In presenting the dissertation as a partial fulfillment of the requirements for an advanced degree from the Georgia Institute of Technology, I agree that the Library of the Institute shall make it available for inspection and circulation in accordance with its regulations governing materials of this type. I agree that permission to copy from, or to publish from, this dissertation may be granted by the professor under whose direction it was written, or, in his absence, by the Dean of the Graduate Division when such copying or publication is solely for scholarly purposes and does not involve potential financial gain. It is understood that any copying from, or publication of, this dissertation which involves potential financial gain will not be allowed without written permission.

7/25/68

AN EVALUATION OF REPLACEMENT FLUIDS AND PHYSICAL PERFORMANCE FOLLOWING EXERCISE

A THESIS

Presented to

The Faculty of the Division of Graduate

Studies and Research

by

James Gregory Knight

In Partial Fulfillment

of the Requirements for the Degree

Master of Science in Industrial Engineering

Georgia Institute of Technology

August, 1971

AN EVALUATION OF REPLACEMENT FLUIDS AND PHYSICAL PERFORMANCE FOLLOWING EXERCISE

Approved:

Chairman

Date approved by Chairman: 8/16/71

ACKNOWLEDGMENTS

I gratefully acknowledge the assistance, counsel, and continued encouragement of Drs. Thomas L. Sadosky and F. Levering Neely. Without their help this research would not have been undertaken nor have reached a successful completion. Their many hours of work and assistance are certainly appreciated.

I would also express my thanks to Drs. D. C. Montgomery and J. J. Talavage, who served on the reading committee. Dr. Montgomery's assistance in the statistical analysis is greatly appreciated.

Special thanks are due Drs. Floyd James and J. A. Harrison. Dr. Harrison's advice in the design of the experiment was most helpful. Dr. James provided many hours of supervision in the collection of data and many suggestions which improved the quality of this work.

To Coca-Cola, U.S.A., appreciation is extended for their support of this study.

To my wife Liz and son Jon I say "thank you" for your never-failing support.

Finally, I would like to express my thanks to Mrs. Lydia Geeslin for her excellent typing.

TABLE OF CONTENTS

TABLE OF CONTENTS (Concluded)

LIST OF TABLES

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (Concluded)

SUMMARY

The primary purpose of this study was to evaluate the efficacy of five fluids in replacing sweat losses and to evaluate the effects of these fluids on physical performance following strenuous work or exercise. The five fluids studied were water, Athletes Replacement Fluid, Olympade, Coca-Cola, and Gatorade. No fluid replacement served as the control.

Five subjects ran on six different occasions on a treadmill at 4.5 miles per hour on a 6.5 percent incline. The ambient temperature was maintained at 90°F dry bulb, 82°F wet bulb. Following four, 12 minute runs with three, 10 minute interspaced rest periods, the subject was given a quantity of fluid equal in weight to the body weight loss of the subject.

Evaluation of replacement of sweat losses was based on changes in blood chemistry determined from samples taken before exercise, immediately after exercise, 30 minutes after exercise, and one hour after exercise. The particular blood chemistry parameters used were:

1. serum sodium concentration
2. serum potassium concentration
3. serum chloride concentration
4. carbon dioxide concentration
5. total protein concentration
6. blood sugar concentration
7. serum osmolarity.

Urine sodium and potassium concentrations in samples taken before exercise, immediately after exercise, and one hour after exercise were also used in this evaluation. Evaluation of fluid effects on physical performance was based on maximum voluntary strength and coordination test results. The tests were performed at the same times indicated for taking blood samples.

Using multivariate analysis of variance, it was shown that the s[illegible] treatment conditions differed significantly ($\alpha = .01$). The simultaneous confidence interval method and multivariate analysis of variance of the rate of recovery data failed to demonstrate the specific nature of the significant differences. The following conclusions are based on a graphical analysis of the data obtained.

There is a definite preference for fluid replacement to prevent dehydration and the subsequent temperature increase. Based on blood chemistry changes and physical performance measures and considering only the short term effects (one hour) there does not appear to be sufficient grounds for preference of replacement type fluids over water or other commonly available fluids such as Coca-Cola.

CHAPTER I

INTRODUCTION

Physiological responses to work and physical exertion in a hot environment can result in several adverse reactions, ranging from mild discomfort to the more severe heat exhaustion and even death. In almost all cases, reduced performance accompanies these adverse reactions or stresses. In groups such as men working in a hot environment, soldiers in a hot climate, and athletes exercising strenuously this reduced performance is undesirable.

People working or exercising generate heat internally due to an increased metabolic rate. If a man is working in an environment where the temperature of the air or his surroundings is greater than his body temperature, there will be a further heat gain from the surroundings by convection or radiation or both. The physiological processes which enable man to work are dependent upon a rather limited temperature range. In order for man to continue to function, the heat gain must be balanced by heat loss, or his temperature will increase. There are several body functions which regulate temperature. Among these is sweating or perspiration. By sweating, the body eliminates heat by the vaporization of water from the skin. The heat supplied by the body affects the rate of vaporization of the sweat. Atmospheric conditions, e.g., ambient temperature, movement of air, and relative humidity, exert a much greater influence on the rate of vaporization. If the relative humidity is high, then the rate of vaporization will be low and vice versa. To compensate for a low vaporization rate the body increases the sweat rate in an effort to eliminate more heat (20).

In hot humid conditions, Edholm (4) states that a person will lose approximately two liters of sweat in a four hour work period. Under similar conditions Pitts (18) found sweat rates to vary from 0.98 liter to 1.48 liters per hour during moderate exercise. If a person were to continue to lose water at this rate without replacement, body reserves would be depleted and dehydration and heat illness would occur. The resulting dehydration places an additional strain on the cardiovascular system because of a decrease in circulating blood volume and an increase in blood viscosity. Pitts (18) also has shown that subjects reached a point of impending exhaustion in approximately three hours when their water losses were not replaced. These experiments were carried out in conditions of low relative humidity which favors heat loss by evaporation and also the subject was allowed to rest.

Present in sweat are the salts sodium and potassium chloride. (These salts are essential for the normal functioning of the body.) During high sweat rate periods it has been shown that sweat contains up to 5 grams of sodium chloride per liter (21). A salt intake of 20 gm per day is achieved through the normal diet (4). Although only strenuous exercise would result in the depletion of salt reserves, other problems arise from reduced salt levels in the body. The salts play an important role in the stimulation of thirst. Although the mechanism of thirst is not completely known, it has been shown that, when normal salt levels are maintained, the individual has the desire to drink and replace water losses but as the salt level is lowered so the desire to drink is decreased (15). Once sweating has begun, there will be some salt lost. Pitts (18) points this out very clearly. "It should be emphasized that during work men never voluntarily drink as much as they sweat, even though this is advantageous for maintaining heat balance, but usually drink at a rate approximating about two-thirds of the water loss in sweat." As men become acclimatized to working in a hot environment the salt content of the sweat lessens but the sweat rate increases (4). Even with acclimatization there will be a reduced thirst.

The immediate effect of continued work without water replacement is increased body core temperatures. Some of the more acute heat disorders are heat exhaustion, heat cramps, dehydration, and heat stroke can be easily avoided. Other less acute problems do exist which may affect an individual's ability to work. Wor' in a hot environment can result in some loss or mental initiative. "Accuracy may be noticeably affected in poorly motivated persons" or a person may feel that a task requires greater concentration but without a deterioration in accuracy (3).

The problem of physical exertion in a heat stress environment is frequently encountered. People working in laundries, paper mills, textile mills, and canneries frequently encounter hot humid conditions. High temperature and low relative humidity are common in glass production, steel mills, foundries, and reduction plants. Depending upon the particular operation, the mining and chemical industries present either set of conditions. In the case of mine workers in England, the accident rate showed a marked increase during high temperatures. In another study of English mine workers, a decline in production of 41 percent was observed when the temperature rose from 73° to 86°F dry bulb and 66° to 79°F wet bulb (4). Brouha (4) also points out that steel production is "greatest in winter and least in summer." Similar trends have been observed in the glass industry, foundries, rolling mills, smelting plants, and textile factories. Much has been done to alleviate the heat stress conditions in industry, but this is not possible everywhere.

The problem encountered by the soldier and athlete is more acute due to the more strenuous nature of the exercise. At the Marine Corps Recruit Depot at Parris Island, S. C., a program to prevent the high rates of heat casualties was successful "but success was achieved only at considerable cost in hours scheduled for drill" (13).

The major problems arising from dehydration are, then, the decrease in work capacity, limited ability to work through impaired cardiovascular function, faster onset of fatigue, and increased resting pulse rate.

There are currently several fluids commercially available as replacement fluids. These fluids were designed to replace the water and salt loss which accompany sweating. However, there is very little information on the efficacy of these fluids as replacement fluids or on their effects on physical performance in man.

Statement of the Problem

The primary problem was to evaluate the efficacy of five fluids in replacing body losses in sweat and to evaluate the effects of these fluids on physical performance following strenuous work or exercise. The five fluids were water, Athletes Replacement Fluid, Olympade, Coca-Cola, and Gatorade. The control was no fluid replacement.

CHAPTER II

REVIEW OF THE LITERATURE

There is a great deal of literature regarding dehydration by sweating and its subsequent effects on the body. Presented here are some of the more pertinent literature regarding dehydration, rehydration, and their effects on physical performance.

In experiments by Pitts (18), fully acclimatized subjects marched up a grade of 2.5 percent at a constant rate of 3.5 miles per hour. The two climatic conditions used were hot dry (100°F, 30 percent relative humidity) and hot moist (95°F, 83 percent relative humidity). One subject performed six experiments under the hot dry conditions. In two experiments the subject was not permitted to drink any water, in two water equal in weight to subject weight loss, and in two water was permitted ad libitum. In the case where no water was permitted, the rectal temperature rose to the "zone of impending exhaustion" (temperatures above 102°F) in less than 3.5 hours (18). In the case of water ad libitum, the temperature remained between 100.5 and 101.5°F for approximately four hours and then began a sharp increase at which time the experiments were terminated. Where water equaled weight loss, the temperature rose to approximately 100.5°F and remained at that point. After 5.5 hours at this level the subject "said he could easily go on all day" (18). One important point Pitts brings out at this point is that, during work, men voluntarily drink only at a rate approximated by two thirds the water loss in sweat, as previously mentioned.

Further tests were also conducted to evaluate the effects of salt supplementation. In the controlled environment, either 10 percent saline solution or salt tablets without water were given. Salt in this form was too distressing for some subjects to continue. It was concluded from those that did complete the test that the sweat rate was maintained better but overall there was little or no benefit from the salt alone. In tests conducted outside during a Boston summer, three 3 gm salt tablets were administered at intervals during the march. This group also received water approximately equal in weight to the sweat loss. A second group was given only water as just described. There was no significant difference between these two groups except that "gastrointestinal uneasiness was felt by those who had received salt tablets . . . ." (18).

Tests on the effects of glucose were also conducted. In the case where large doses (100 gm per hour) were given, the subjects became uncomfortable and nauseated and the tests were discontinued. In the experiments with 25 gm of glucose and water equal to sweat, there was a slightly more favorable pulse rate, i.e. reduced heart rate (18).

Pitts et al. concluded from these experiments that the best performance of fully acclimatized men can be achieved by hour by hour replacement of water lost by sweat provided there is adequate salt in the diet (18).

Taylor (24) studied the effects of various levels of sodium chloride intake over a period of three days. In these experiments, men walked at 3.25 miles per hour at 7.5 percent grade for six 10 minute periods in the morning and afternoon. The walks were conducted in hot dry conditions (120°F, 25 percent relative humidity). All other time was spent in cooler, moister surroundings (85°F, 45 percent relative humidity). The salt intake of the subject was controlled by diet. Three groups were tested, but only two are significant as the second and third groups did not differ significantly. The first group had a low salt intake (5.8 ± 2 grams per day). A t-test was used to compare the differences of the means of physiological data (12). Taylor observed that the men on the low salt intake lost more than twice as much weight, drank less water, and sweated less than those on the moderate salt intake. The low salt group ended the first 24 hours with a dehydration of 2.5 percent of body weight as compared to 0.77 percent for the moderate group. Taylor attributed this difference to failure of the thirst mechanism to demand adequate water. On the second and third days, the sweat rate of the low group 11 markedly as compared with no significant change for the moderate group (24).

Adolph and associates (1) conducted extensive studies of the physiological effects of men working and exercising in the desert. Adolph drew the following conclusions from a variety of experiments in the desert using soldiers as subjects. A stress is induced on the circulating system because of dehydration and the subsequent decrease in plasma volume. This stress is evidenced by an increased heart rate. Dehydration by water restriction and sweating resulted in increased body core temperature and a decreased sweat rate. Adolph also observed that 15 percent of the group of subjects were unable to complete an endurance hike without water whereas only 1.7 percent failed to complete the hike with water.

