significant when analyzed by a one way analysis of variance for repeated measures at the .05 level of significance for all three conditions.

The decrease in plasma volume and increase in hemaglobin, when analyzed by a "t"-test for correlated means, were significant at the .05 level of significance for the two thermal dehydration treatments.

It was believed that the decrease in circulating plasma did not affect maximum oxygen uptake because of the 1) redistribution of blood to the working muscles and 2) increased muscle pump action of the legs as the subjects approached maximum. In addition, a significant correlation coefficient between percentage increase in hemaglobin versus percentage decrease in plasma volume (.91 A.A.T.D., .87 A.P.T.D.) showed that the oxygen carrying capacity of the diminished blood volume had not reduced per millilitre of blood. This high correlation also provides a reliable means of measuring plasma volume modification, as a result of dehydration.

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Chapter I

Introduction

The negative effect of extreme environmental conditions on endurance performance levels has long been realized by coaches and researchers. The interaction between high ambient temperatures and humidity on steady state or aerobic activities has been studied extensively by various researchers to date (1,6,7,12,26,27,28,30,38). If the environment in which activity occurs is excessively hot, the loss of water and body electrolytes through sweating may be considerable and acute dehydration may result. An individual exposed to the sun for a period of six hours and performing passive activity will lose approximately 2400 millilitres of sweat and become mildly dehydrated if fluid is not ingested ad lib (26).

This result is augmented by participation in different activities at varying intensities. Marathon runners, for example, may lose 4 to 5 litres of fluid during a race conducted under extremely high temperatures or humidity (13,26, 38). Football players, practising 1 1/2 to 2 hours, fully equipped in similar environmental conditions, may lose

7 to 10 pounds of their pre-practice weight (8).

Dehydration due to physical activity in high ambient temperatures is not the only type peculiar to athletes. Wrestlers, in order to lose weight "to make" a specific weight class, often voluntarily reduce their fluid intake causing self-induced dehydration. Bock et al. (6) report that varsity wrestlers may lose from 5 to 20 pounds of their body weight in order to "weigh-in" for a meet. It is not uncommon for the more keen competitor to lose in excess of 12 percent of their normal pre-season body weight. This dietary form of dehydration causes a considerable decrement in body weight and thus allows the individual to compete at a level where he feels it is to his advantage to be lighter but maintain the same strength and endurance of his pre-dehydration weight.

Acute dehydration produced by physical activity in hot environmental situations and by voluntarily reducing fluid intake, has been investigated by various experimenters. However, results regarding the effects of these various methods of dehydration on physical work capacity and their actual mechanism are conflicting. In particular, findings in regard to changes in hematology, maximum oxygen uptake and worktime after dehydration have produced a dichotomy in the published literature related to this field. More specifically, some investigators have reported no decrease in plasma volume, maximal oxygen uptake, or worktime to exhaustion following varying degrees of dehydration. At the same time, other studies have reported significant decreases in the three preceding variables.

Statement of the Problem and Purpose of the Study

Conclusions concerning the effects of dehydration on performance are coloured by the criteria selected to reflect performance decrements and dehydration levels; the time required to reach the dehydrated condition; the method by which dehydration was achieved, and the environmental conditions under which the tests of decrement were conducted (34). The physiological implications of various levels of dehydration from previous studies have contended that in certain cases, dehydration does not cause any significant decrease in aerobic work capacity or in an individual's ability to perform work over a specified worktime. The main purpose of this research was to investigate how a mild degree of dehydration predominantly caused by thermal heat load, metabolic-thermal heat-load and voluntary dietary dehydration influenced an individual's aerobic work capacity and worktime to maximum.

The secondary purpose of this research was to investigate if a mild degree of dehydration would significantly decrease the intravascular fluid or blood plasma of the body by examination of various hematological parameters.

Limitations of the Study

1. The subjects in this study were volunteers and thus a bias was built into the data collected.
2. Temperature and humidity in the treatment environment were difficult to control to a strict degree of accuracy.
3. The study was limited by equipment error and the technical error of the researcher during data collection and analysis.
4. Control over a given subject's level of motivation to perform maximally during the testing situation cannot be exercised. The experimenter, however, did encourage the subjects to perform maximally.
5. The subjects were on their honour to follow the desginated dietary restrictions imposed upon them.

Delimitations of the Study

This study was delimited to 11 healthy male university athletes of the University of Alberta in Edmonton and between the ages of 20 to 28.

Definition of Terms

(1) Dehydration: The negative disruption of water balance in the body caused by excessive loss of water.

(2) Acute Active Thermal Dehydration (A.A.T.D.): Dehydration caused by a combined thermal and metabolic heatload over a short period of time.

(3) Acute Passive Thermal Dehydration (A.P.T.D.): Dehydration which occurs in a resting or passive state in a hot or humid environment over a short period of time.

(4) Acute Dietary Dehydration (A.A.D.): Dehydration caused by the deprivation of normal fluid intake over a relatively short time period.

(5) Intravascular Fluid: All fluid contained in the blood vessels of the body.

(6) Maximal Oxygen Consumption (MVO_2): The point at which oxygen consumption per minute has attained its maximum in an exercise to exhaustion. (Expressed in volume of oxygen consumed per minute, as a function of body weight--ml./kg./min.)

(7) Maximal Aerobic Work Capacity: The highest oxygen uptake an individual can attain during physical work, breathing air at sea level.

(8) Treadmill Grade: The treadmill "grade" or elevation is defined as units of rise per 100 horizontal units and is expressed in percentages. A grade of 100 percent is equal to an angle of 45°.

(9) Cardiac Output: The volume of blood ejected by the heart per unit of time. Cardiac Output=Heart Rate x Stroke Volume.

(10) Stroke Volume: The amount of blood ejected by the left ventricle per heart beat.

(11) Respiratory Quotient (R.Q.): The relationship of carbon dioxide produced to the amount of oxygen consumed. A ratio of 1.00+ indicates maximum oxygen uptake or aerobic work capacity.

Basic Assumptions

The study proceeded under the following basic assumptions:

(1) Maximum oxygen uptake was a reliable method of testing aerobic work capacity.

(2) The treatment situations were not of such a duration as to deplete local muscle glycogen stores. This was of particular importance during the acute active thermal dehydration phase.

(3) The methods and techniques developed to create a dehydrated state are reliable and valid.

(4) The subjects were self-motivated to finish the maximum oxygen uptake tests.

Hypotheses

For the purpose of investigating the problem, the following set of hypotheses were constructed:

(1) It was hypothesezed that a decrease occurred in maximum

aerobic capacity, as measured by maximum oxygen uptake, after dehydration.

$H_1: > U_1 \quad U_2, U_3, U_4$.

(2) It was hypothesized that dehydration would decrease a subject's total worktime to reach exhaustion on the treadmill.

$H_2: > U_1 \quad U_2, U_3, U_4$.

(3) It was hypothesized that plasma volume or intravascular fluid of the body would decline significantly after active and passive thermal dehydration.

$H_3: > U_1 \quad U_2, U_3$.

In addition to the preceding three hypotheses, the following subproblem was investigated, with no statistical analysis, in order to aid in the clarification of the relationship to be tested for significance.

(4) To evaluate the effect of acute and passive dehydration on plasma volume changes, other hematological parameters were examined to ascertain the best predictor of plasma modification.

Alternative Hypotheses

In the event of the rejection of any or all of the hypotheses proposed above, the following set of alternative hypotheses were constructed:

(1) H_o: $U_1 - U_2 - U_3 - U_4 = 0$ (3) H_o: $U_1 - U_2 - U_3 = 0$

(2) H_o: $U_1 - U_2 - U_3 - U_4 = 0$

Chapter II

Review of Related Literature

Aerobic Work Capacity Following Dehydration

A thorough examination of all relevant publications reveals two major consenses regarding the area of dehydration and its effects on aerobic work capacity. Many researchers indicate there is no significant decrement in an individual's aerobic capacity following acute dehydration, while other studies have reported findings to the contrary. The degree, however, to which each researcher dehydrated their subjects and the different methods used to create a dehydrated state vary from study to study, thus confusing the results. Despite the difference in conditions under which the data was collected, some comparisons of results regarding dehydration and aerobic power are permissable.

Adolph et al. (1) provide some of the earliest and most reliable research in regard to aerobic work performance following acute dehydration. They reported that the rate of oxygen consumption, whether measured under basal conditions, or at work on a stationary bicycle in the laboratory, showed no appreciable change.

Buskirk et al. (7), in 1956, produced results contrary to those of Adolph. Using three groups of 5 male subjects, each group was dehydrated in 115°F heat overnight, yielding a drop in body weight of approximately 5.5 percent of their initial body weight. Before and after dehydration, each subject was asked to perform two walking and running bouts on a treadmill. The results showed that dehydration was associated with an equal decrement of maximum oxygen uptake in all groups.

In 1961, Palmer (27) did similar research on selected physiological responses of ten normal young males following dehydration. The subjects were dehydrated by means of repeated 20 minute exposures in a sauna, with a 10 minute break between each exposure. Individuals incurred approximately 4.5 percent weight reduction from this passive thermal dehydration. Maximum oxygen uptake measures taken before and after this treatment exhibited no significant decrement.

Similar research involving dehydration and work performance was conducted by Blyth and Burt in the same year (5). In this study, the experimenters dehydrated the subjects for a 24 hour period by depriving them of water, coupled with sitting in a heat room for 30 to 40 minutes at 120° F wearing sweat clothing. Each subject lost approximately 3 percent of their initial body weight. The total time each subject could run on a treadmill after dehydration was compared with the run time prior to the treatment. This comparison revealed a statistically significant decrease in endurance time following dehydration.

The next major research on the effect of dehydration and aerobic work capacity was carried out by Saltin in 1964 (30). Ten healthy men, with marked differences in physical fitness took part in the experiment. Oxygen uptake was determined before and after varying degrees of dehydration caused by thermal and metabolic heat loads and a combination of both. In all three types of dehydration treatments, each subject was dehydrated so that almost the same decrease in body weight was obtained by all. (1.7 - 4.6 kg. or 4 to 6 percent of body weight.) When re-tested for maximal oxygen uptake after each dehydration period, there was no significant statistical difference. However, despite the same aerobic work capacity after dehydration, there was a definite decrease in the capacity to perform extended heavy work at maximum. This phenomena tended to be more pronounced after dehydration caused by long term exercise.

The following year, Craig and Cummings (12) compared maximal oxygen uptake and endurance walking before and after 6 hours of sweating at rest with a water restricted intake. In nine men, the average dehydration was 4.3 percent of their initial body weight. They reported that walking time to exhaustion was reduced an astounding 48 percent and that maximal oxygen uptake decreased 27 percent following dehydration.

More recent studies have been concerned with specific competitive activities where the effect of severe dehydration may significantly alter an athlete's performance. In 1967, Bock et al. (6) examined the effect of a 40 hour water restriction period upon the cardio-respiratory endurance of a group of 10 collegiate wrestlers. Maximum oxygen uptake was evaluated on a bicycle ergometer before and after the period of total abstinence from water. On completion of this dehydration treatment, the weight loss ranged from .07 to 3.85 percent of initial starting weight. Findings showed that 7 out of 10 wrestlers reduced their maximal oxygen uptake, but when statistically analyzed, no significant difference was reported.

Dehydration and Plasma Volume Modification

Closely linked with an individual's ability to perform steady state aerobic exercise is the blood and its oxygen carrying capacity. Since the term "aerobic" distinguishes the fact that oxygen is present during the synthesis of ATP at the muscle site, the volume of blood pumped by the heart per minute or "stroke volume", controls the amount of oxygen which reaches the active muscle groups. Research dating back to 1941, has indicated that there may be a decrement in total plasma volume as a result of acute dehydration (19). More recent studies have reported that initial compensation for a negative water balance is derived from the intravascular fluid or blood plasma (1,8,11,23,27, 29,32,33).

In 1941, Glickman et al. (19) completed research which observed changes in plasma volume after exposure to hot environmental conditions for several hours. Of the 24 subjects involved in the study, findings showed that 6 had increased plasma volume after dehydration, 14 remained unchanged and 4 subjects had decrements in total plasma volume.

Adolph et al. (1) who conducted studies under simulated desert conditions in 1946, reported that men who lose 1 - 11 percent of their initial body weight by rapid sweating, show a significant loss of circulating plasma. As estimated by the method of dye solution, the plasma volume diminished 2.5 times as much as did equal volumes of fluid from other tissues of the body. This would tend to indicate that plasma suffers proportionately greater reduction than the entire body, suggesting that dehydration does not affect all tissues equally. The decreased plasma volume of the blood was illustrated more clearly by the fact that in a dehydrated state, subjects tend to exhibit higher resting pulse rates per minute than at pre-dehydration levels (1).