Pearcy et al. (17) conducted experiments in which individuals alternated between a hot room in which they worked for one hour and a cool room in which they rested. The alternation was continued for either eight hours or 25 hours. During the study, the weight, urine flow, and skin temperature of the subjects were observed. In the subjects who were dehydrated, Pearcy observed sweat rates 15 percent below the rates of those who were fully hydrated. When the dehydrated subjects attempted to regain their water balance by drinking there was a reduction of serum chloride, marked diuresis, and secondary dehydration.

In experiments by Blyth (5), the 18 subjects were subjected to exhaustive treadmill runs at a temperature of 120°F. Before one run, the subject was hydrated with two liters of .450 percent saline solution. In another run the subject was given no fluid and in the last run the subject was dehydrated three percent of his body weight by thermal heat loading. The time each subject ran before exhaustion was significantly longer for the prehydration and normal water balance cases. Eleven of the 18 subjects were athletes and their time to exhaustion was significantly longer in the prehydration case when compared to the non-athletes.

The developer of Gatorade, Dr. Robert Cade (6) studied changes in body fluid composition of 10 college football players while practicing. Before and after a two hour practice session the body weight, plasma volume, extracellular fluid volume, sodium and potassium concentration of plasma, and sweat and plasma osmotic pressure were determined. Plasma calcium, magnesium, total protein, glucose, and total lipids were also determined. The average weight loss during the two hour period was 2.7 kg or 2.9 percent of the body weight. Cade observed an average loss of 2.0 liters in extracellular fluid and 0.3 liter in plasma volume. From this study Cade concludes that ingestion of salt tablets without water replacement would aggrevate the physiological disturbance evidenced by increased plasma sodium and potassium levels. His principal conclusion regards the content of an athletic replacement fluid. "The ideal replacement fluid for an athlete who is vigorously perspiring, then, is a hypotonic salt solution to which glucose has been added." (6)

The five fluids included in this study were water, Athletes Replacement Fluid (ARF), Olympade, Coca-Cola, and Gatorade. Coca-Cola contains sucrose and its degradation products are fructose and glucose. The sodium and potassium content is essentially the same as the water used in its preparation. All of the other special replacement fluids contain glucose, sodium, potassium, and water. For this reason, some of the more pertinent literature regarding absorption of the substances in the human gut are included here.

In 1965, Malawar (12) studied the interrelationship between sodium, glucose, and water in the human jejunum. In repeated experiments on 18 normal males, test solutions were infused into the jejunum. Malawar observed a 3.1 milliequivalents (mEq) per hour absorption of sodium from isotonic saline without glucose. When two to ten millimoles of glucose were added, sodium absorption increased by 9.2 mEq to 12.3 mEq per hour. It was also observed that two mEq of sodium was transported per millimole of glucose. Water absorption was directly proportional to net solute movement and was maximal (303 milliliters per hour) with 140 millimoles of glucose.

In a study of glucose absorption, Olsen (16) observed that glucose absorption was inhibited when the glucose concentration of the infused fluid was less than that of the blood and sodium was absent. When the glucose concentration of the fluid was greater than that of the blood, absorption of glucose was unaffected by the absence of sodium.

Fordtran (10) subjected five subjects to one hour of exercise at loads of 64 to 78 percent of maximum oxygen uptake. Gastric absorption of a solution of 13.3 percent glucose and 0.3 percent sodium chloride was not affected by exercise. This observation is based on a comparison with resting absorption data. In addition, only slight inhibition of gastric absorption of water was observed.

The literature contains very little regarding rehydration with special electrolytic fluids designed as replacement fluids or on their effect on physical performance. Included here is a discussion of all papers found to date.

Schamadan (22) conducted a study using college football and basketball players as subjects. Subjects were divided into three groups and given a fluid before athletic practice. One group received a solution containing sodium and potassium, one a solution containing only potassium, and the third a standard salt tablet with water which contained only sodium chloride. The chloride content of the urine was determined before practice on one day and after practice at one to two week intervals. Results of this experiment were inconclusive. Subjective evaluations by the subjects showed a preference for the solution containing potassium only.

Studying the endurance of college wrestlers, Eaves (8) subjected five subjects to dehydration by six percent of their body weight by any method the subject chose. Two percent rehydration using either water, Coca-Cola, Gatorade, or Cramer's "Take-5" followed. No replacement served as a control. The subjects then ran on a treadmill until a heart rate of 180 beats per minute was reached. Based on the amount of time run, core temperatures, oxygen uptake, and excess carbon dioxide production, no statistically significant difference between fluids was found.

Witten (26) had six subjects dehydrate two percent of their body weight in a sweat box on four occasions. The subjects were then given 15 minutes to rehydrate the weight loss by ingestion of Coca-Cola, water, or Gatorade. No replacement served as the control. Blood and urine samples were taken before dehydration, after dehydration, one half hour after the beginning of ingestion, one hour after, one and one-half hours after, and following exhaustive exercise. One and one-half hour after beginning ingestion of the fluids the subjects ran on a treadmill at three miles per hour which increased in grade one percent per minute. The time required for the subjects' heart rates to reach 180 beats per minute was observed. During the exercise, oxygen consumption was taken. Witten observed a slightly more rapid return to pre-dehydration level of plasma sodium concentration in the case of Gatorade. No significant difference was found in time to exhaustion, heart rates, temperature, or oxygen consumption.

In a follow-up study Cade (7) evaluated the effects on physical performance and blood chemistry of exercise with no fluid replacement, water, saline, and a glucose-electrolyte solution which had the same glucose-electrolyte content as Gatorade. Four subjects ran one mile by running 440 yards then walking 220 yards. The subjects continued to run in this manner for seven miles or until exhaustion, except that every other 440 yard run was replaced by an 880 yard run. The subjects ran three times each week for three weeks using either no replacement, water, or glucose-electrolyte. The three week period was then repeated by the same subjects with 0.1 percent saline replacing water. (There was 17 mEq/ℓ sodium in both the saline and glucose-electrolyte solution.) Before and after each run blood samples were taken for determination of sodium, potassium, and glucose. Oral, rectal, and skin temperatures were also recorded in the three sets of runs involving saline. The time required to complete the run and the time of the last 880 yards were the evaluators of endurance and maximum ability to perform work.

In the three week water studies, Cade observed a passive concentration of sodium when the subjects relied on thirst and drank during walks. An average decrease of 22.8 milligram per 100 milliliters in blood sugar and an increase of 3.3 mEq/ℓ in sodium were observed using water. Runs using the glucose-electrolyte solution resulted in a 1.2 mEq/ℓ increase in sodium and blood sugar increase 17.5 mg/100 ml. Plasma potassium did not change significantly. There was no significant difference in the time required to complete the run or the last 880 yards between no replacement and water. The same times for the glucose-electrolyte runs were significantly shorter (7).

During the set of runs with saline, higher environmental temperatures and higher humidity prevented any subject from completing the seven miles with no replacement and few were able to complete the run on saline. The average distance run was 4.7 miles with no fluid and 5.5 miles with saline. The subjects were able to complete the run using the glucose-electrolyte solution. At the end of five miles run, rectal temperature averaged 1.9°C increase with no replacement, 1.6°C with saline, and 1.0°C with glucose-electrolyte (7).

The need for adequate hydration with physical work and sweating is quite evident based on the literature presented here. Replacement of body fluid losses results in greater endurance, lower heart rates, lower body temperatures, and higher sweat rates (1,5,6,7,8,24,27,28). It is also evident that sodium, potassium, and glucose can be readily absorbed by the human gut during exercise as well as at rest (12,16,10).

There does not appear to be any literature regarding the effects of replacement fluids on the performance of submaximal or nonendurance tasks. The situation encountered by the athlete is well modeled by the experiments reported, but the industrial situation may require finer motor skills and extends over a longer period of time at a lower level of physical exertion.

CHAPTER III

METHODS AND PROCEDURES

The purpose of this study was to evaluate the efficacy of five fluids in replacing body losses due to sweating and to evaluate the effects of these fluids on physical performance following strenuous work or exercise. The five fluids studied were water, Athletes Replacement Fluid, Olympade, Coca-Cola, and Gatorade. No fluid replacement served as the control.

Subjects

The age, height, and weight of the subject at the initial run are given in Table 1. All subjects were right handed. Prior physical conditioning by the subjects varied considerably. Subject N.N. participated in intercollegiate cross country and was accustomed to running up to five miles each day. Subjects J.C. and G.W. ran one to two miles three times per week. Subjects A.C. and D.M. did not exercise regularly but played handball or tennis infrequently. Prior to actual participation in the experiment, each subject was examined by a physician and ran for the same amount of time and in the same environmental conditions as required by the experiment. Completion of this preliminary run without signs of adverse reaction or stress was the only criterion for participation. No other assessment of physical condition was made.

Table 1. Age, Height, and Weight of Subjects

Subject	Age (years)	Height (inches)	Initial Weight (pounds)
J.C.	29	70.0	167
A.C.	24	71.5	174-1/4
N.N.	19	72.0	141-1/2
G.W.	25	74.5	189-1/4
D.M.	18	71.0	156-1/4

Experimental Design

A randomized block design was used to establish the sequence of treatment conditions for each subject. Each subject was represented by a block in the design and assignment of subjects to blocks and treatments to positions in the first sequence was made at random. This design appears in Table 2. It should be noted that each subject used the six treatments in a unique sequence. This was done to randomize the effect of conditioning resulting from the experiment itself.

Test for Coordination

The primary muscle groups fatigued by this experiment were those of the legs. A method to measure any decrement in coordination of the legs was not readily available in the literature. Poock (19) presents a test for eye-hand coordination in which the subject followed a path of holes in the form of a maze inserting a stylus in each hole. The elapsed time to trace out the entire maze was the test parameter.

Table 2. Experimental Design

Subject	Run					
	1	2	3	4	5	6
J.C.	A_n	B_w	C_a	D_o	E_c	F_g
A.C.	B_w	C_a	D_o	E_c	F_g	A_n
N.N.	C_a	D_o	E_c	F_g	A_n	B_w
G.W.	D_o	E_c	F_g	A_n	B_w	C_a
D.M.	E_c	F_g	A_n	B_w	C_a	D_o

A_n - No Replacement

B_w - Water

C_a - Athletes Replacement Fluid

D_o - Olympade

E_c - Coca-Cola

F_g - Gatorade

The present test for measure of coordination is pictured in Figs. 1 and 2. A maze was formed by 14 red buttons on a pale green background. The buttons were mounted with the top of the button flush with the surface of the test board. A hole one inch in diameter surrounded the button. This arrangement prevented the subject from dragging his foot over the buttons to depress them. A bright red line between the buttons indicated the path to be followed by the subject. The button in the lower right hand corner contained a switch which started and stopped a clock.

The subject sat on a stool as shown in Fig. 1A and was allowed to adjust the height of the stool and the position of the board relative to the stool. The subject then followed the path indicated by the painted lines, depressing each button with his right big toe. Before performing the test the subject was allowed to practice the test as desired with a minimum requirement of completing the maze three times correctly. When ready, the subject was instructed to trace the pattern three consecutive times without pausing between cycles and depressing each button in succession. The test parameter for this test was the time in thousandths of a minute required to trace the pattern three times.

Test for Maximum Voluntary Strength

Maximum voluntary strength was measured using the device pictured in Fig. 3. The subject sat in the chair pictured on the left. A wire strap was then placed around the heel of the subject's right shoe. The subject's chair was positioned so as to achieve a near right angle at the knee. The subject was then instructed to retract his heel as hard as he

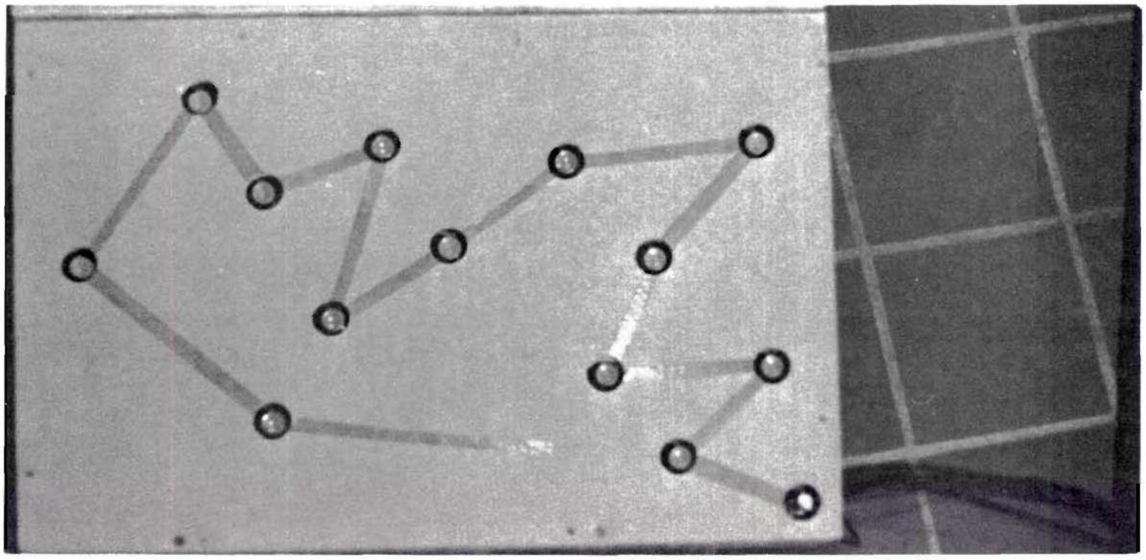

Fig. 1 A.