Concerning the observed change in plasma volume, Adolph states:

> The most interesting feature of the change in plasma is that while the body loses 6 percent of its weight, the plasma loses 15 percent of its volume. The ratio of approximately 5:2 is characteristic of all individuals tested; it shows that in dehydration the plasma gives up more than its share of water . . . . This reduction definitely embarrasses the

> circulation, and much of the deterioration characteristic of dehydration may be credited to the deficient blood supply of the body. (1)

This conclusion is not universally accepted by other researchers who have compiled data in similar studies and thus provides conflicting results.

Palmer, in 1961, studied selected physiological responses of men following dehydration (27). Two parameters, hematocrit and heart rate, both increased in subjects who where in a dehydrated state. The increased hematocrit concentration indicated indirectly that the plasma component of the blood had diminished due to the effect of dehydration and that heart rate increased in order to compensate for the loss in circulating blood volume.

Conclusions reached by Kozlowski and Saltin (23) in 1964 reinforced the beliefs that plasma volume did decrease significantly with dehydration but complicated the issue by revealing a large difference in figures presented for the percentage distribution of water loss from various body fluid compartments. Similar to the methodology of earlier studies completed by Saltin, six healthy subjects were examined for hematological changes under normal conditions and after mild dehydration caused by sweating produced in (1) a sauna at 80° C, (2) by hard work at 18° C, and (3) by mild exercise at 38° C. The dehydration period in each case lasted 2.5 to 3.5 hours and the average decrease in total body weight for each treatment was 3.1 kg., 3.1 kg., and 3.5 kg. respectively. From the dilution of a quantity of injected dye, Saltin reported a significant decrease in plasma for all three testing conditions although there was a marked difference between the three modes of dehydration treatment.

In direct conflict with these findings, Astrand and Saltin (2) reported no decrease in plasma volume, as measured by dye solution after prolonged severe exercise which created a negative water balance in the body. These researchers believed no significant decrease in plasma occurred because water, which is produced as a by-product of glycolysis, prevented a noticeable loss of plasma. According to Astrand (4), sitting in a sauna will cause a greater reduction in blood volume because there is a lower rate of water liberation from glycogen metabolism. During exercise, approximately three grams of water are associated with 1 gram of glycogen (3, 4). This water is utilized in sweating, reducing the ratio of plasma lost during acute dehydration.

In a study involving circulatory response to maximal and submaximal exercise following dehydration, Saltin (29) reinforced his colleagues conclusions that there was a decrement in plasma volume. Three subjects were studied under normal conditions and after dehydration in which they lost up to 5.2 percent of their initial body weight from exposure in a sauna bath. The results of dye solution showed a pronounced 25 percent decrease in plasma volume in the dehydrated state. Maximum oxygen uptake was also estimated in this study and no significant changes occurred following dehydration. However, the maximal worktime was much shorter which might tend to indicate that the decreased circulating blood volume had a negative effect on performance not reflected by maximum oxygen uptake.

A more recent study by Senay and Christensen, using the same techniques, has confirmed these findings (32). They reported that plasma volume reduced 2 to 4 times that of other body fluid compartments when subjects were dehydrated at a rate of .45 to .5 percent of their initial body weight per hour.

Senay completed a follow-up study on changes in plasma volume and protein content during exposure of working ment in various high ambient temperatures in 1972 (33). The findings of this study concurred with his previous work, by reporting increased hematocrit and decreased plasma volume ratios.

Cade et al. in 1971 (8) presented data which tended to support the findings of all authors to date regarding hemoconcentration of the blood. This study was designed to examine any changes in composition and volume of plasma in 10 varsity football players exercised vigorously in a warm and humid environment for two hours. Each athlete lost an average of 2.7 kg. or 2.9 percent of their initial pre-practice weight during the exercise period.

The volume of circulating plasma, as determined by the injected dye solution technique, significantly decreased. It should be noted that electrolyte measures taken before and after the practice disclosed that the loss of water significantly exceeded the loss of electrolytes such as sodium or potassium. This would strengthen the concept that it is the actual water loss which produces deterioration in aerobic performance, rather than any significant alterations in body electrolytes caused by acute thermal dehydration.

The latest research in the area of dehydration and hematological changes was completed by Costill et al. 1974 (11). Six subjects were dehydrated to approximately 4 percent of their initial body weight by intermittent exposure to a hot dry environment (75-80°C; rh. 9-12%) Blood samples were taken before and after dehydration and assayed for changes in plasma volume and other hematological data. Similar to the findings of preceding studies, a mean weight reduction of 2 percent of the subject's initial body weight produced a statistically significant decrease in plasma volume.

Conclusions From the Literature

An overall summary of the related literature has revealed certain accepted conclusions on acute mild dehydration and its effects on the circulating volume of blood in the body. The majority of research to date would have one believe that excessive fluid loss or dehydration, regardless of the manner in which it was instituted, will have no significant effect upon maximal oxygen uptake, but reduce total worktime of performance and the total volume of circulating blood. These studies raise two interesting questions: Why does the maximal oxygen uptake not reflect the reduction in performance capacity? If the plasma volume is decreased, causing hemoconcentration, why is maximum oxygen uptake not affected?

It is in the light of these unresolved and conflicting results reported in the literature that has given basis for this present study.

Chapter III

Methodology

Sample

Because of the severity of the physical stress involved in the testing procedure, 11 highly fit university athletes were selected to take part in the study. All subjects underwent a medical examination, with special attention given to the cardio-vascular respiratory system, prior to the dehydration treatments, by a qualified physician to insure the safety of all involved.

Pre-Test Data and Procedure

All subjects performed a familiarization walk-run on the treadmill in order to acquaint each subject with the various required workloads and to minimize, as much as possible, any learning effect which might significantly alter their total worktime to exhaustion. This procedure was felt necessary because worktime was one of the major dependent variables being evaluated, and any decrement which might have occurred as a result of dehydration may have been offset by a learning effect. The initial session also served as a brief introduction to the respiratory apparatus utilized for the collection of expired gases.

Data on age, weight, maximum oxygen uptake, respiratory quotient, maximum heart rate and total worktime to exhaustion was recorded in a control condition or in the "pre-dehydrated" state for all subjects.

To measure the extent of the dehydration treatments, body weight changes were recorded before and after the active and passive phases of the study. Due to daily fluctuations in normal resting body weight, a mean was calculated for the pre-dietary dehydration phase from the initial body weights noted in the other testing sessions. All body weights were measured on a balance which was calibrated to an accuracy of ± 50 grams.

Maximal oxygen uptake before and after all dehydration phases was determined by a modified Bruce and Kasser multistage treadmill test (22). (Appendix A) A test-retest reliability of .95 was calculated from a pilot study of 10 subjects for this treadmill test.

The actual gas measurements were made using the open circuit technique (35). A Collins High-Speed Triple-"J" valve and a set of 1.5 I.D. corrugated rubber hoses were used to partition inspired and expired gases. The volume of expired air was measured by a Parkinson-Cowan Dry Gas Meter which was calibrated prior to each testing session with a 150 litre spirometer. All expired air was collected in 200 litre plastic Douglas bags, from which sample air was taken and analyzed for oxygen by a Beckman E-2 analyzer and for carbon dioxide by a Godart Capnograph. The Beckman and the Godart analyzers were calibrated before every testing session with reference gas concentrations that spanned the analysis range. Heart rate was monitored throughout the maximal oxygen uptake test and at exhaustion by a calibrated Sanborn 500 Viso-Cardiette.

Dehydration Treatments

The subjects were instructed to drink at least 1 litre of fluid extra the evening before the experimental day, with the exception of the dietary dehydration phase of the study. Figure I represents the entire procedure for the experiment.

To minimize any effect on an ordered pattern in the testing schedule, each of the 11 subjects were randomly treated with all three of the proposed dehydration phases at various times. Measurements for maximal oxygen uptake and total worktime to exhaustion followed each treatment. A minimum of 72 hours was allowed between each session, in order to insure a return of body fluid balance and electrolytes to a normal resting level.

On the morning of testing, the subjects were instructed to have a light breakfast, if desired. During the experimental periods, no food or water was allowed until the completion of the maximal oxygen uptake test. All subjects were carefully dried off before and after the thermal

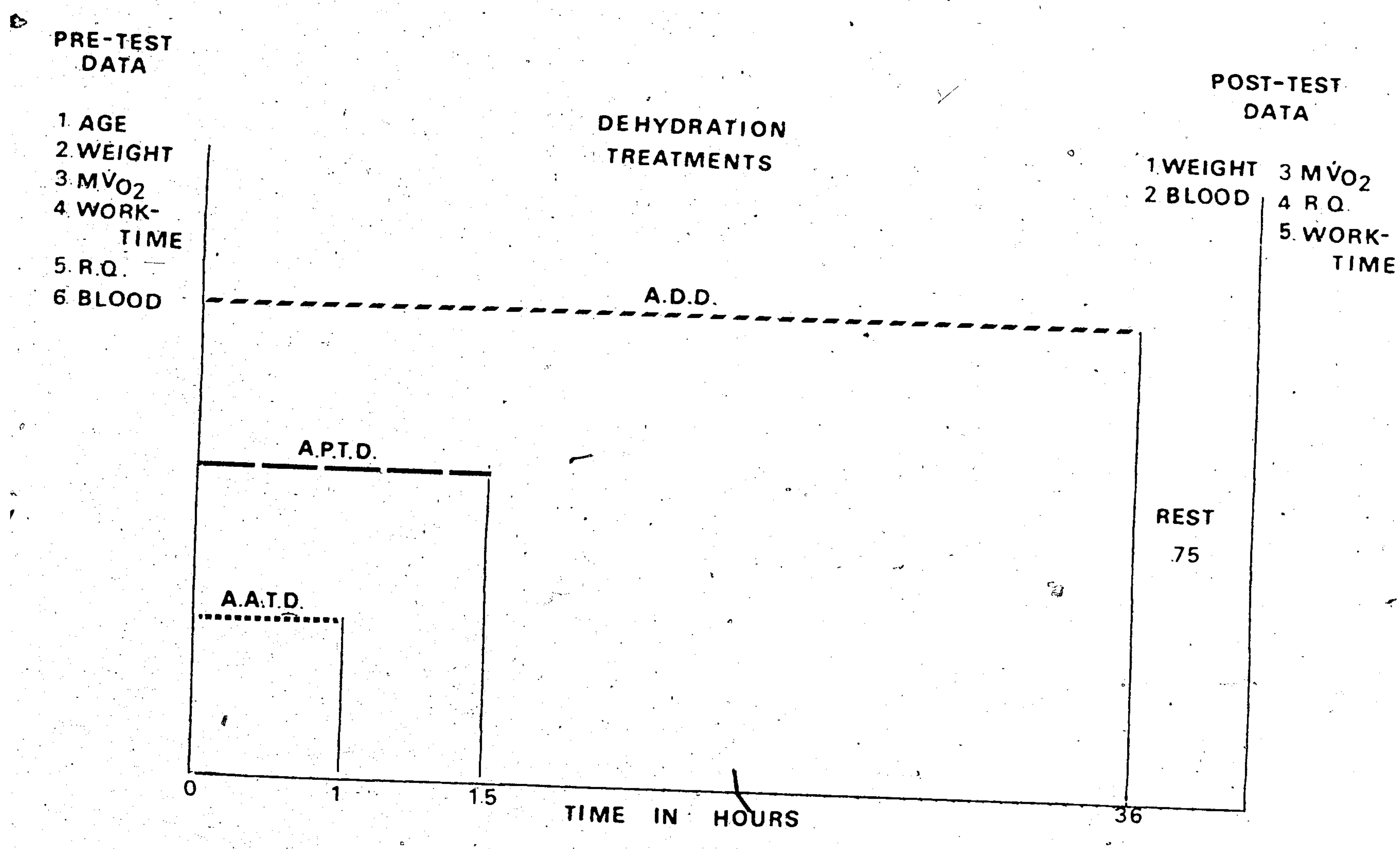


FIGURE 1 PROCEDURE FOR STUDY

dehydration phases and weighed in the nude in order to reduce error in weight measurements due to excessive surface moisture or clothing.

(a) Acute Active Thermal Dehydration Treatment (A.A.T.D.)

All subjects were dressed similarily in this treatment: running shoes, socks, shorts, light top and a sweat suit. Prior to treatment, a blood sample was taken from the anti-cubital vein of the forearm to determine hematocrit concentration, red blood cell count, hemoglobin and osmolarity. Plasma volume was estimated from the method used by Dill and Costill in 1974 (15) (Appendix B). After being carefully weighed in the nude, to the nearest 1/4 pound, each subject was placed in a heat room at a mean temperature of 33.7° C. (92.8° F) and performed light muscular work in a sitting position on a Monarch bicycle ergometer at an absolute workload of 600 kpm. for 1 hour.