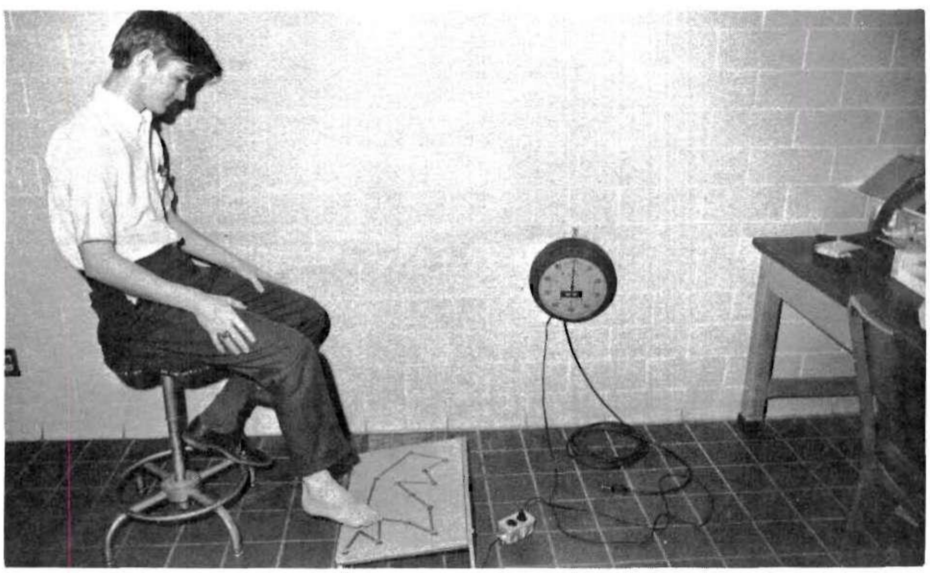

Fig. 1 B.

Figure 1. Test for Coordination

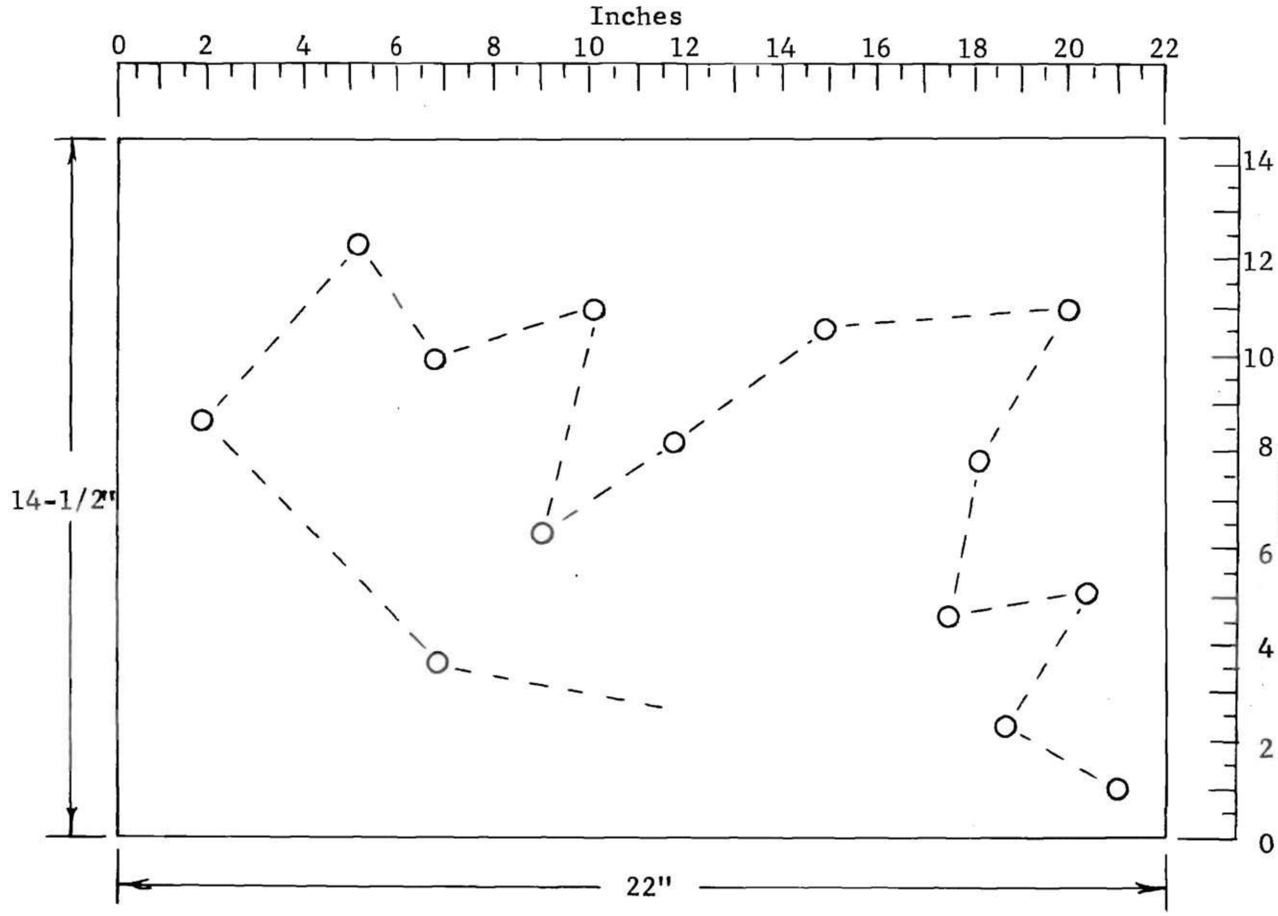

Figure 2. Location of Buttons in Test for Coordination

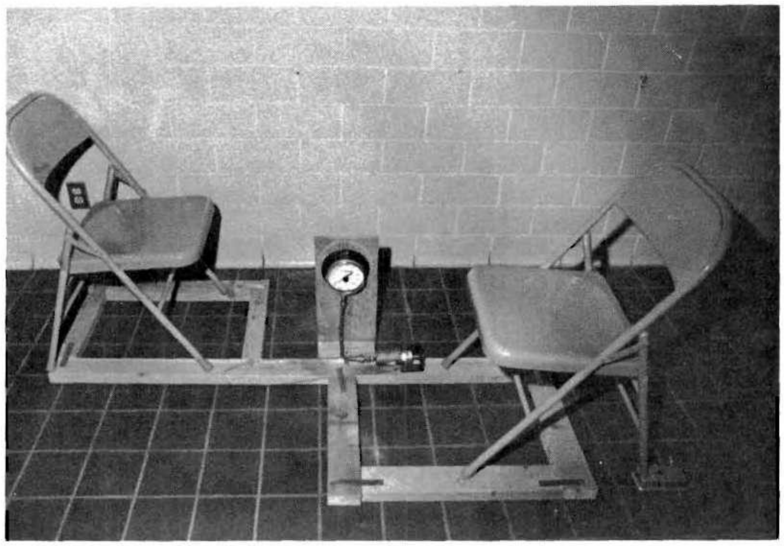

Figure 3. Maximum Voluntary Strength Test

could against the restraining wire strap. The force exerted by the subject was applied to a hydraulic cylinder filled with a hydraulic fluid. The maximum pressure reached in the cylinder was then measured using a maximum reading pressure gage. This maximum pressure in pounds per square inch gage was then recorded. This measurement constitutes the strength extend response. The pressure gage was then zeroed and the subject instructed to move to the chair pictured on the right in Fig. 2. The wire strap was then placed around the toe of the right shoe of the subject and the subject instructed to extend his toe as hard as he could. Again the maximum pressure reached in the cylinder was recorded. This measurement constitutes the strength extend response. At no time during the course of the experiment was the subject allowed to see the result of his performance.

Experimental Protocol

Subjects were scheduled for individual runs with a minimum of 48 hours between each run. This was done to allow for a complete recovery from the previous run and to reduce physical conditioning by the experiment. Subjects were instructed to eat their normal diet during the two days preceding the test and to avoid high salt intake. The diet of the subject for the 24 hour period immediately preceding the run was recorded. The subjects were also instructed to void their urinary bladder one hour before the scheduled run.

Before the experiment began, subjects again voided and a venous blood sample was drawn using an evacuated tube which did not contain anticoagulants. The pulse, blood pressure, and oral temperature of the subject were then taken and recorded. The subject was then weighed nude and the weight recorded. The subject then was allowed to practice the coordination test as much as desired with a minimum requirement of tracing the pattern three times. Following the coordination test, the subject performed the maximum voluntary strength test in the retract and extend modes. The results of the chemical determinations and test during this portion of the run will be referred to as the preliminary results.

The subject then put on a rubber glove covering his right hand and forearm. Sweat from the forearm of the subject accumulated in the glove and was removed at the conclusion of exercise by a syringe.

Following the preliminary data collection, the subject began the exercise portion of the run. This portion of the run consisted of four 12 minute running periods with three 10 minute interspaced rest periods. The subject ran on a treadmill at 4.5 miles per hour with a 6.5 percent inclination. The temperature in the testing room was maintained at 90°F dry bulb and 82°F wet bulb or 75 percent relative humidity. During the rest periods the subject's blood pressure, pulse, and oral temperature were measured to insure that the subject did not over exert himself. During these rests, the subject was allowed to sit or stand, whichever he chose.

Immediately following the fourth 12 minute running period, the subject's blood pressure, pulse, and oral temperature were taken. A blood sample was then taken called the stress sample and the subject performed the coordination and maximum voluntary strength tests. A sweat sample was then removed from the glove, the glove removed, and the subject toweled dry. He was again weighed nude and a urine sample was taken as the subject voided. The volume of urine output was recorded. These data represent the stress results.

The subject was then given an amount of fluid which had been cooled to 40°F and was equal in weight to his loss in body weight. The subject was not told the identity of the fluid at any point during the experiment. It was required that one half of the fluid be consumed in the fifteen minute period which immediately followed drawing the stress blood sample. The subject then had fifteen minutes to consume the remaining fluid.

Thirty minutes after drawing the stress blood sample a third blood sample was drawn. The coordination and maximum voluntary strength tests were repeated. These data represent the absorption results. The subject then rested for a period of thirty minutes. A fourth blood sample was then taken and the coordination and maximum voluntary strength tests repeated. This last set of data represents the recovery results.

The experimental protocol is represented schematically in Fig. 4.

Procedures

Sweat

Sweat samples were collected by means of a rubber glove on the subject's right arm. A clean, dry rubber glove which covered the subject's hand and forearm was secured at the elbow by means of tape to prevent leakage. A four milliliter sample was drawn from the glove by means of a needle and syringe.

The sodium and potassium ion concentrations were determined by means of a flame photometer using the internal lithium standard.

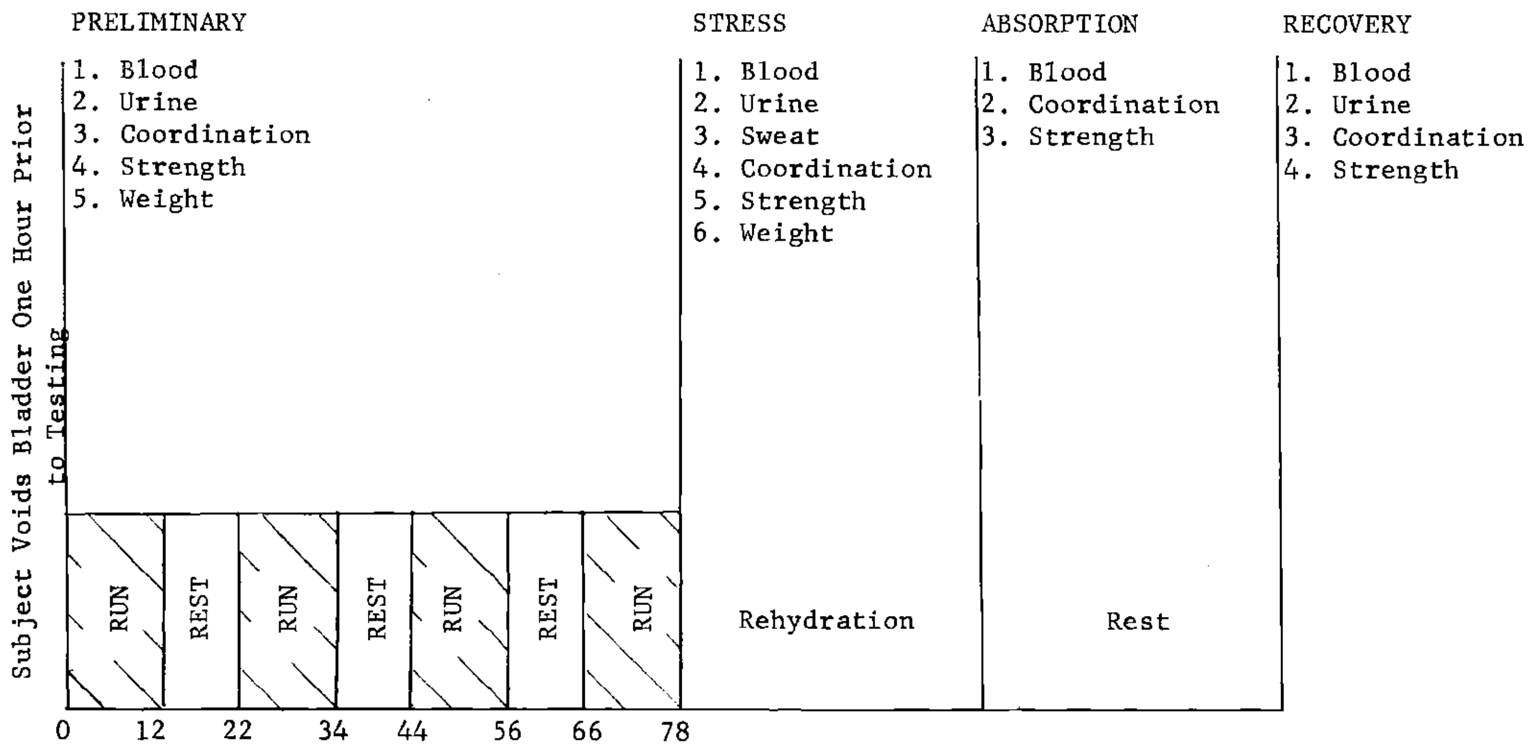

Figure 4. Experimental Protocol

Urine

At each urine collection the subject was instructed to void the bladder as completely as possible. The volume of urine collected at stress and recovery periods was recorded. The flame photometer was used to determine the sodium and potassium concentrations in the urine. Urine was collected before the preliminary weighing.

Blood

Blood was collected from a vein in the antecubital space by means of a needle inserted into the vein and connected to an evacuated test tube. The blood was then agitated to hasten clotting and then allowed to stand for ten to fifteen minutes. After the formation of a clot the blood was centrifuged and the serum removed.

The following parameters were determined by means of a Technicon SMA-12 Autoanalyser:

1. sodium concentration
2. potassium concentration
3. chloride concentration
4. carbon dioxide concentration
5. total protein concentration
6. albumin concentration
7. calcium concentration
8. alkaline phosphatase concentration
9. bilirubin concentration
10. blood urea nitrogen concentration
11. blood sugar concentration

12. serum glutamic-oxalacetic transaminase concentration.

The following parameters were determined by means of a Technicon SMA-2 Autoanalyser:

1. uric acid concentration
2. phosphorous concentration
3. cholesterol concentration.

Serum osmolarity was determined by the freezing point depression method.

CHAPTER IV

RESULTS

To detect differences between the various fluids and evaluate their efficacy in replacing body sweat losses, the data from the Preliminary and Recovery points were further reduced. A quantity Δ_i was defined as follows:

$$\Delta_i = (\text{Recovery})_i - (\text{Preliminary})_i$$

where $(\text{Recovery})_i$ and $(\text{Preliminary})_i$ represent the value of parameter i at the preliminary and recovery points as indicated in Fig. 4. The quantity Δ_i then represents the change in the parameter in going from the Preliminary point to the Recovery point. If the value of the parameter returns to the value at Preliminary then Δ_i will be zero.

Misplaced or broken sample containers and inavailability of equipment resulted in missing data values. A method described by Hicks (11) for the univariate case was used to replace these values. The error sum of squares was computed and then minimized by differentiation with respect to the missing data point.

The following parameters were chosen from the nineteen total parameters measured for inclusion in the statistical analysis:

1. Serum sodium Δ
2. Serum potassium Δ
3. Serum chloride Δ

4. Serum carbon dioxide △
5. Total serum protein △
6. Blood sugar △
7. Total serum osmolarity △
8. Urine sodium △
9. Urine potassium △
10. Maximum voluntary strength retract △
11. Coordination △.

The statistical methods used required matrix inversion. In order to maintain computational accuracy while performing this operation on a digital computer the total number of parameters had to be limited. In the cases where it was felt that the parameter should be unaffected by the various treatment conditions, the parameter was excluded. Parameters in this category included SGOT, bilirubin, albumin, and others. In the cases where the parameter provided essentially the same information as another parameter, one was excluded. An example of this is the two maximum voluntary strength parameters. Only the retract parameter was included.

Multivariate analysis of variance for a randomized block design as described by Morrison (14) was employed to test the equality of the six treatment-effect vectors. A necessary assumption for this type analysis is that there be no block-treatment interaction or in this case subject-treatment interaction. Other assumptions are that the random effect vectors have the p-dimensional multinormal distribution with null mean vector and common covariance matrix. It is also assumed that the random effect terms be independently distributed in any block. The null hypothesis was rejected at the .01 level of significance ($\theta_s = .985 > X_{.01,5,2,5,4}$). This means that based on the eleven parameters included there was a significant difference between the six treatments used.

To determine which parameters differed between treatments and how they differed the method of simultaneous confidence intervals as described by Morrison (14) was employed. This method failed to identify the differences implied by the analysis of variance.

In a further effort to identify the parameter-treatment differences, the rate at which a particular parameter returned to a pre-exercise level was examined. To do this the quantity R_i is defined by

$$R_i = \frac{(\text{Absorption})_i - (\text{Stress})_i}{(\text{Recovery})_i - (\text{Stress})_i}$$

where $(\text{Recovery})_i$, $(\text{Stress})_i$, and $(\text{Absorption})_i$ are the values of parameter i at the recovery, stress, and absorption points indicated by Fig. 4. Time was not included in the formulation of R_i because the time lapsed between stress and absorption and between absorption and recovery were equal and were constant for all experimental runs. R_i is then the fraction of recovery which has occurred during the first half of the time period alloted for recovery. In the cases where $(\text{Recovery})_i$ was equal to $(\text{Stress})_i$, R_i was assigned a value of zero since no change from stress had occurred.

Multivariate analysis of variance for a randomized block design was used to test the null hypothesis of equal treatment-effect vectors for the following quantities:

1. Serum sodium R
2. Serum potassium R
3. Serum chloride R
4. Serum carbon dioxide R
5. Blood sugar R
6. Total serum osmolarity R
7. Maximum voluntary strength retract R
8. Maximum voluntary strength extend R.

The null hypothesis was not rejected at the .05 level of confidence (θ_s = .796 < $X_{.05,5,1,5.5}$). This approach failed to demonstrate the parameter-treatment differences.

The final method employed was a graphical interpretation of the results. The treatment mean for each parameter of interest was computed at the preliminary, stress, absorption, and recovery points. The resulting means were plotted as shown in Figures 5 through 15. The first parameter to be discussed will be blood sugar concentrations.

Blood Sugar

Of the five fluids tested only water did not contain sugar. Referring to Fig. 5 it can be seen that water and no replacement resulted in essentially stable blood sugar levels. All other fluids resulted in sharp increases in blood sugar with a subsequent decline toward the preliminary level.

Serum Potassium

In Figure 6 the effect of dehydration can be seen in the increase

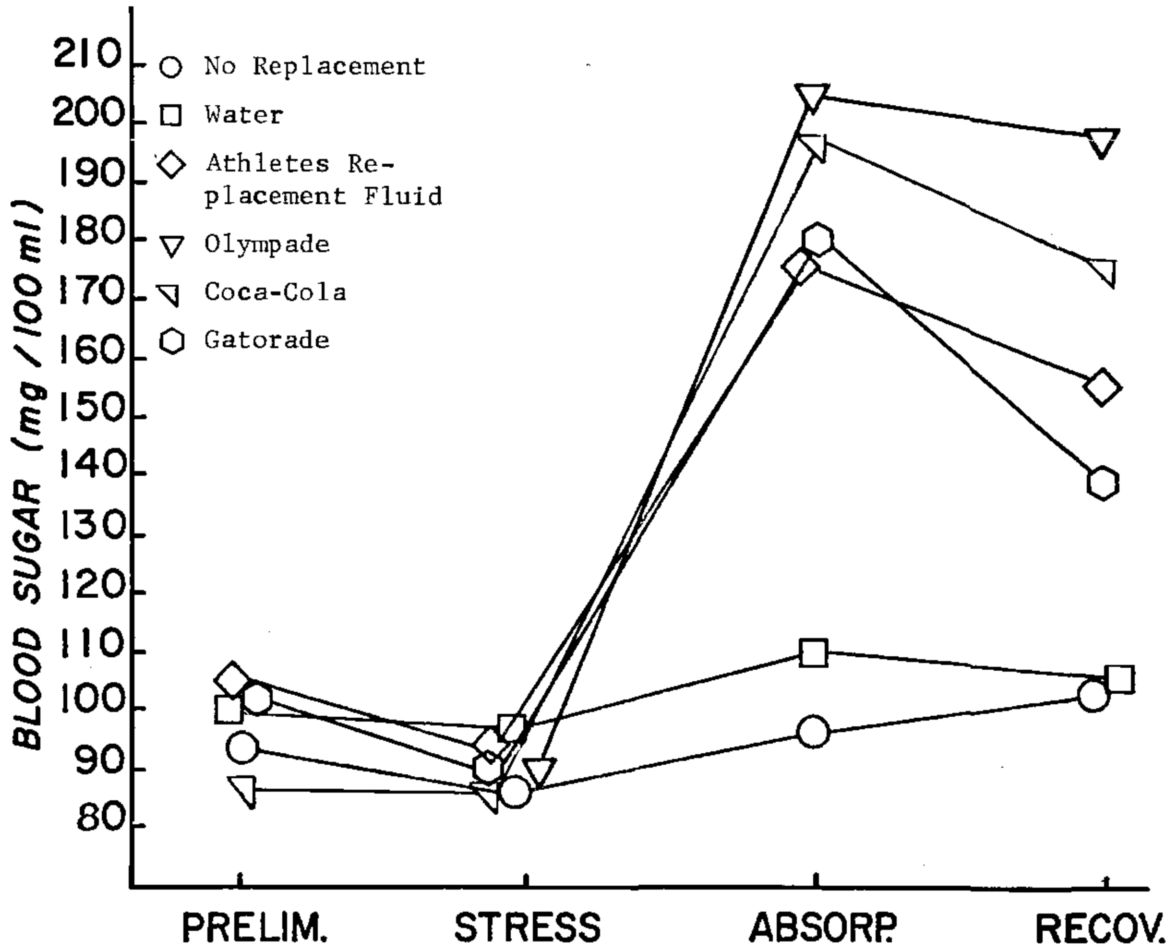

Figure 5. Mean Blood Sugar Concentrations for Five Men Under Six Treatment Conditions