Following the completion of the treatment, the subjects removed all clothing, dried off all excessive moisture and were re-weighed. Another blood sample was taken to determine levels of hematocrit, hemoglobin, red blood cell count, osmolarity and plasma volume.

After a 45 minute rest period, each subject was re-tested for maximal oxygen uptake and total worktime to exhaustion on the treadmill. Expired air was collected for 30 seconds at 3 minute time intervals throughout the test and for a minimum of 30 seconds when the subjects approached their maximum. The end-point of the test was subjectively determined by the subject, although all subjects were verbally encouraged by the researcher to achieve their highest level of performance. Maximal oxygen uptake was chosen as the highest level of oxygen reported during the test (24). All raw data was recorded on an oxygen uptake data sheet (Appendix A) and fed into the Olivetti Programma 101 for analysis.

Following the maximum oxygen uptake test, each subject was provided with fluid ad lib in order to restore necessary body fluid and electrolytes to normal. This was basically provided as a safety feature since most effects of dehydration will disappear within an hour after water is freely ingested (1).

(b) Acute Passive Thermal Dehydration Treatment (A.P.T.D.)

This treatment followed a procedure similar to that of the acute active phase. Data on each subject's weight and various hematological parameters were measured and recorded as previously mentioned in the active phase. Each of the 11 subjects were then placed nude in a heat room at a mean temperature of 57.2° C (135.1° F) on a bench 4 feet above the floor and received 20 minutes of heat exposure alternated with 10 minute breaks for 1.5 hours. Upon completion of the 1.5 hours, the subjects were dried off and re-weighed. Another blood sample was drawn to measure post-treatment hematocrit, hemoglobin, red blood cell count and osmolarity. Plasma volume was again estimated before and after dehydration by the method utilized by Dill and Costill (15).

After a 45 minute rest, maximum oxygen uptake and total worktime to exhaustion was measured on the treadmill following the same procedure as the acute active thermal dehydration phase.

(c) Acute Dietary Dehydration Treatment (A.D.D.)

The procedure for the dietary phase of the study varies somewhat from the two previous treatments. All subjects were instructed to reduce fluid intake for a period of 36 hours prior to the testing for maximal oxygen uptake on the treadmill. To accomplish this objective and to give a practical guideline to voluntary dietary dehydration, each subject was given a list of recommendations to follow prior to the commencement of the treatment (Appendix C).

Blood samples were not taken for this particular treatment. The initial weight of each subject was estimated by the mean calculated from the three previous "pre-dehydration" weights recorded in order to reduce any error which might occur due to daily fluctuations in metabolic rate or water retention. Maximum oxygen uptake and worktime to exhaustion was measured as in the previous two treatments.

Statistical Design

In order to determine any significant statistical difference in maximal oxygen uptake, worktime to exhaustion or plasma volume, a dependent group was utilized. Since each subject was his own control, the amount of variability present was greatly reduced. Under the present statistical design, many factors which produce variability between two individuals, such as level of motivation and physical condition would vary less between the pre- and post-experimental tests on the same individual than if measurements were made on two different subjects (21).

Statistical Procedure

To test the hypotheses, the following statistical procedures were employed, using $\alpha = .05$ as the level of significance.

1. The maximal oxygen uptake measurements during each of the three dehydration phases and in a normal state were subjected to a one-way analysis of variance for repeated measures (37) to determine any significant variations.

2. The worktime to exhaustion measurements for each group were subjected to a one-way analysis of variance for repeated measures (37) to determine the effect of dehydration on performance as measured by total time on the treadmill.

3. A "t"-test for correlated observations (17) was used to test for significant differences between pre- and

post-hematocrit concentrations, hemoglobin, red blood cell count, osmolarity and plasma volume in the active and passive thermal dehydration treatments.

4. In an attempt to further clarify the relationships tested, a correlation matrix was constructed for the three methods of dehydration.

Chapter IV

Results and Discussion

The "pre-dehydration" or control data for each subject, as well as the means and standard deviations for the various dependent variables, are presented in Table 1. Post-dehydration data collected on each subject for acute active thermal (A.A.T.D.), acute passive thermal (A.P.T.D.) and acute dietary dehydration (A.D.D.) treatments, along with means and standard deviations appear in Tables 2, 3, and 4 respectively.

Maximum Oxygen Uptake

The mean oxygen uptake measurements for A.A.T.D., A.P.T.D., and A.D.D. were 55.40 ml/kg/min., 53.07 ml/kg/min., and 53.79 ml/kg/min. (Figure 2). These values, expressed as percentage change from the control maximum oxygen uptake, were .40%, -3.62%. amd -1.81% respectively (Tables 9, 10, 11). Analysis of variance for repeated measures indicated no significant difference among the three dehydration oxygen uptake measurements and control at the .05 level (Table 5).

Worktime to Exhaustion

Figure 3 illustrates the mean worktime to exhaustion

TABLE 1

PRE-DEHYDRATION DATA SUMMARY

[illegible]	Age	Weight kg.	[illegible] L/min.	[illegible] ml/k[illegible]	Max. H.R. Beats/min.	Worktime Min.	R.Q.
RF	28	79.09	4.21	53.33	180	9:47	1.08
BH_1	24	81.13	5.38	66.36	188	10:57	1.08
BH_2	25	80.45	5.00	62.18	195	8:47	1.07
SI	23	79.54	4.37	54.68	180	10:13	1.06
GI	20	89.77	5.21	58.10	191	10:21	1.10
BJ	24	99.31	4.97	50.04	191	9:21	1.12
JP	21	82.95	4.80	57.42	195	10:30	1.06
GP	25	97.50	4.20	43.34	195	7:09	1.15
GR	25	79.65	4.81	60.47	191	9:18	1.09
TT	21	98.52	5.37	54.55	170	10:00	1.09

TABLE 1 CONTINUED

JW	23	118.63	5.79	48.85	195	9:11	1.07
Mean	23.54	88.86	4.91	55.39	188.27	9:35	1.08
S.D.	2.18	12.98	.48	6.22	7.82	:59	.03

TABLE 2

ACUTE ACTIVE THERMAL DEHYDRATION DATA (A.A.T.D.)

Subj. (N=11)	Weight kg.	Weight Lost Kg.	MVO_2 L/min.	MVO_2 ml/kg/min.	Max. H.R. Beats/Min.	Worktime Min.	R.Q.	% Weight Lost	Mean Temp. °F
RF	78.64	-1.48	4.87	62.01	184	10:00	1.11	-1.88	93.5
BH_1	79.32	-1.48	4.75	59.96	187	9:53	.98	-1.87	93.5
BH_2	79.09	-2.27	4.51	57.04	197	8:16	1.04	-2.85	92.3
SI	79.55	-1.36	4.30	54.10	190	10:09	1.13	-1.71	90.8
GI	86.82	-1.82	4.65	53.61	191	9:30	1.04	-2.10	93.5
BJ	98.64	-1.25	5.13	52.05	200	8:50	1.06	-1.27	93.5
JP	80.91	-1.82	4.81	59.45	200	10:06	1.02	-2.25	92.3
GP	98.98	-1.48	4.17	42.21	188	7:10	1.09	-1.50	93.5
GR	77.84	-1.25	4.78	61.40	193	8:25	1.00	-1.61	92.3

TABLE 2 CONTINUED

TT	94.32	-1.82	5.27	55.95	176	9:59	1.07	-1.93	93.5
JW	116.48	-1.48	6.02	51.70	195	9:10	1.00	-1.27	92.5
Mean	88.23	-1.59	4.84	55.40	191.00	9:14	1.04	-1.84	92.8
S.D.	11.88	.29	.48	5.42	6.86	:55	.04	.43	.85

TABLE 3

ACUTE PASSIVE THERMAL DEHYDRATION

DATA (A.P.T.D.)

Subj. (N=11)	Weight kg.	Weight Lost kg.	MVO_2 L/min.	MVO_2 ml/kg/min.	Max. H.R. Beats/min.	Worktime Min.	R.Q.	% Weight Lost	Mean Temp. °F
RF	78.29	-1.13	4.50	57.56	184	10:05	1.14	-1.45	138.0
BH_1	79.09	-2.27	4.36	55.21	191	10:34	1.16	-2.87	140.0
BH_2	78.40	-1.36	4.20	53.56	193	8:57	1.04	-1.74	140.0
SI	79.88	-2.04	4.27	53.51	187	10:07	1.09	-2.56	133.5
GI	87.72	-1.36	4.80	54.73	191	10:07	1.11	-1.55	138.0
BJ	100.00	-1.13	4.99	49.93	200	9:35	1.10	-1.13	133.5
JP	81.81	-1.36	4.98	60.92	195	10:17	1.14	-1.67	140.0
GP	99.31	-1.13	4.29	43.25	195	7:05	1.08	-1.14	130.5
GR	77.50	-1.47	4.12	53.27	191	9:16	1.11	-1.90	131.8

TABLE 3 CONTINUED

TT	94.54	-1.82	5.17	54.72	173	10:06	1.10	-1.92	138.0
JW	115.90	-2.27	5.46	47.17	187	8:16	1.14	-1.96	122.9
Mean	88.40	-1.57	4.64	53.07	189.72	9:29	1.11	-1.80	135.1
S.D.	11.95	.42	.43	4.60	6.77	:59	.03	.51	5.0

TABLE 4

ACUTE DIETARY DEHYDRATION

DATA (A.D.D.)

Subj. (N=11)	Weight kg.	Weight Lost kg.	MVO_2 L/min.	MVO_2 ml/kg/min.	Max. H.R. Beats/min.	Worktime Min.	R.Q.	% Weight Lost
RF	78.86	- .68	4.40	55.85	185	10:15	1.13	- .86
BH_1	79.32	-1.78	4.82	60.83	190	10:10	1.07	-2.24
BH_2	78.41	-2.12	4.39	56.01	191	9:18	1.03	-2.70
SI	78.98	-1.97	4.34	55.07	191	10:41	1.14	-2.49
GI	87.39	-1.78	4.51	51.69	197	10:56	1.18	-2.04
BJ	98.64	-1.48	4.90	49.76	204	9:49	1.13	-1.50
JP	82.73	- .23	4.38	53.05	187	10:02	1.10	- .28
GP	96.82	-2.79	4.43	45.80	191	7:22	1.10	-2.88
GR	79.09	- .19	4.41	55.77	193	10:03	1.17	- .24

TABLE 4 CONTINUED

TT	95.45	-1.55	5.52	57.91	173	10:25	1.09	-1.62
JW	116.36	-1.94	5.82	50.03	187	9:10	1.06	-1.66
Mean	88.36	-1.50	4.72	53.79	189.00	9:50	1.11	-1.68
S.D.	11.63	.16	.48	4.05	7.31	:55	.04	.87