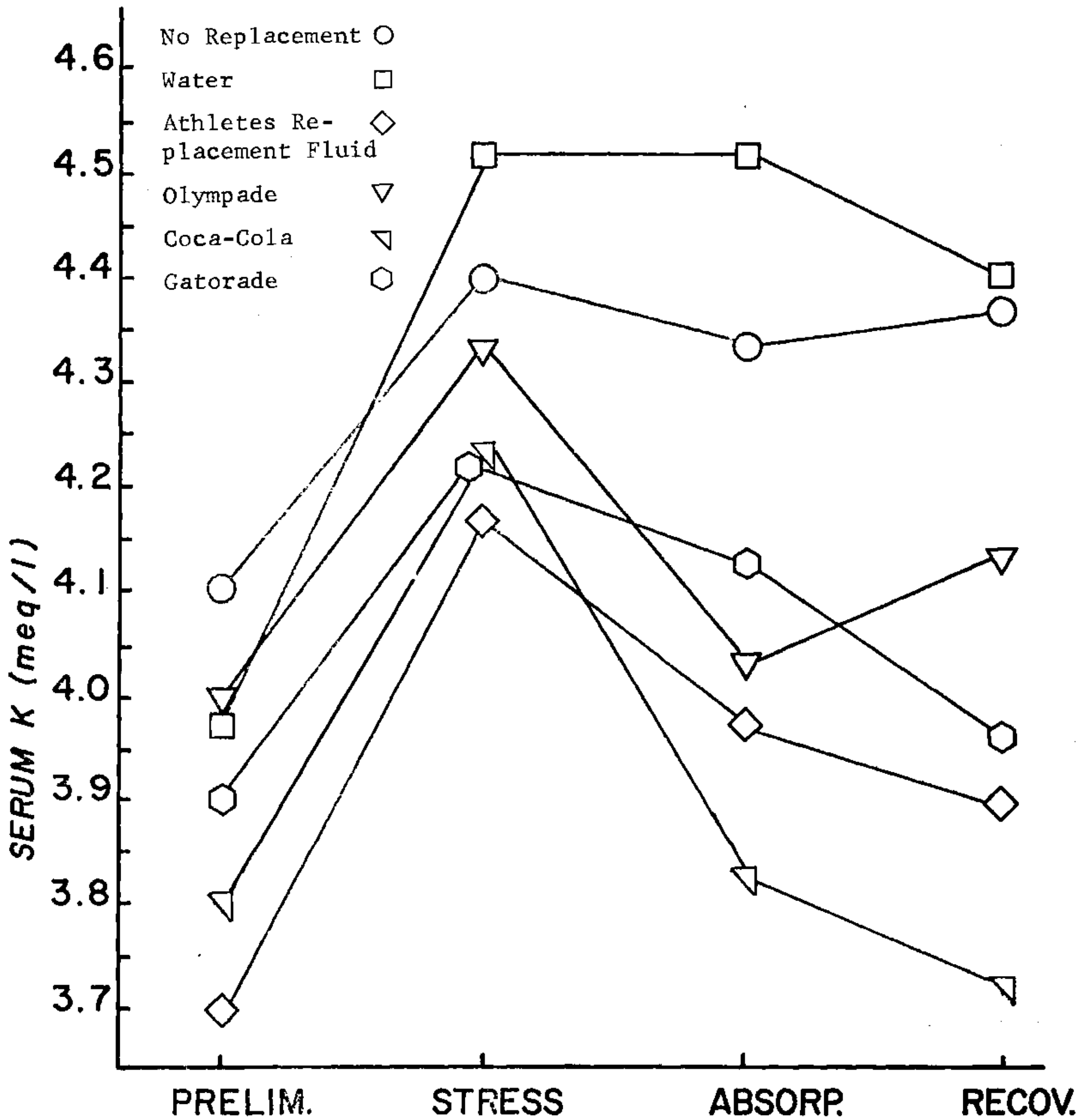

Figure 6. Mean Serum Potassium Concentrations for Five Men Under Six Treatment Conditions

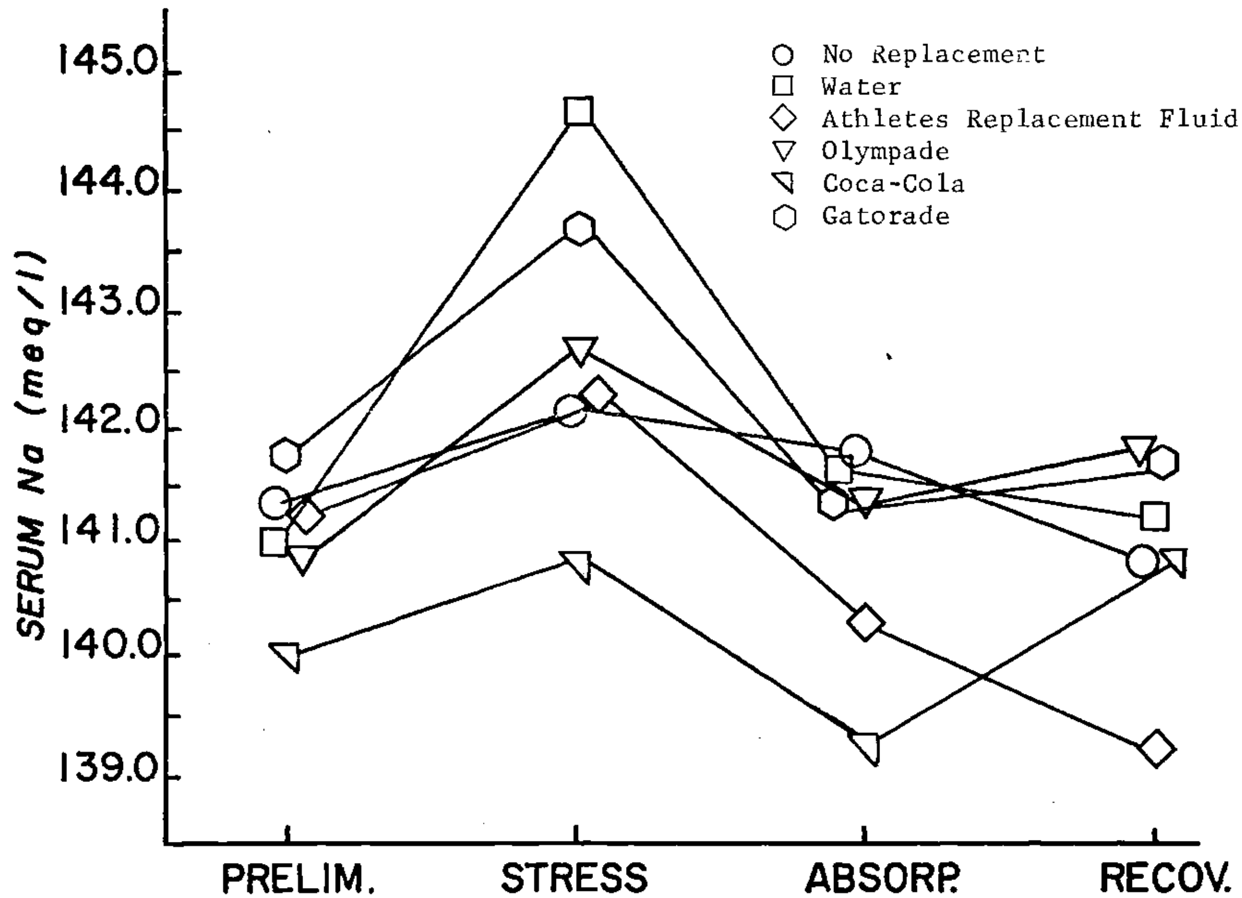

Figure 7. Mean Serum Sodium Concentrations for Five Men Under Six Treatment Conditions

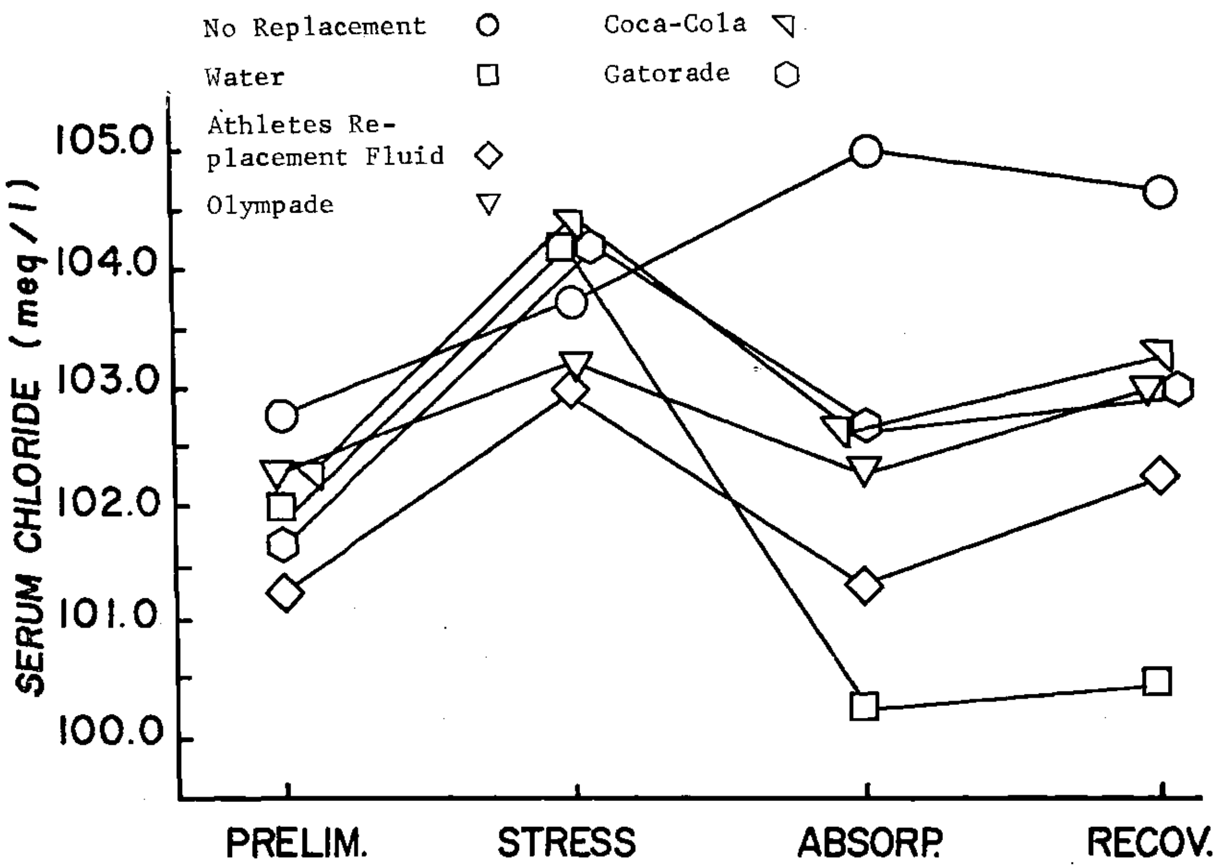

Figure 8. Mean Serum Chloride Concentrations for Five Men Under Six Treatment Conditions

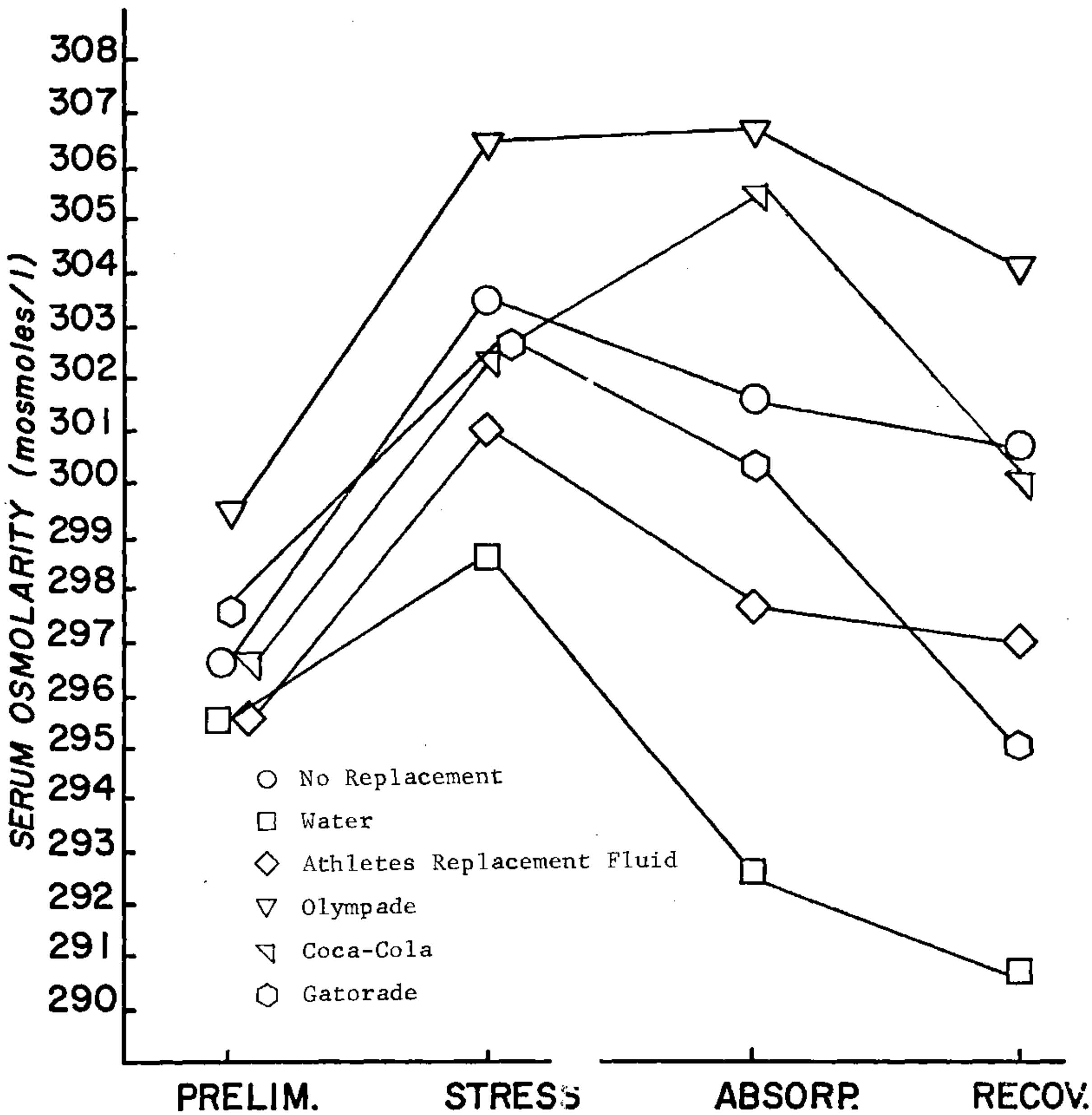

Figure 9. Mean Serum Osmolarity Concentrations for Five Men Under Six Treatment Conditions

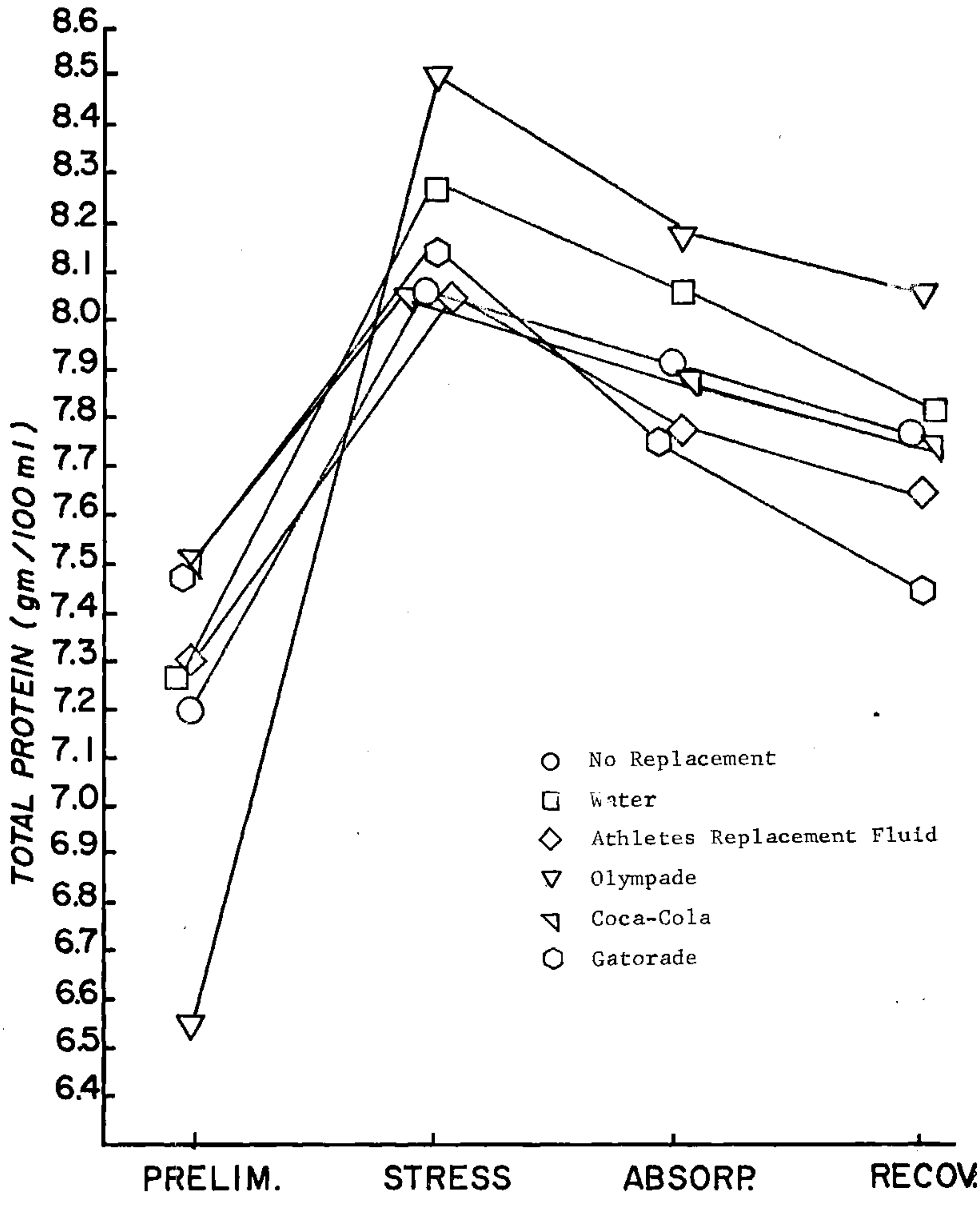

Figure 10. Mean Total Serum Protein Concentrations for Five Men Under Six Treatment Conditions

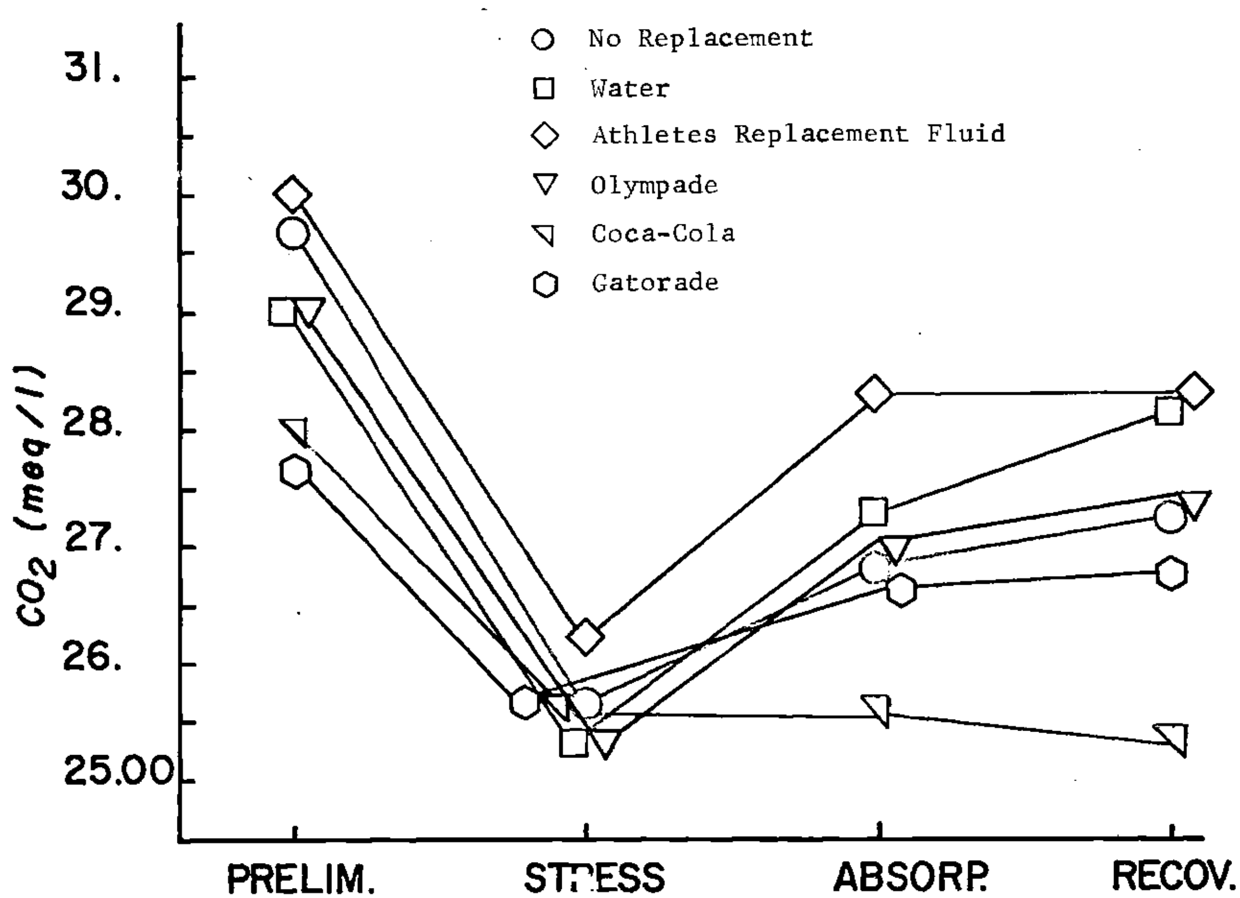

Figure 11. Mean Serum Carbon Dioxide Concentration for Five Men Under Six Treatment Conditions

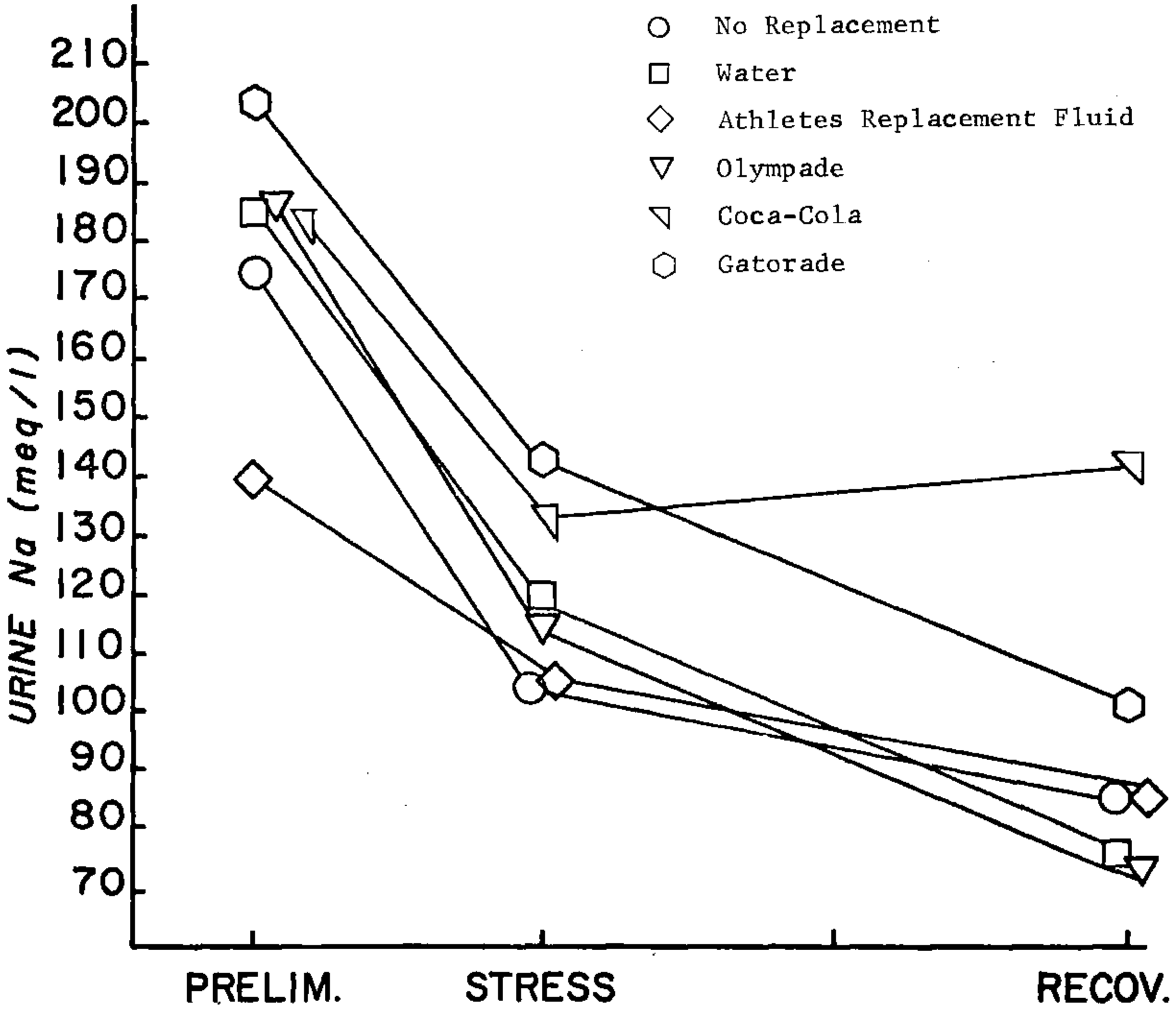

Figure 12. Mean Urine Sodium Concentrations for Five Men Under Six Treatment Conditions