FIGURE 2

MEAN MAXIMUM OXYGEN UPTAKE UNDER THE THREE DEHYDRATION TREATMENTS AND CONTROL

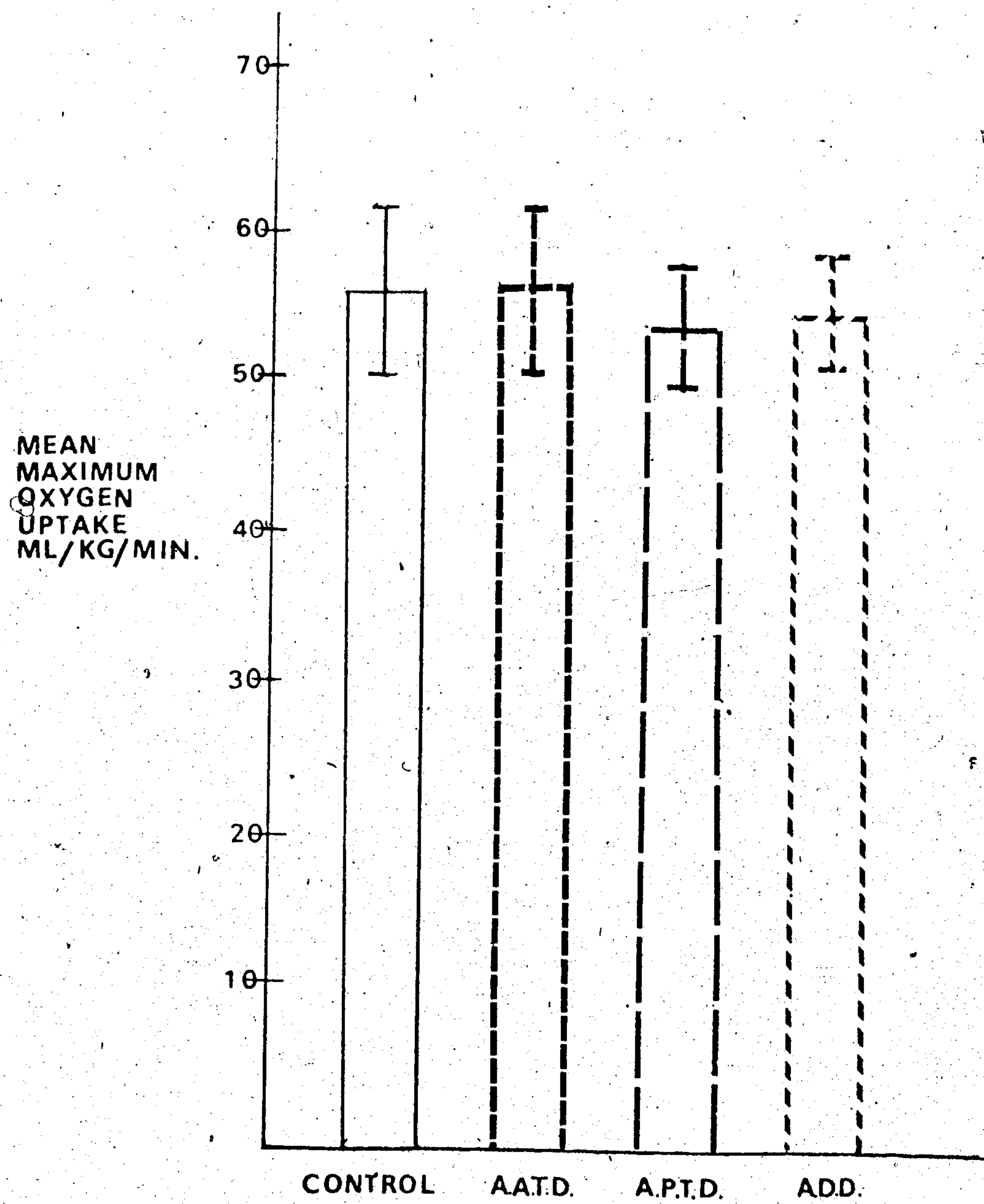


TABLE 5

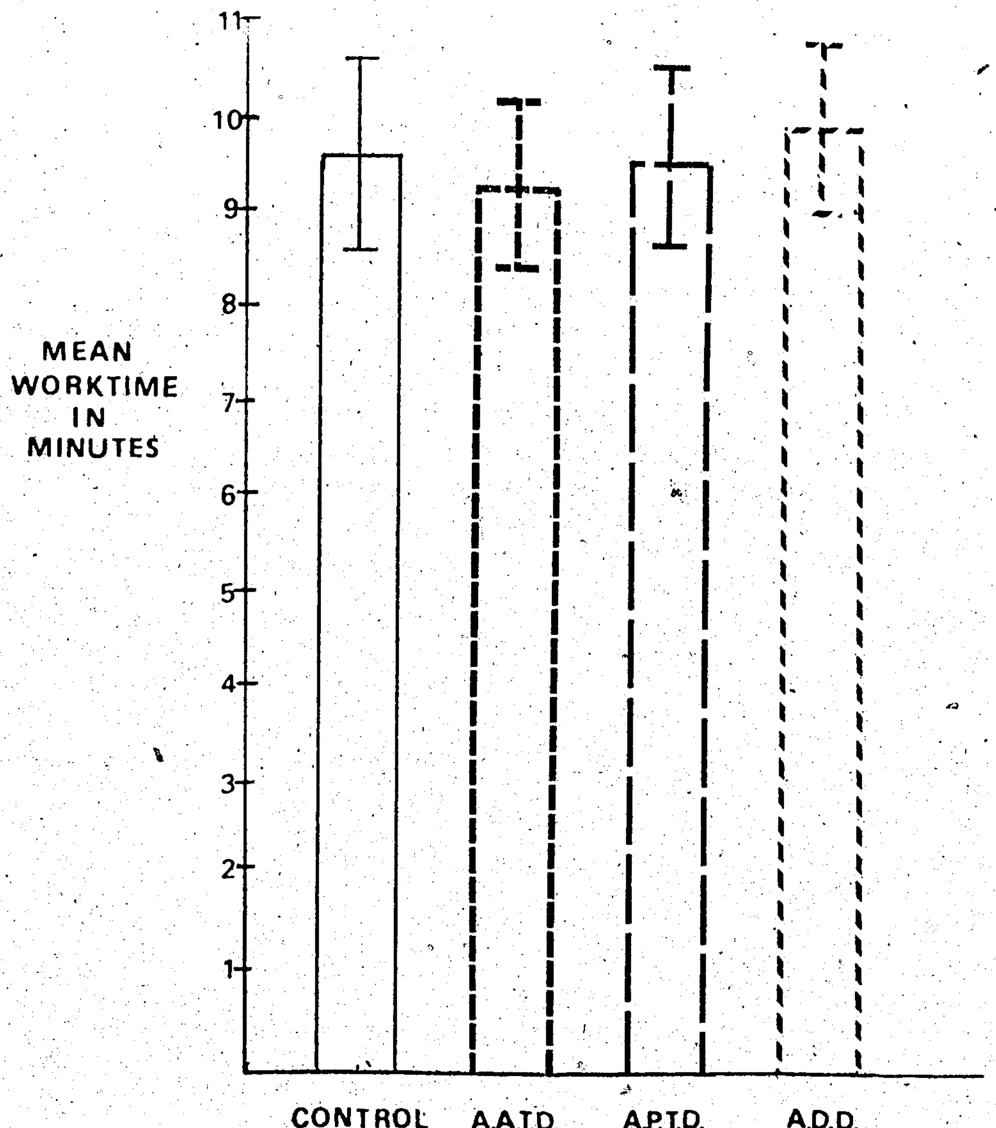
ANALYSIS OF VARIANCE FOR
MAXIMUM OXYGEN UPTAKE

Source of Variance	S.S.	df	M.S.	F.
Between	45.2811	3	15.09	.5190
Within	1163.2870	40	29.08	
Total	1208.5681	43		

$F_{.95}(3,40) < 8.60$

FIGURE 3

MEAN WORKTIME TO EXHAUSTION UNDER THE THREE DEHYDRATION TREATMENTS AND CONTROL



on the treadmill following the three dehydration treatments and in the control or normal state. The mean worktime for control, A.A.T.D., A.P.T.D., and A.D.D. were 9:35 min., 9:14 min., and 9:29 min., and 9:50 min. respectively. This represents a mean percentage change from control worktime to exhaustion of -3.80%, -1.05%, and 2.66% for A.A.T.D., A.P.T.D., and A.D.D. (Tables 9, 10, 11). When statistically analyzed by analysis of variance for repeated measures, no significant difference in worktime occurred at the .05 level (Table 6).

Plasma Volume Modification

The plasma volume in millilitres, calculated by the method proposed by Dill and Costill (15), is presented in Appendix B, Tables 14 and 15 for each subject. Absolute changes in other hematological parameters such as hemaglobin (Hb), hematocrit (Hct), osmolarity, and red blood cell count (RBC) before and after each of the thermal dehydration treatments are reported in Appendix B, Tables 16, 17, 18, and 19. Mean pre- and post-treatment plasma volume measurements for acute active and passive thermal dehydration are graphically illustrated in Figure 4. A "t"-test for correlated means was applied to each of the before and after treatment means and revealed a significant "t" ratio at the .05 level of 9:30 and 3.58 for A.A.T.D. and A.P.T.D. respectively (Tables 7, 8). In absolute terms, this is a mean percentage decrease of

TABLE 6

ANALYSIS OF VARIANCE FOR
WORKTIME TO EXHAUSTION

Source of Variance	S.S.	df	M.S.	F.
Between	.7667	3	.2555	.7079
Within	14.4389	40	.3609	
Total	15.2056	43		

$F_{.95}(3,40) < 8.60$

TABLE 7

CORRELATED "t"-TESTS FOR A.A.T.D.

HEMATOLOGICAL DATA CHANGES

	RBC Count	Hct	Osmolarity	Hb	PV
t-ratio	2.528*	4.4258*	1.86	9.58*	9.30*

$t_{.95} < 2.015$

TABLE 8

CORRELATED "t"-TESTS FOR A.P.T.D.

HEMATOLOGICAL DATA CHANGES

	RBC Count	Hct	Osmolarity	Hb	PV
t-ratio	1.617	2.558*	1.87	4.648*	3.582*

$t_{.95} < 2.132$

TABLE 9

PERCENTAGE CHANGE IN QUANTITATIVE

FUNCTIONS AS A RESULT

OF A.[illegible]

Subj. (N=11)	%MVO_2 Δ	%Worktime Δ	%Weight Δ	%Hct Δ	%RBC Count Δ	%Osmo-larity Δ	%Hb Δ	%PV Δ
RF	16.27	2.16	-1.88	2.98	2.36	-.33	3.37	-5.52
BH_1	-9.64	9.74	-1.87	2.18	4.30	1.97	4.45	-7.27
BH_2	-8.26	-5.88	-2.85	*	*	*	*	*
SI	-1.06	-1.30	-1.71	*	*	*	*	*
GI	-7.72	-8.21	-2.10	2.03	-1.82	2.58	2.61	-4.1[illegible]
BJ	4.01	-5.52	-1.27	1.50	2.49	3.13	3.16	-4.34
JP	3.53	-3.80	-2.25	*	*	*	*	*
GP	-2.60	.23	-1.50	2.76	2.76	.67	2.50	-4.83
GR	1.53	-9.49	-1.61	*	*	*	*	*

TABLE 9 CONTINUED

Subj. (N=11)	%MVO_2 $\triangle$	%Worktime $\triangle$	%Weight $\triangle$	%Hct $\triangle$	%RBC Count $\triangle$	%Osmolarity $\triangle$	%Hb $\triangle$	%PV $\triangle$
TT	.31	1.00	-1.92	*	*	*	*	*
JW	-3.43	-9.98	-1.96	2.23	8.08	5.137	6.02	-7.4
Mean	-3.62	-1.05	-1.80	1.97	3.45	3.84	4.41	-4.98
S.D.	7.48	3.45	.51	1.57	3.40	4.58	1.93	2.66

*Data not available

TABLE 10

PERCENTAGE CHANGE IN QUANTITATIVE

FUNCTIONS AS A RESULT

OF A.P.T.D.

Subj. (N=11)	%MVO_2 Δ	%Worktime Δ	%Weight Δ	%Hct Δ	%RBC Count Δ	%Osmo-larity Δ	%Hb Δ	%PV Δ
RF	7.93	3.06	-1.45	*	*	*	*	*
BH_1	-16.65	-3.50	-2.87	*	*	*	*	*
BH_2	-13.86	1.89	-1.74	*	*	*	*	*
SI	- 2.13	- .97	-2.56	3.09	3.40	10.88	6.25	-5.1
GI	- 5.80	-2.25	-1.55	*	*	*	*	*
BJ	- .21	2.49	-1.13	0.00	-1.31	- 3.36	1.25	- .85
JP	6.09	-2.06	-1.67	*	*	*	*	*
GP	- .20	- .93	-1.14	.40	.92	4.1	3.12	-3.41
GR	-11.90	- [illegible]	-1.90	4.16	6.16	2.49	5.44	-8.17

TABLE 10 CONTINUED

Subj. (N=11)	%MVO_2 Δ	%Worktime Δ	%Weight Δ	%Hct Δ	%RBC Count Δ	%Osmo-larity Δ	%Hb Δ	%PV Δ
TT	2.56	-.16	-1.93	4.67	3.13	4.52	4.34	-8.16
JW	5.83	-.18	-1.27	*	*	*	*	*
Mean	.40	-3.80	-1.84	2.68	2.20	2.09	3.40	-5.70
S.D.	7.15	4.03	.43	1.01	1.90	1.58	.76	1.51