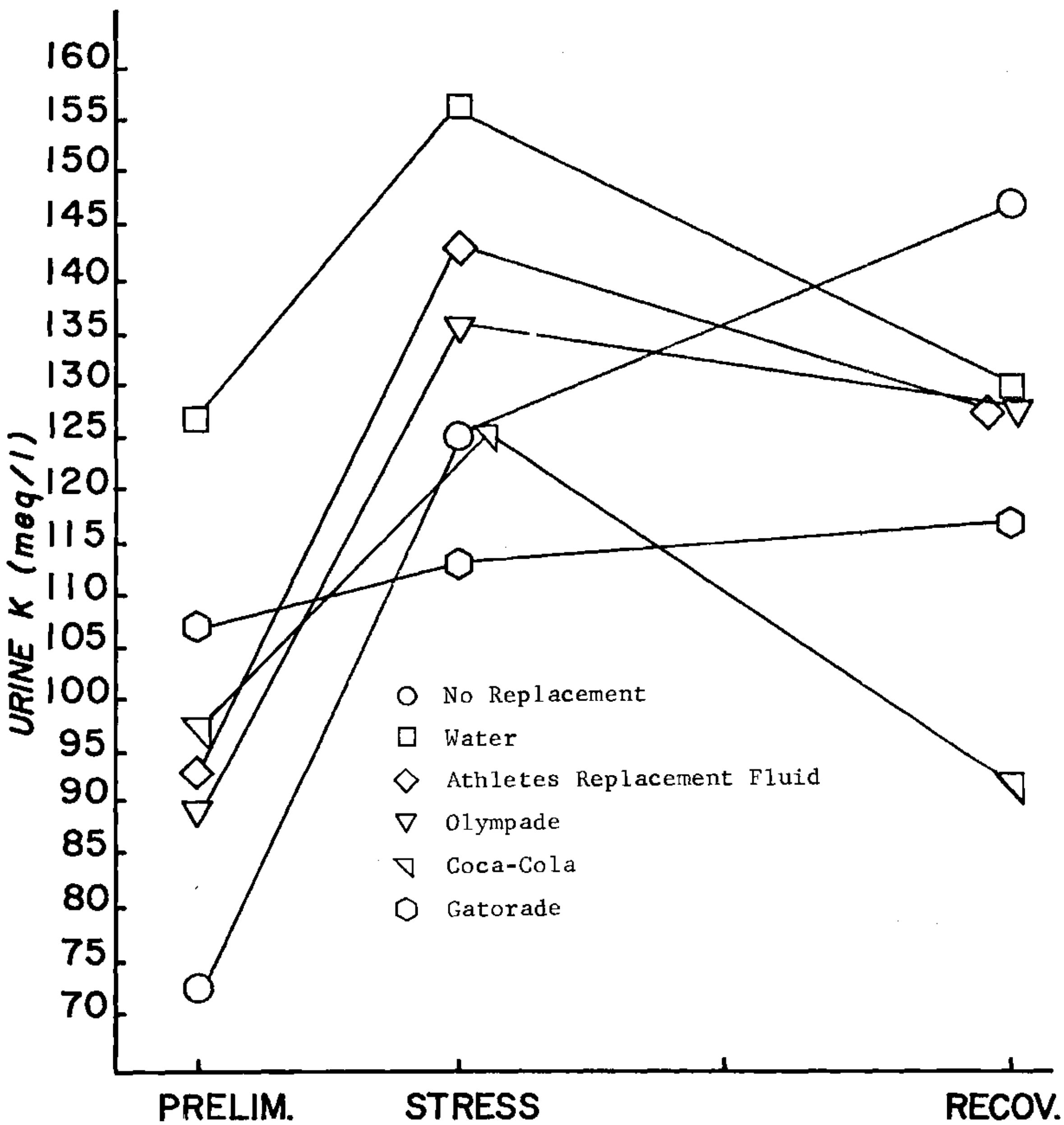

Figure 13. Mean Urine Potassium Concentrations for Five Men Under Six Treatment Conditions

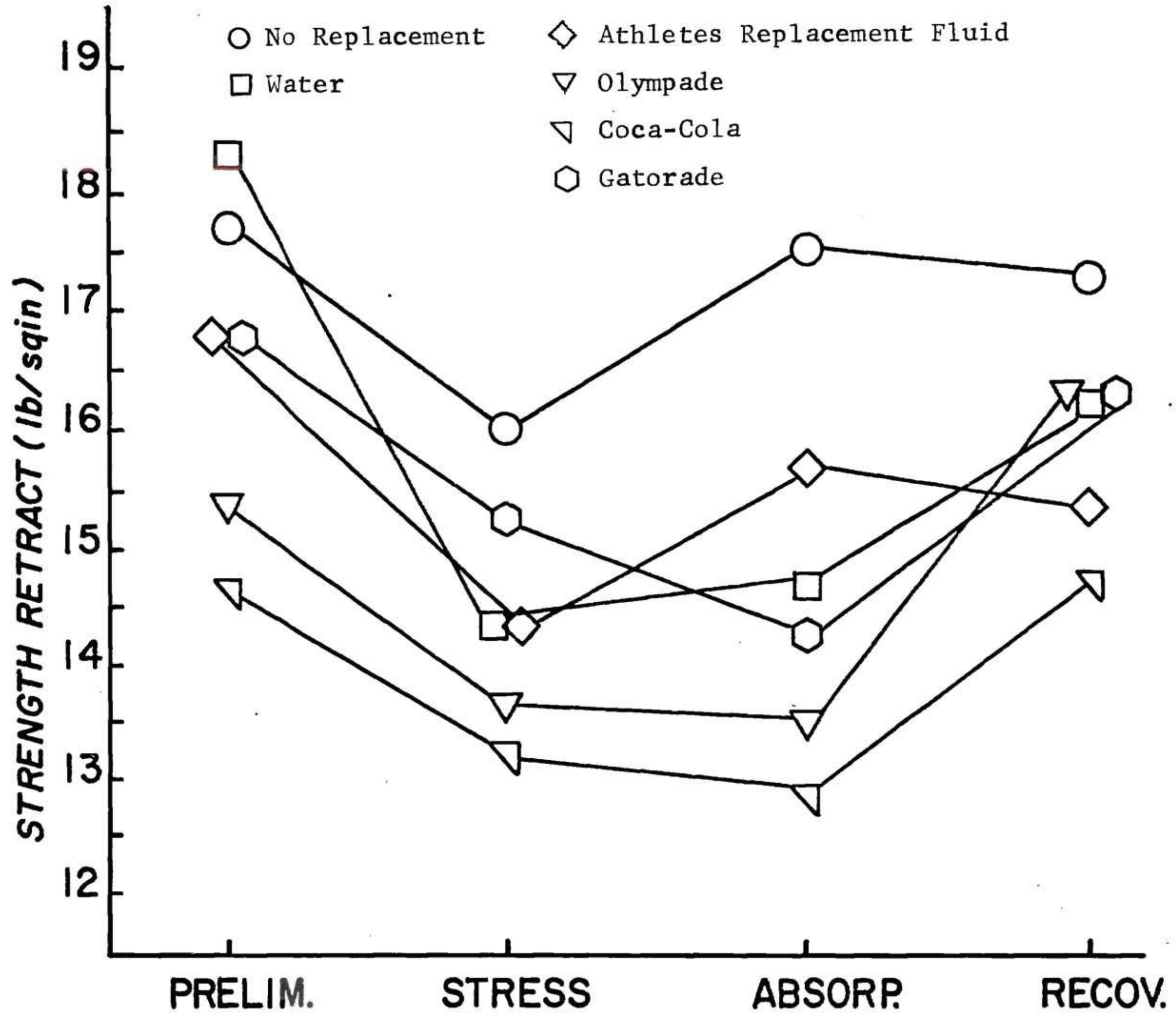

Figure 14. Mean Maximum Voluntary Strengths for Five Men Under Six Treatment Conditions

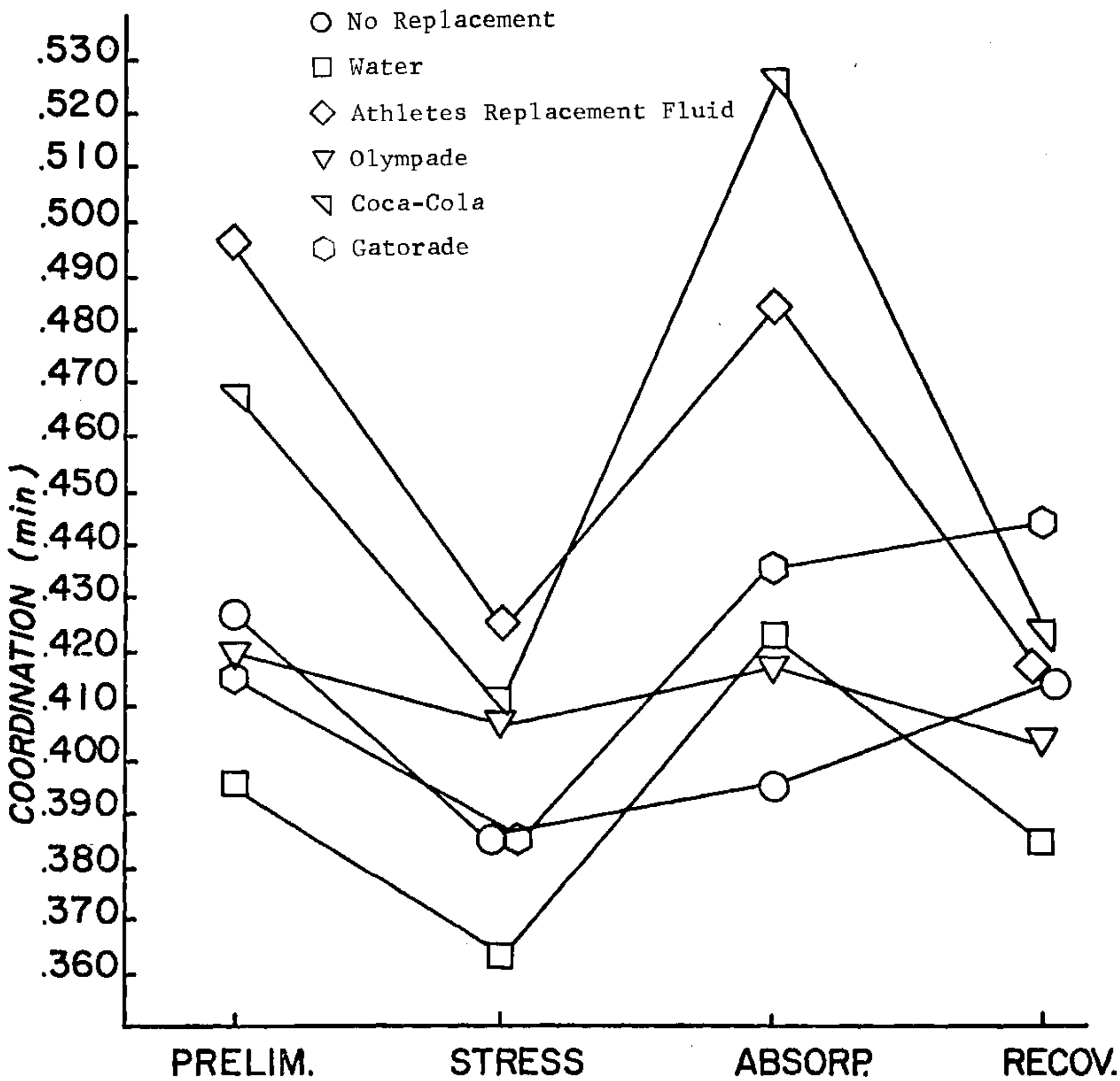

Figure 15. Mean Times for Coordination Test for Five Men Under Six Treatment Conditions

in serum potassium levels following exercise. With all fluids except water there was a decline to near pre-exercise levels following rehydration. Water and no replacement resulted in continued high serum potassium levels. This implies that in the short term water is not as effective in rehydration as the other fluids studied. However, this is probably not the case since a reduced serum glucose (Fig. 5) can result in an elevated serum potassium (23,26).

Serum Sodium

The same dehydration effect just mentioned is evident in the serum sodium concentration as seen in Fig. 7. All treatments including water and no replacement resulted in a return to preliminary levels.

Serum Chloride

No replacement after exercise resulted in continued elevated serum chloride level (see Fig. 8). All fluids brought the serum chloride back to a near preliminary level. Water brought the chloride concentration down the fastest and to the lowest point. With no fluid replacement there was an obvious dehydration which persisted to the recovery point. With water there was an apparent reduction in chloride reserves and rehydration resulted in a dilution of circulating chloride. All other fluids contained chloride in an ionizable form and seemed to replace chloride losses.

Serum Osmolarity

The effect of some salt depletion and a subsequent rehydration and dilution by water can be seen in Figure 9. An important point to note is that no replacement resulted in essentially the same pattern as the fluids but for a different reason. With no replacement there was a continued partial salt deficit, but by adjusting body fluids between the circulating volume, the interstitial spaces, and the cells, a return to normal concentration was achieved. The result is a reduced total body water and salt content but with serum concentration returning to normal. All the fluids with the exception of water supplemented the body salt and water content, and returned the total body water and salt to its pre-exercise level. The net result appears to be the same in this and other parameters consequently no replacement is not indicated as being statistically different.

Total Serum Protein

No replacement resulted in a pattern very much like that of all other treatments (Fig. 10). This case also demonstrates the physiological processes which supplement circulating fluid volume by removing fluid from the interstitial spaces and cells.