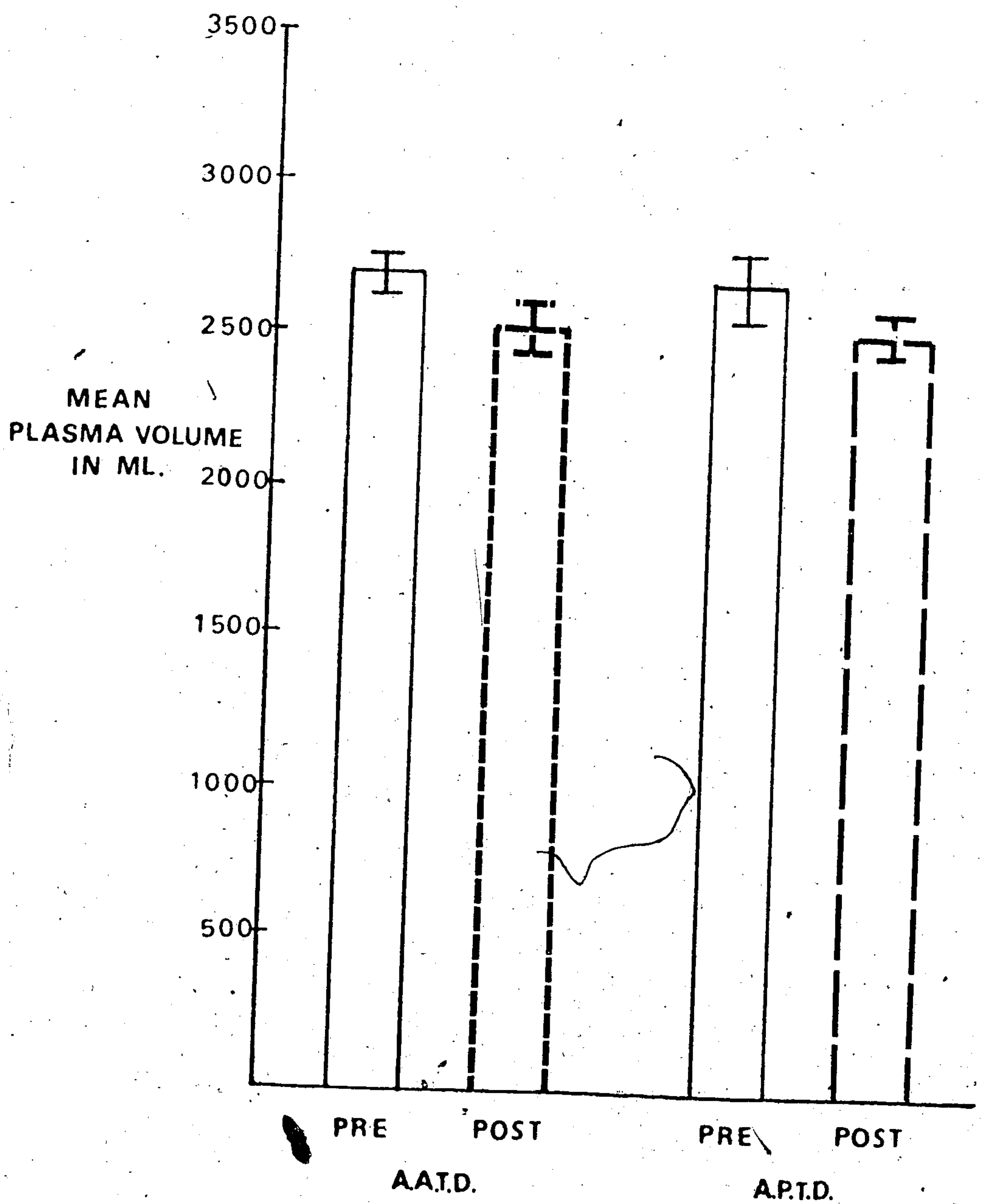
*Data not available

TABLE 11

PERCENTAGE CHANGE IN QUANTITATIVE FUNCTIONS AS A RESULT OF A.D.D.

Subject (N=11)	%MVO_2 Δ	%Worktime Δ	%Weight Δ
RF	10.35	4.77	- .86
BH_1	- 8.33	-7.15	-2.24
BH_2	- 9.22	5.88	-2.70
SI	.71	4.56	-2.49
GI	-11.03	5.63	-2.04
BJ	- .55	4.99	-1.50
JP	- 7.61	-4.45	- .28
GP	5.67	3.03	-2.88
GR	- 7.77	8.06	- .24
TT	6.15	4.16	-1.62
JW	2.41	- .18	-1.66
Mean	-1.81	2.66	-1.68
S.D.	7.10	4.66	.86

FIGURE 4
MEAN PLASMA VOLUME BEFORE AND AFTER ACTIVE AND PASSIVE THERMAL DEHYDRATION



-5.70% and -4.98% of the pre-dehydration plasma volume noted for A.A.T.D. and A.P.T.D. prior to treatment (Tables 9, 10).

In order to determine a more accurate method of predicting adjustments in plasma volume, a correlation matrix was constructed from the percentage change in all quantitative functions as a result of acute active and passive thermal dehydration treatments (Tables 12, 13).

Although several hematological parameters such a percent change in hematocrit ratio (% Hct△) and red blood cell count (% RBC△) (Table 12) revealed a fairly high relationship with changes in plasma volume (% PV△), only the correlation coefficient of .91 between percentage change in hemaglobin (% Hb△) versus plasma volume (% PV△) was statistically significant at the .05 level for A.A.T.D. It should be noted that the small sample size available was a limiting factor and that a larger sample size would have given sufficient degrees of freedom to produce stastistically significant correlation coefficients.

The correlation matrix constructed for acute passive thermal dehydration yielded several statistically significant coefficients at the .05 level (Table 13). As in acute active thermal dehydration, a significant coefficient of .87 occurred between percentage change in hemaglobin (% Hb△) versus percentage change in plasma volume (% PV△). In addition, significant relationships existed between percentage change in red blood cell count (% RBC△) versus plasma volume

TABLE 12

CORRELATION MATRIX FOR PERCENTAGE CHANGE IN QUANTITATIVE FUNCTIONS AS A RESULT OF A.A.T.D.

	% MVO₂ Δ	% Worktime Δ	% Weight Δ	% Hct Δ	% RBC Count Δ	% Osmolarity Δ	% Hb Δ	% PV Δ
%MVO_2 Δ	1.00	.6470	.3898	.2845	.1561	-.3403	.0188	.0334
%Worktime Δ		1.00	.2233	.6289	-.4936	-.3381	.1324	-.1084
%Weight Δ			1.00	.3831	.3852	.0504	.2749	.3582
%Hct Δ				1.00	.2735	.2610	-.4466	-.7297
%RBC COUNT Δ					1.00	-.0464	-.6509	-.6414
%Osmolarity Δ						1.00	-.3961	-.3654
%Hb Δ							1.00	.9178*
%PV Δ								1.00

*Significant at α = .05

TABLE 13

CORRELATION MATRIX FOR PERCENTAGE CHANGE IN QUANTITATIVE FUNCTIONS AS A RESULT OF A.P.T.D.

	% MVO_2 Δ	% Worktime Δ	% Weight Δ	% Hct Δ	% RBC Count Δ	% Osmolarity Δ	% Hb Δ	% PV Δ
% MVO_2 Δ	1.00	.1944	.5194	-.8321	-.6304	-.0176	.4928	.7816
%Worktime Δ		1.00	.3774	-.2355	-.7900	-.3872	.6095	.6077
%Weight Δ			1.00	-.8082	-.6307	-.8089	.8997*	.6346
%Hct Δ				1.00	.7609	-.5264	-.8508	-.8715
%RBC Count Δ					1.00	.4569	-.8655	-.9584*
%Osmolarity Δ						1.00	-.8150	-.4746
%Hb Δ							1.00	.8718*
%PV Δ								1.00

*Significant at $\alpha = .05$

(% PV△) and between percentage change in hemaglobin (% Hb△) versus percent reduction in body weight of .95 and .89 respectively. It should also be noted that the relationships, although not statistically significant, were somewhat high between percent changes in hemaglobin (% Hb△) versus all other dependent variables measured, indicating that hemaglobin may be a general predictor as to the degree of dehydration occurring throughout the body and to possible alterations in performance measures such as maximal oxygen uptake and worktime to exhaustion.

Summary of Results

A graphic summary of the relationship between the various significant quantitative functions and body water deficit as measured by percent of initial weight are illustrated in Figures 5 and 6 for acute active and passive thermal dehydration. Since worktime and maximum oxygen uptake were the only variables recorded for the dietary phase of the study, no graphic presentation was made. Although the A.P.T.D. treatment had many factors which correlated highly with weight loss, only increase in hemaglobin and hematocrit ratio showed any significant relationship with the acute active dehydration effect.

FIGURE 5

RELATION BETWEEN VARIOUS QUANTITATIVE FUNCTIONS AND BODY WATER DEFICIT FOLLOWING A.A.T.D.

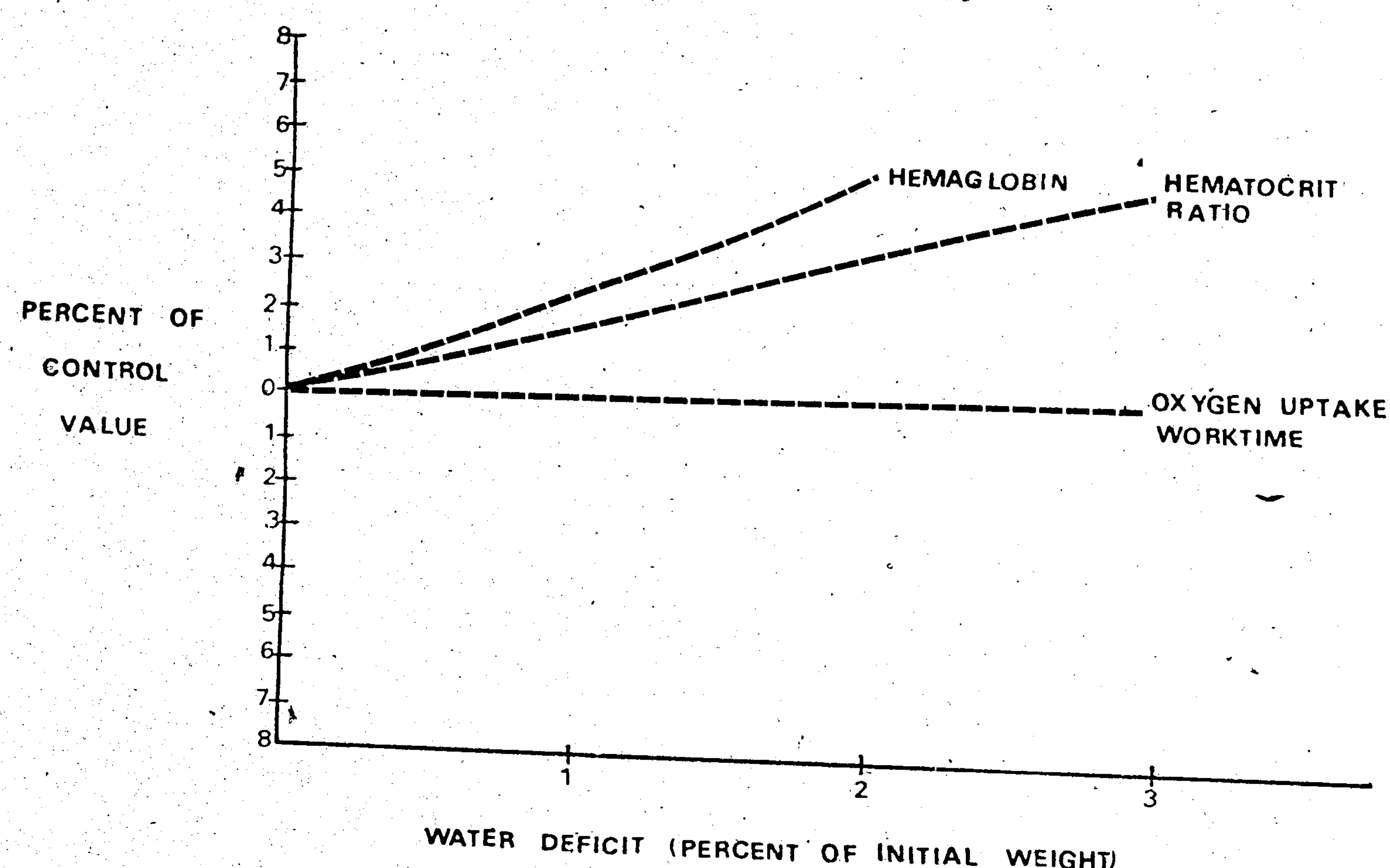
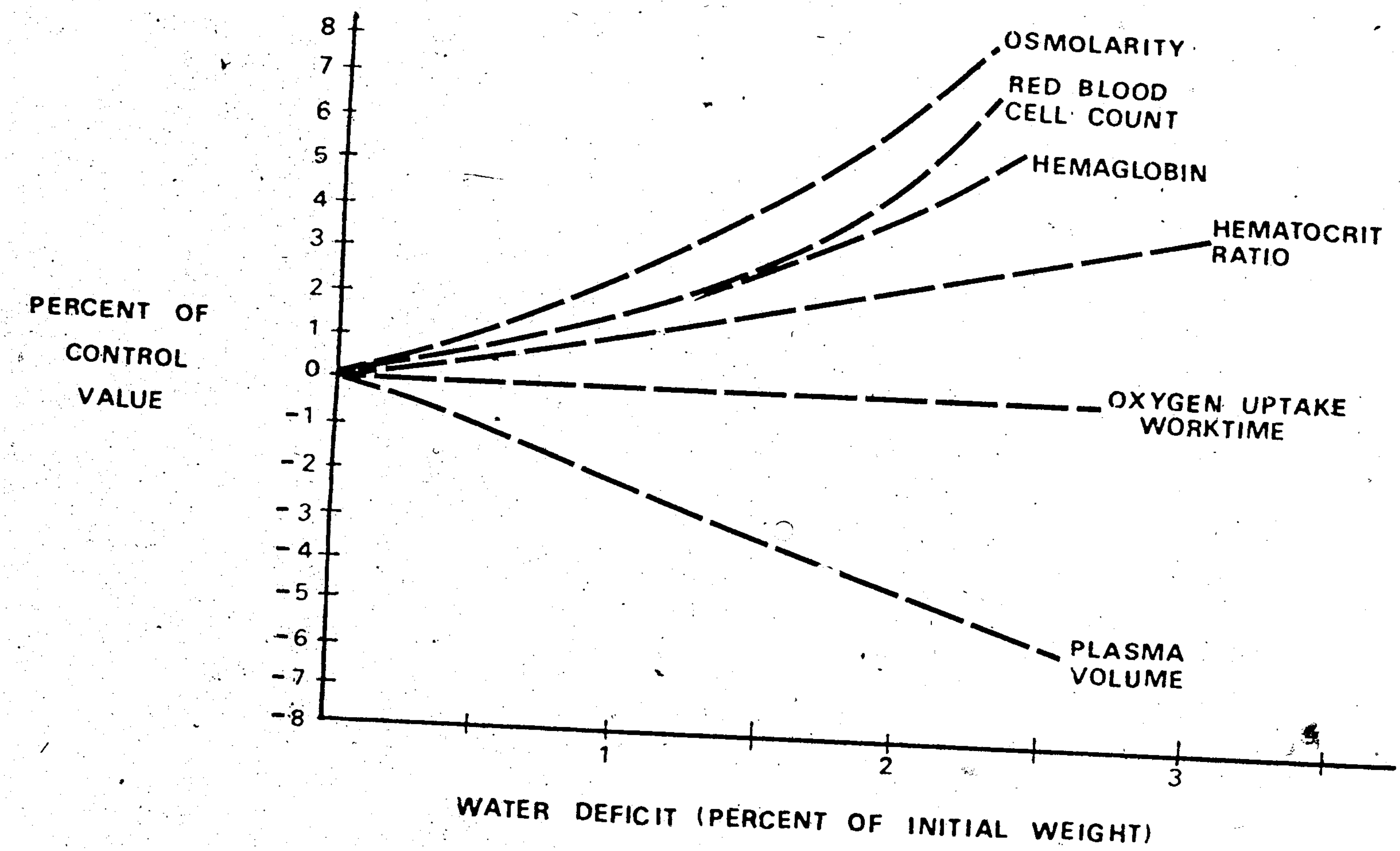


FIGURE 6

RELATION BETWEEN VARIOUS QUANTITATIVE FUNCTIONS AND BODY WATER DEFICIT FOLLOWING A.P.T.D.



Discussion of Results

Maximum Oxygen Uptake-Worktime

The results of this study would tend to support that group of exercise physiologists which have found no significant decrease in aerobic work capacity as measured by maximal oxygen uptake, (1,6,27,30). The subjects in this study were dehydrated to a mild degree (approximately 2% of initial body weight) by thermal heatload (A.P.T.D.), metabolic-thermal heatload (A.A.T.D.) and voluntary dietary dehydration (A.D.D.) treatments. This degree of dehydration is much less than that reported by all previous researchers. It must be kept in mind, however, that the weight loss recorded in this study occurred from dehydration treatments whose length and temperatures were purposely regulated to duplicate the average practice or activity session as close as possible. Therefore, weight losses of 4 to 6 percent of the initial body weight, which are reported by Saltin (30) and others are much too severe to be of practical application in physical activities such as football, wrestling and soccer.

Since absolute maximal oxygen uptake and worktime are closely correlated in this study (A.A.T.D. .60, A.P.T.D. .86, A.D.D. .62) it would be expected that worktime to exhaustion would not significantly decrease. This result is contrary to the findings of Craig and Cummings (12). In nine men dehydrated an average of 4.3 percent of their initial body weight, they reported a decrease of 48% in walking time to exhaustion.

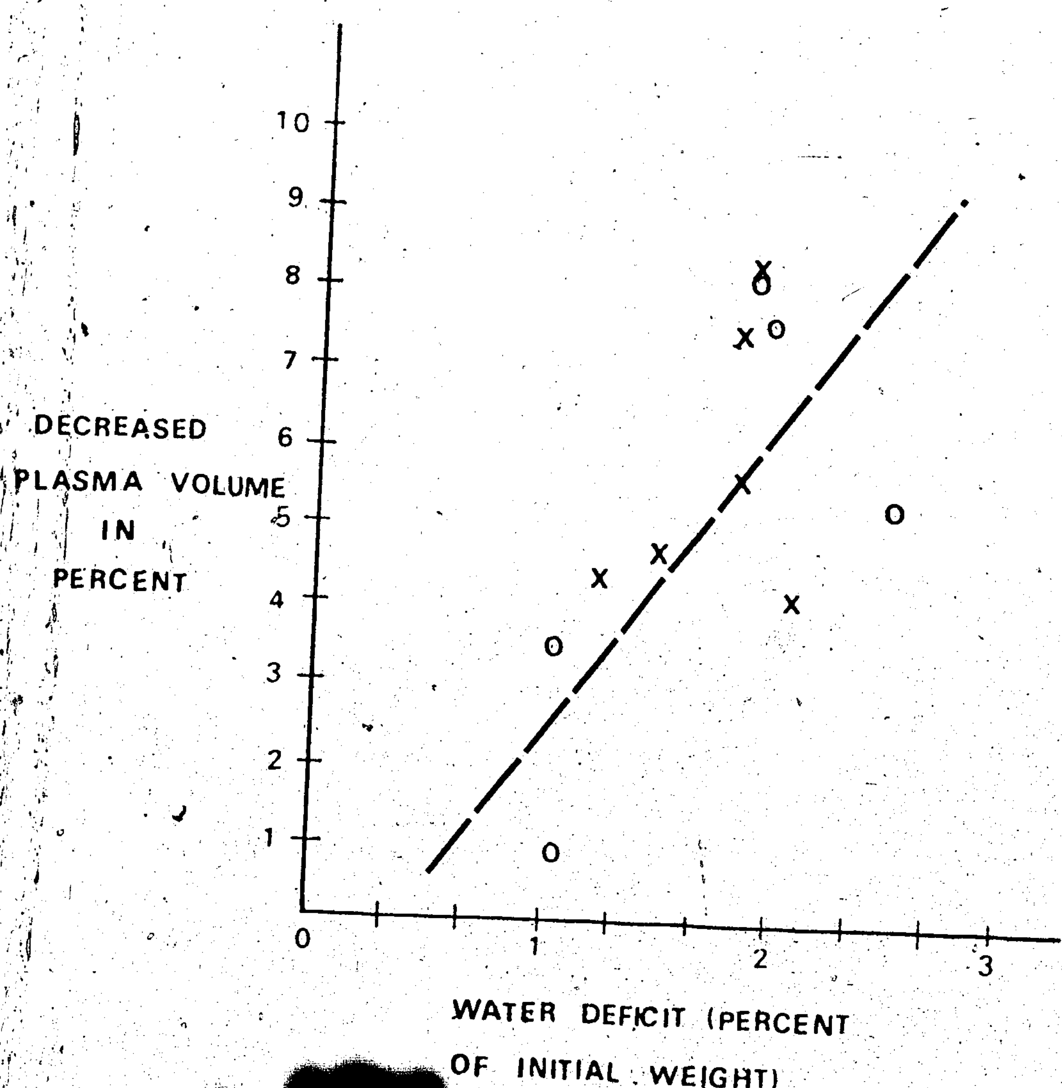
Supporting these results is research completed in 1961 by Blyth and Burt (5). Significant decreases in worktime to exhaustion were noted after the subjects were dehydrated for a period of 24 hours by depriving them of water, coupled with sitting in a heat room for 30 to 40 minutes at 120°F wearing sweat clothing. These findings would have been more meaningful had the researchers stated the test utilized to measure maximal oxygen uptake. Often, long drawn out continuous maximum oxygen uptake tests have the subjects fatigue long before they have actually attained the maximal oxygen consumption. Consequently, worktime to exhaustion may have been altered as much as reported by Craig and Cummings (12) and Blyth and Burt (5).

Plasma Volume Changes

The results of this study showed statistically significant decreases in plasma volume following both thermal dehydration treatments. This finding confirms reports that the initial compensation for a negative water balance is derived from the intravascular fluid or blood plasma (1, 8, 11,23,27,29,32,33). Figure 7 graphically illustrates decreased plasma volume in percent versus water deficit as measured by percent loss of initial weight for A.A.T.D. and A.P.T.D. The correlation coefficient for percent change of plasma (% PVΔ) versus weight loss is quite high (.63) for A.A.T.D. and relatively low (.35) for A.P.T.D. (Tables 12,13).

FIGURE 7

RELATION BETWEEN CHANGE IN PLASMA VOLUME AND BODY WATER DEFICIT



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Saltin (29) reports a correlation coefficient of .61 for dehydration similar to the A.P.T.D. in this study. These relationships may be explained by the mild workload imposed upon subjects during the active phase of dehydration. As suggested by Astrand (4) exercising at moderate workloads will liberate 3 grams of water from 1 gram of glycogen utilized in metabolism. This metabolically produced water is used in sweating, reducing the ratio of plasma lost during acute dehydration. Consequently, passive activity, such as sitting in a sauna , will cause a greater strain on the blood volume because there is a lower rate of water liberation from glycogen metabolism. The use of some glycogen during A.A.T.D. treatment is reflected in the lower R.Q.'s recorded at maximal oxygen consumption. The mean R.Q. for A.P.T.D. was 1.11 (Table 3) while the mean R.Q. for A.A.T.D. was 1.04 (Table 2) indicating some glycogen utilization during the active thermal phase and thus lowering the demand on the blood volume.

Figures 8, 9, and 10 are graphic representations of various significant relationships between modifications in plasma volume and percentage change in hemaglobin (% HbΔ), red blood cell count (% RBCΔ), hematocrit ratio (% HctΔ), and water loss (% WeightΔ) for both A.A.T.D. and A.P.T.D. Percentage change in hemaglobin (Figure 8) red blood cell count (Figure 9) and hematocrit ratio (Figure 10) versus decrease in plasma volume for both thermal dehydration

FIGURE 8

PERCENTAGE CHANGE IN PLASMA VOLUME VS BLOOD HEMAGLOBIN FOLLOWING ACTIVE AND PASSIVE THERMAL DEHYDRATION

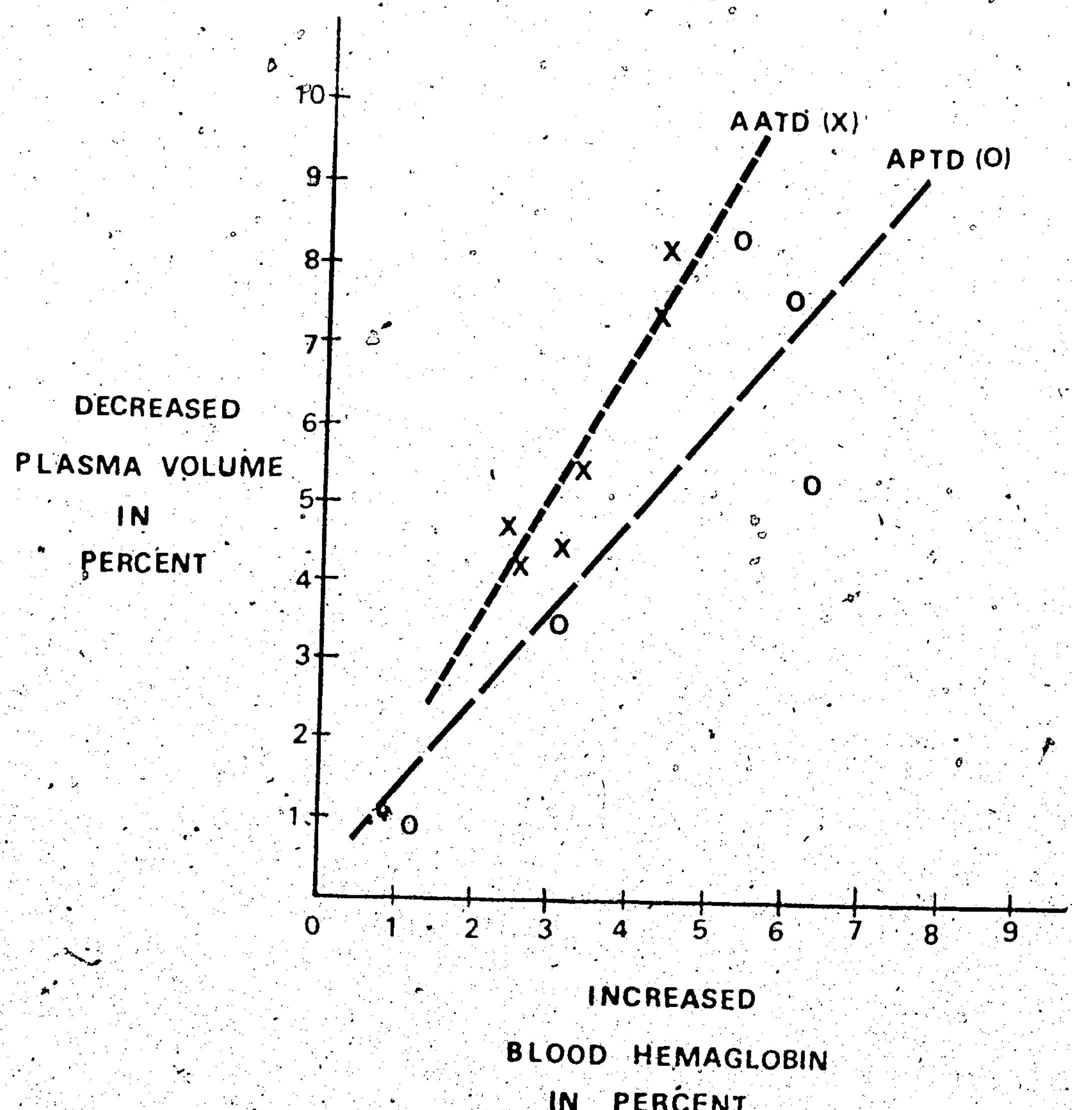


FIGURE 9

PERCENTAGE CHANGE IN PLASMA VOLUME VS RED BLOOD CELL COUNT FOLLOWING ACTIVE AND PASSIVE THERMAL DEHYDRATION

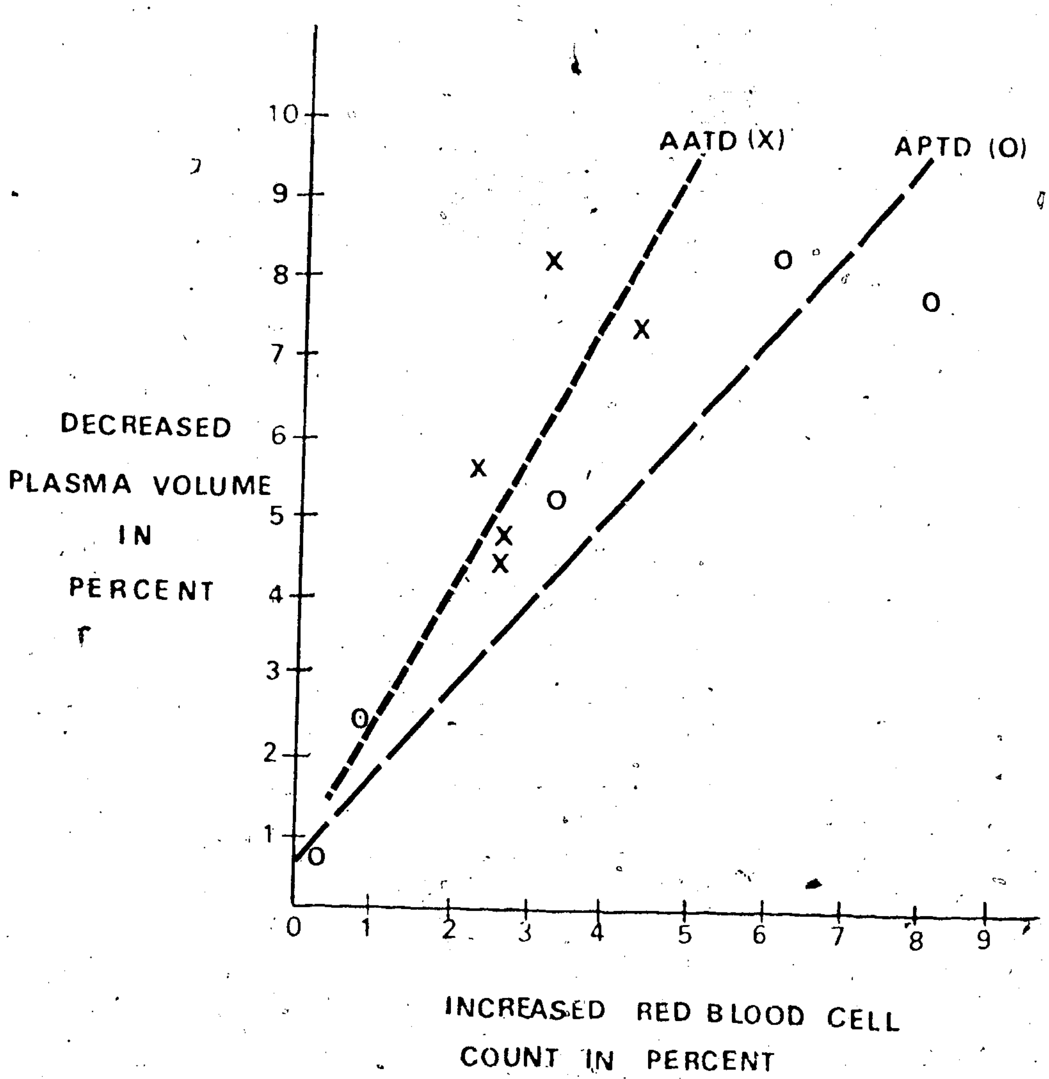
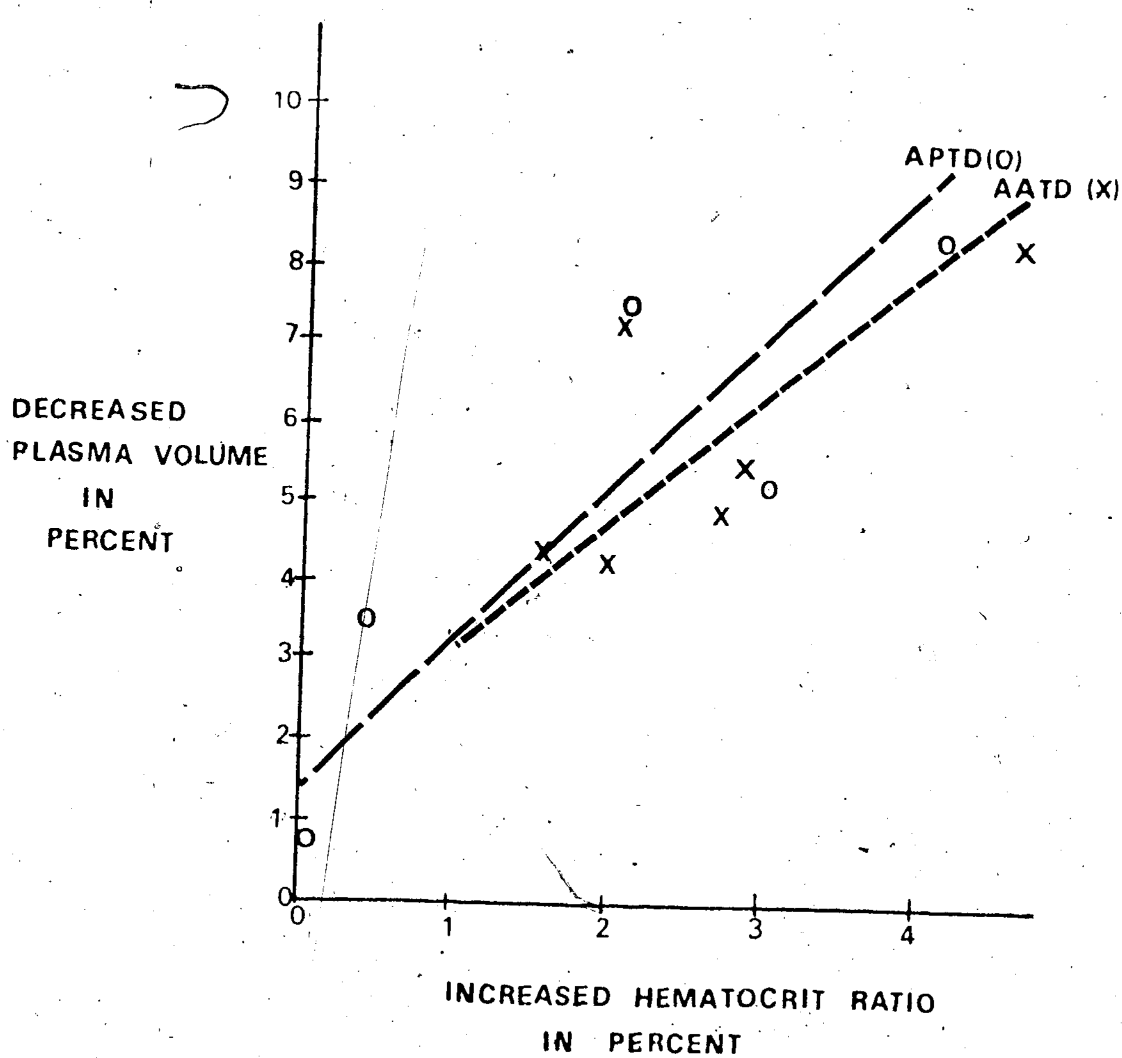


FIGURE 10

RELATION BETWEEN DECREASED PLASMA VOLUME AND INCREASED HEMATOCRIT RATIO FOLLOWING ACTIVE AND PASSIVE THERMAL DEHYDRATION



treatments, indicate a high negative relationship. This result is contrary to Saltin (29) who found a meaningless correlation between decreases in plasma volume and hemoconcentration judged from hematocrit and hemaglobin measurements. This conclusion, however, may not be valid in that blood drawn from fingertip samples, as in Saltin's study, are often contaminated by interstitial fluid.

The high negative relationship found in the present hematological parameters provides a fairly simple and reliable method of assessing changes in plasma volume as a result of dehydration by measuring hematocrit ratio or hemaglobin, as opposed to the dye solution technique used by other researchers to date. The dye solution technique involves the measurement of plasma by injecting some substance that will stay in the plasma compartment of the circulating blood. Such a substance frequently utilized is a dye called T-1824 or Evans blue (20) which, upon injection, combines almost immediately with the plasma proteins. Since plasma proteins do not leak readily out of the plasma compartment of the blood, neither will the dye. Within 10 minutes of the injection, the dye is sufficiently mixed and a sample is removed, plasma separated, and the concentration of the dye in the plasma measured. If a loss of plasma occurs due to excessive sweat rates, a post-treatment sample will indicate a higher concentration of dye for the same volume of plasma.

The dye solution method makes the major assumption that the level of plasma proteins to which the dye combines, remains the same throughout dehydration and does not diffuse out of the blood into the intracellular fluid compartment. The increased osmolarity values obtained for all subjects in the present study following thermal dehydration, would tend to support this principle (Table 9, 10). However, the high negative relationship reported between simple percentage change of hematocrit, hemaglobin or red blood cell count versus percent decrease of plasma volume would provide a simple accurate alternative method of estimating plasma changes and thus the degree of physiologic dehydration.

Aerobic Work Capacity Versus Plasma Volume Decrease

If the plasma volume is decreased, causing hemoconcentration, why is maximum oxygen uptake not affected?

The answer to this question may lie in several basic physiological principles. Under normal exercising conditions, a redistribution of blood to the working muscles of the legs takes place. After dehydration reduces the circulating blood volume, this shift of blood is probably even more pronounced. As the workload becomes heavier or maximal, the muscle pump of the legs is more effective and thus enables a greater venous return to the heart. This redistribution of the blood volume enables the subject to attain a normal stroke volume and cardiac output despite the reduced blood volume.

The second major principle operating to maintain the same volume of oxygen to the working muscles is reflected in the hemaglobin and red blood cell increases, following dehydration. Even though the total volume of circulating blood has diminished, the amount of hemaglobin and red blood cells per millilitre of blood has increased. Since these two components are the primary oxygen carrying agents of the body, their increased concentration due to plasma loss allows for identical oxygen transport capacity per millilitre of blood, and thus maximal oxygen uptake of an individual after mild acute dehydration will be unaffected. This concept may not hold true of more severe dehydration levels (5%+ of initial body weight) in that increased hemoconcentration produces a dangerous increase in blood viscosity. This added strain on the pumping action of the heart may reduce the cardio-vascular respiratory system's efficiency to maintain oxygen consumption requirements at maximal workloads.

The Hypotheses

In view of the results observed, the following conclusions, with respect to the hypotheses originally drawn, are justified.

1. Hypothesis #1, that a decrease occurs in maximum aerobic capacity, as measured by maximum oxygen uptake after dehydration is rejected. In its place, the alternative hypothesis H_0: $U_1 - U_2 - U_3 - U_4 = 0$ is accepted.

2. Hypothesis #2, that dehydration would decrease

a subject's total worktime to reach maximum on the treadmill is rejected. In its place, the alternative hypothesis $H_o: U_1 - U_2 - U_3 - U_4 = 0$ is accepted.

3. Hypothesis #3, that plasma volume or intravascular fluid of the body would decline significantly after active and passive thermal dehydration is accepted.

Chapter V

Summary and Conclusions

The maximum oxygen uptake, total worktime to exhaustion, and various hematological parameters such as plasma volume, hemaglobin, hematocrit, red blood cell count and osmolarity were measured in 11 healthy subjects before and after acute mild dehydration caused predominantly by 1) thermal heatload (A.P.T.D.), 2) metabolic-thermal heatload (A.A.T.D.), and 3) voluntary dietary (A.D.D.) dehydration treatments. The mean loss from initial body weight as a result of the three treatments was -1.80% (A.A.T.D.), -1.84% (A.P.T.D.), and -1.68% (A.D.D.).

The results indicated: 1) that maximum oxygen uptake is not affected by a mild degree of dehydration created by the designated treatments; 2) that worktime to exhaustion on the treadmill is not significantly decreased by the three assigned treatments; 3) that the plasma component of the blood decreases as a result of increasing acute dehydration levels; and 4) that various hematological parameters such as hemaglobin, hematocrit ratio, red blood cell count and osmolarity change progressively with the degree of dehydration.

General Conclusions

In light of the results observed in this study, several generalizations may be directed at the male athlete population between the ages of 20 to 28 and participating in such activities as marathon running, football, soccer, or any other sporting activity which requires prolonged exertion in excessively hot environmental conditions. In addition, conclusions regarding athletes, such as wrestlers, who must voluntarily dehydrate themselves, in order to "weigh-in" may also be stated.

Aerobic work capacity, as measured by maximum oxygen uptake and worktime to maximum, did not significantly decrease following any form of aforementioned dehydration. Thus, wrestlers may feel relatively safe in mildly dehydrating themselves in order to make weight restrictions, by any of the preceding methods investigated and not fear any reduction in endurance performance levels, as measured by maximum oxygen uptake.

The volume of circulating plasma, as estimated from hemaglobin and hematocrit (15), decreased significantly following the thermal forms of dehydration. In particular, a high negative relationship occurred between simple percentage in hematocrit and hemoglobin (Figures 10, 8) versus percent decrease of plasma volume. If this connection holds true, this would provide a simple and reliable alternative method of measuring plasma volume changes and thus the degree of dehydration. From a physical education standpoint, and particularly in field work, this is a more practical method. Simple micro-hematocrit measurements could be drawn from venous samples and utilized to estimate the degree of dehydration in such activities as field hockey, soccer, football or cross country running, as long as the samples were immediately spun in a small centrifuge before clotting. This would negate the use of sophisticated dye solution techniques such as Evans blue, or elaborate laboratory facilities.

Although no significant decreases in maximum oxygen uptake were noted from mild dehydration in the present study, other researchers (1,26) have indicated that the problems related to more severe dehydration, such as heat cramps, heat exhaustion and heat stroke are possible if proper preventative steps are not taken to replace lost fluids and electrolytes.

Recommendations for Further Research

The following set of recommendations are listed in the hope that future research conducted along these lines will ultimately unravel the mechanisms and their interactions, between various types of dehydration, time required to reach dehydration, and by the criteria selected to reflect performance decrements and dehydration levels.

1. This research was conducted on the major

assumption that maximum oxygen uptake was a reliable method of assessing aerobic work capacity. This study could be repeated using a different set of criteria to measure aerobic work capacity.

2. Further research could examine changes in anaerobic work capacity as a result of various degrees and levels of dehydration.

3. Field work could be conducted on specific groups of athletes to determine various effects of dehydration. Marathon runners, football players, and soccer players would be possible candidates for this type of research.

4. Future investigations as to the effects of dehydration on a sample of women athletes is necessary.

APPENDIX A

APPENDIX A

Kasser and Bruce Test

The multistage exercise test involves an uninterrupted series of workloads on a motor driven treadmill; the initial submaximal load (Stage I) requires walking slowly on a 12% grade. Since there is no increase in O_2 uptake after 3 minutes of submaximal exertion, the speed and grade are increased every 3 minutes.

Stage	Speed	Grade	Average O_2 Consumption Required
	(mph)	%	(ml/kg/min.)
I	2.5	12	24.5
II	3.4	14	34.0
III	4.2	16	56.0
IV	5.0	18	64.3
V	5.8	20	70.0+

OXYGEN UPTAKE DATA SHEET

Date: ____________ Age: ____________

Name: ____________

Weight: ____________(Pre-Dehydration

____________(Post-Dehydration)

Total Worktime: ____________Min./sec.

Sample Intervals: ____________________________________

Pre-exercise H.R.: ____________

Barometric Pressure: ____________mm.Hg.

Room Temperature: ____________°C

Correction Factor: ____________(STPD).

Time Grade (%) Speed (mph)	0-3 min. 12% 2.5 (23%)	3-6 min. 14% 3.4 (30%)	6-9 min. 16% 4.2 (36%)	9-12 min. 18% 5.0 (42%)
H.R.				
Vol. Ex.				
Vol./min.				
% CO_2				
O_2 Reading				
% O_2				
VO_2 (L/min.)				
VO_2 (ml/kg/min.)				
R.Q.				

APPENDIX B

APPENDIX B

Determination of Plasma Volume Modification

The following formula is that given by Dill and Costill (15) for the calculation of plasma volume changes due to dehydration. Such computation makes two major assumptions: 1) that the volume of circulating red corpuscles is constant, and 2) that the relationship between venous hematocrit volume and whole-body hematocrit remains unaffected by exercise and dehydration. Previous studies suggest that the first assumption is valid (9,11). Costill and Saltin (10) have recently reported no change in the ratio of venous hematocrit to whole-body hematocrit following dehydration of up to 4 percent of the initial body weight.

Since changes in hemaglobin concentrations reflect the changes in blood volume, it is possible to calculate the percentage change in blood (%ΔBV), cell volume (%ΔCV) and plasma volume (%ΔPV) from the following equation:

$$BV_A = BV_B \frac{Hb_B}{Hb_A}$$

$$CV_B = BV_B \, (Hct_B)$$

$$CV_A = CV_A \, (Hct_A)$$

$$PV_B = BV_B - CV_B$$

$$PV_A = BV_A - CV_A$$

$$\% \Delta PV = 100 \frac{PV_A - PV_B}{PV_B}$$

The subscripts "B" and "A" refer to before and after dehydration. When calculating $\% \Delta BV$, and $\% \Delta PV$ only the volume for Hb_B, Hb_A, Hct_B, and Hct_A, are required. In this equation, it is not necessary to know the absolute value for blood volume before treatment as a value of 5000 millilitres is assumed.

TABLE 14

DETERMINATION OF PLASMA VOLUME CHANGES AS A RESULT OF A.P.T.D.

Subject	BV_B	BV_A	CV_B	CV_A	PV_B	PV_A	$PV_B - PV_A$	% ΔPV
SI	5000	4869.5	2265	2274.1	2825	2595.4	-139.6	-5.10
BJ	5000	4938.5	2375	2335.9	2625	2602.6	-022.4	-0.85
GP	5000	4848.5	2470	2404.8	2530	2443.7	-086.3	-3.41
GR	5000	4742.0	2160	2133.9	2840	2608.1	-231.9	-8.17
JW	5000	4716.0	2250	2169.4	2750	2546.6	-203.4	-7.40
Mean							-136.72	-4.9
S.D.							76.32	2.66

TABLE 15

DETERMINATION OF PLASMA VOLUME CHANGES

AS A RESULT OF A.A.T.D.

Subject	BV_B	BV_A	CV_B	CV_A	PV_B	PV_A	$PV_B - PV_A$	% Δ PV
RF	5000	4836.5	2175	2166.75	2825	2669.75	-155.25	-5.52
BH	5000	4786.5	2285	2268.8	2715	2517.7	-197.3	-7.27
BJ	5000	4846.5	2330	2292.4	2670	2541.0	-129.0	-4.34
GI	5000	4872.5	2210	2197.0	2790	2675.5	-114.5	-4.10
GP	5000	4878	2350	2356.0	2650	2522.0	-128.0	-4.83
TT	5000	4791.5	2355	2362.2	2645	2429.3	-215.7	-8.16
Mean							-156.62	-5.70
S.D.							37.64	1.51

TABLE 16

HEMATOLOGICAL DATA FOR A.A.T.D.

PRE-TREATMENT					
Subj.	Hct %	Hb g/100 ml.	RBC Count x 10^6	Osmo-larity MOSOM/L.	PV ml.
RF	43.5	14.8	5.07	301	2825
BH_1	45.7	15.7	5.34	305	2715
GI	44.2	15.3	5.47	309	2790
BJ	46.6	15.8	5.22	319	2670
GP	47.0	16.0	5.42	295	2650
TT	47.1	16.1	5.42	287	2645
Mean	45.68	15.61	5.32	302	2715.80
S.D.	1.38	.44	.14	10.61	19.36

TABLE 17

HEMATOLOGICAL DATA FOR A.A.T.D.

POST-TREATMENT					
Subj.	Hct %	Hb g/100 ml.	RBC Count x 10^6	Osmo-larity MOSOM/L.	PV ml.
RF	44.8	15.3	5.19	300	2669.75
BH_1	47.4	16.4	5.57	311	2517.7
GI	45.1	15.7	5.37	317	2675.5
BJ	47.3	16.3	5.35	329	2541
GP	48.3	16.4	5.57	297	2522
TT	49.3	16.8	5.59	300	2429.3
Mean	47.03	16.15	5.44	309	2559.2
S.D.	1.61	.49	.14	11.35	87.61

TABLE 18

HEMATOLOGICAL DATA FOR A.P.T.D.

PRE-TREATMENT					
Subj.	Hct %	Hb g/100 ml.	RBC Count x 10^6	Osmo-larity MOSOM/L.	PV ml.
SI	45.3	14.4	5.00	294	2735
BJ	47.3	16.0	5.34	297	2625
GP	49.4	16.0	5.43	292	2530
GR	43.2	14.7	5.03	281	2840
JW	45.0	16.6	5.07	292	2750
Mean	46.04	15.54	5.17	291.2	2696
S.D.	2.12	.84	.17	5.41	107.4

TABLE 19

HEMATOLOGICAL DATA FOR A.P.T.D.

POST-TREATMENT					
Subj.	Hct. %	Hb g/100 ml.	RBC Count x 10^6	Osmo-larity MOSOM/L.	PV ml.
SI	46.7	15.3	5.17	326	2595.4
BJ	47.3	16.2	5.27	287	2602.6
GP	49.6	16.5	5.48	304	2443.7
GR	45.0	15.5	5.34	288	2608.1
JW	46.0	17.6	5.48	307	2546.6
Mean	46.9	16.22	5.34	302.4	2559
S.D.	1.54	.81	.12	14.31	66.53

APPENDIX C

APPENDIX C

Dietary Procedure

Do's and Don'ts

1) You may consume any vegetable which contains moderate amounts of water when ever thirsty. For example, lettuce, carrots, celery. Take these only when you really need them.

2) Avoid food with excessive moisture. For example, mashed potatoes, stews, soups, sauces, and gravies.

3) Ice cubes may be consumed periodically when you are extremely thirsty. (Maximum of 8)

4) Allow 1-4 oz. glass of fluid 24 hours after dehydration starts.

5) No fluid, of any kind, other than the above is to be ingested during the 36 hour period.

6) A light breakfast is recommended on test day.

7) Avoid activities in which excessive sweating might occur during the dehydration period.

*****REMEMBER: WHEN YOU FEEL LIKE TAKING A DRINK -- DON'T!!! YOUR CO-OPERATION WILL PRODUCE MEANINGFUL RESULTS.

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