Serum Carbon Dioxide

At the stress point all subjects appeared slightly acidotic (Fig. 11) due to exercise as evidenced by lower carbon dioxide levels. All treatments with the exception of Coca-Cola resulted in a return toward preliminary levels. Coca-Cola is carbonated and is therefore acidic due to carbonic acid. Absorption of this acid results in lower carbon dioxide levels.

Urine Sodium and Potassium

After exercise urine sodium concentrations declined and urine potassium concentration increased (Figs. 12 and 13). This is the normal physiological response expected and appears independent of treatment condition (2,17,25).

Maximum Voluntary Strength Retract

Under all treatment conditions a decline in strength followed exercise (Fig. 14). After rest it appeared that strength returned to normal irrespective of treatment.

Coordination

In Fig. 15 the treatment means for the coordination parameter are shown. Following exercise there is a marked improvement in coordination as indicated by the reduced time to complete the test. After rest the coordination returns to pre-exercise levels and appears independent of the treatment condition. A possible explanation is the running has served the same function as the warm-up exercise performed by many athletes. After a rest period of one hour used in these experiments coordination returns to its normal level. An important consideration when studying coordination is motivation. The attitude of each subject could not be regulated.

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

The purpose of this study was to evaluate the efficacy of five fluids in replacing body losses due to sweating and to evaluate the effects of these fluids on physical performance following strenuous work or exercise. The five fluids studied were water, Athletes Replacement Fluid, Olympade, Coca-Cola, and Gatorade. No fluid replacement served as the control.

Conclusions

All fluids tested with the exception of water contained sugar in some form and resulted in an elevated blood sugar at 30 minutes and one hour after exercise. Water and no replacement resulted in essentially unchanged blood sugar levels following exercise. Coca-Cola and Olympade resulted in the highest level of blood sugar. Blood sugar (glucose) is of importance to all physical and mental activity because it is the most readily available source of energy to the cells. For the short term (one hour) effects studied here all the sugar containing fluids provided an adequate supply of sugar for metabolism.

From the data on the serum electrolytes, sodium, potassium, and chloride, and the serum osmolarity, a definite salt deficit can be seen for the water and no replacement cases. There are no apparent differences in electrolyte replacement between the other fluids. None of the fluids intended as replacement fluids appeared outstanding in this respect. The data for serum chloride and serum osmolarity indicate that water is an effective means of rehydration. Serum potassium would indicate just the opposite, but potassium is not a reliable parameter in this respect. Following a decrease in blood volume from dehydration, potassium concentration behaves inversely to blood sugar levels (low blood sugar, high serum potassium concentration) and is not a sensitive index of changes in intracellular potassium concentrations (25,26). For the short term effects those fluids which contained electrolytes did not appear to be of major importance. Evidently the body has sufficient reserves to maintain serum levels. Effects of electrolyte depletion on performance would not appear until a greater deficit has occurred from either a higher sweat rate or prolonged sweating.

In replacement with Coca-Cola, the subjects remained slightly acidotic as a result of acid absorption from the Coca-Cola. The results of total serum protein support the conclusion that water is an effective rehydrator and that in the short term there is an adjustment of body fluid reserves to offset some of the effects of dehydration.

Urine sodium and potassium concentrations reflect the result of increased levels of the hormone aldosterone caused by dehydration. The result is decreased urine sodium output and increased urine potassium output (25). Urine sodium and potassium output appear unaffected by the various treatments.

The results of the maximum voluntary strength test indicate a definite decline in strength as a result of the strenuous exercise. A return to pre-exercise strength was observed for all fluids and no replacement. An interesting corollary result was the observed improvement in coordination which accompanied the decrement in strength. The exercise appeared to improve coordination. This may be the same effect sought by athletes who warm-up before exercising.

In this study only short term effects of rehydration following dehydration by exercise were studied. This is the case frequently encountered in athletics, but in the industrial environment less severe work loads over a much longer period of time are encountered. It is difficult to generalize the results of this study to the conditions of industry.

It has long been evident that fluid replacement is preferential to no replacement to prevent dehydration and the subsequent temperature rise. This is also clearly indicated by the data presented here. Based on blood chemistry changes and physical performance measures and considering only the short term effects (one hour time periods), there does not appear to be sufficient grounds for preference of replacement type fluids over water or other commonly available fluids such as Coca-Cola.

Recommendations

It is recommended that a study of this type be conducted on the long term effects in an environment similar to that encountered in industry. In a study of the proposed type other tests of performance such as mathematical manipulation of numbers should be included.

It is further recommended that a study of the apparent trade-off nature of strength and coordination be conducted. Generally in athletics good coordination is desired at the same time the greatest strength is desired. Warm-up exercises would appear to improve coordination and impair strength. By studying the time history of coordination and strength at various levels of physical exertion an improved pre-competition exercise plan might be developed.

APPENDICES

APPENDIX I

GLOSSARY OF PHYSIOLOGICAL TERMS USED*

1. Albumin--one of a group of simple proteins found in the blood.
2. Alkaline phosphatase--an enzyme of importance in absorption of carbohydrates and is indicative of liver function.
3. Bilirubin--an orange pigment formed as the product of degeneration of hemoglobin.
4. Blood sugar--sugar found in the blood in the form of glucose.
5. Blood urea nitrogen--the nitrogen of urea in the blood formed from ammonia, a waste product.
6. Cholesterol--an alcohol found in the blood. It is of importance in bodily metabolism serving as a precursor of various steroid hormones.
7. Electrolytes--those substances which exist as ions when in solution. In this thesis it is primarily restricted to sodium, potassium, and chloride.
8. Jejunum--the second portion of the small intestines which is approximately eight feet long.
9. Plasma--the liquid portion of blood and lymph.

*All definitions were taken from C. W. Taber, Taber's Cyclopedic Medical Dictionary, 11th edition, F. A. Davis Co., Philadelphia, 1969.

APPENDIX I (Continued)

10. Serum--the liquid portion of the blood remaining after clot formation.

11. Serum glutamic-oxalacetic transaminase (SGOT)--an enzyme found in the liver and other tissues. Injury of the liver liberates this enzyme into the bloodstream.

12. Serum osmolarity--the ionic concentration of dissolved substances per unit of serum.

13. Total protein--in the context of this thesis it will mean those proteins present in the serum such as albumins and globulins.

APPENDIX II

GLOSSARY OF ABBREVIATIONS

Alkaline Phosphatase	Alk. Phos.
Absorption	Absorp.
Blood urea nitrogen	BUN
Carbon dioxide	CO_2
Gram	gm
Liter	L
Milliequivalent	mEq
Milliliter	ml
Milliosmole	mosm
Minute	min.
Preliminary	Prelim
Recovery	Recov
Total protein	T.P.

APPENDIX III

CONTENTS OF FLUIDS USED IN STUDY

Athletes Replacement Fluid:

sodium	29.4	mosm/L
potassium	5.0	mosm/L
calcium	0.6	mosm/L
dihydrogen phosphate	0.4	mosm/L
chloride	33.4	mosm/L
dihydrogen citrate	3.5	mosm/L
citric acid	12.3	mosm/L
saccharin anion	0.4	mosm/L
hydrogen ion	2.9	mosm/L
glucose	259.0	mosm/L

Gatorade:

sodium	21.0	mEq/L
potassium	3.0	mEq/L
chloride	16.0	mEq/L
bicarbonate	1.0	mEq/L
calcium and phosphate	6.0	mgm/100 ml.
glucose	3.0	gm /100 ml.

Olympade*:

sodium	8.5	mEq/L
potassium	1.3	mEq/L

Coca-Cola*:

sodium	2.0	mEq/L
potassium	0.3	mEq/L

*Sodium and potassium content of Olympade and Coca-Cola were determined by a flame photometer.

APPENDIX IV

PRELIMINARY, STRESS, ABSORPTION, AND RECOVERY TREATMENT MEANS FOR FIVE MEN

Table 3. Preliminary Treatment Means for Five Men

	No Fluid	Water	A.R.F.	Olympade	Coca-Cola	Gatorade
Blood:						
Sodium (mEq/L)	141.4	141.0	141.2	140.8	140.0	141.8
Potassium (mEq/L)	4.10	3.98	3.70	4.00	3.80	3.90
Chloride (mEq/L)	102.8	102.0	101.2	102.2	102.2	101.8
CO_2 (mEq/L)	29.6	29.0	30.0	29.0	28.0	27.6
T. P. (gm/100ml)	7.20	7.28	7.30	6.52	7.50	7.48
Albumin (gm/100ml)	4.58	4.64	4.64	4.70	4.72	4.74
Calcium (mg/100ml)	9.70	9.56	10.0	9.78	9.82	9.98
Alk. Phos. (KA units)	11.20	11.50	11.40	11.00	11.80	11.20
Bilirubin (mg/100ml)	.680	.640	.700	.560	.740	.640
BUN (mg/100ml)	17.80	17.60	17.80	17.40	18.40	17.60
Sugar (mg/100ml)	92.0	100.6	101.0	101.2	87.0	100.0
SGOT (SGOT units)	27.4	31.6	28.0	33.0	30.6	29.6
Cholesterol (mg/100ml)	183.6	194.4	173.2	180.2	183.6	188.4
Phosphorous (mg/100ml)	4.02	4.16	4.66	4.82	4.20	4.18
Uric Acid (mg/100ml)	6.66	5.76	6.22	6.62	6.14	6.30
Osmolarity (mosm/L)	296.8	295.5	295.5	299.4	296.8	297.5
Urine:						
Sodium (mEq/L)	173.6	185.3	140.0	187.3	182.4	202.7
Potassium (mEq/L)	72.4	126.0	93.4	89.6	97.0	107.2
Strength:						
Retract (lb/sq. in.)	17.6	18.2	16.8	15.4	14.6	16.8
Extend (lb/sq. in.)	19.8	19.6	20.8	20.0	20.4	22.4
Coordination (min)	.429	.396	.498	.420	.469	.415

Table 4. Stress Treatment Means for Five Men

	No Fluid	Water	A.R.F.	Olympade	Coca-Cola	Gatorade
Blood:						
Sodium (mEq/L)	142.2	144.6	142.4	142.6	140.8	143.6
Potassium (mEq/L)	4.40	4.52	4.16	4.34	4.24	4.22
Chloride (mEq/L)	103.8	104.2	103.0	103.2	104.4	104.2
CO_2 (mEq/L)	25.60	25.40	26.20	25.40	25.60	25.60
T. P. (gm/100ml)	8.08	8.26	8.06	8.50	8.06	8.12
Albumin (gm/100ml)	5.00	5.10	5.22	5.24	5.04	5.06
Calcium (mg/100ml)	10.50	10.76	10.64	10.66	10.44	10.56
Alk. Phos. (KA units)	9.56	11.30	10.08	12.60	11.60	11.00
Bilirubin (mg/100ml)	.640	.580	.780	.740	.680	.700
BUN (mg/100ml)	18.80	19.80	15.64	18.20	19.60	17.40
Sugar (mg/100ml)	88.0	96.6	93.4	89.8	86.2	89.4
SGOT (SGOT units)	34.4	31.8	27.5	32.1	33.0	31.0
Cholesterol (mg/100ml)	199.2	210.8	191.6	194.4	194.0	200.8
Phosphorous (mg/100ml)	4.62	4.40	5.22	4.82	4.52	4.42
Uric Acid (mg/100ml)	7.68	8.06	7.22	7.80	7.06	7.12
Osmolarity	303.4	298.8	301.0	306.4	302.25	302.80
Urine:						
Sodium (mEq/L)	102.2	120.1	104.3	114.9	131.6	141.6
Potassium (mEq/L)	125.2	156.2	143.6	135.4	125.2	113.8
Sweat:						
Sodium (mEq/L)	65.9	58.2	68.4	60.8	49.3	38.3
Potassium (mEq/L)	6.9	4.7	9.2	7.5	5.7	8.0
Strength:						
Retract (lb/sq. in.)	16.0	14.4	14.4	13.6	13.2	15.2
Extend (lb/sq. in.)	20.6	19.2	14.6	17.3	9.5	24.0
Coordination (min)	.386	.362	.427	.409	.411	.386

Table 5. Absorption Treatment Means for Five Men

	No Fluid	Water	A.R.F.	Olympade	Coca-Cola	Gatorade
Blood:						
Sodium (mEq/L)	141.8	141.6	140.4	141.4	139.2	141.4
Potassium (mEq/L)	4.34	4.52	3.98	4.04	3.82	4.12
Chloride (mEq/L)	105.0	100.2	101.4	102.4	102.6	102.6
CO_2 (mEq/L)	26.8	27.3	28.4	27.0	25.6	26.6
T. P. (gm/100ml)	7.90	8.06	7.78	8.18	7.88	7.74
Albumin (gm/100ml)	4.88	4.90	4.88	5.22	4.94	4.80
Calcium (mg/100ml)	10.48	10.26	10.46	10.86	10.36	10.16
Alk. Phos. (KA units)	10.50	10.60	11.00	12.25	11.80	10.90
Bilirubin mg/100ml)	.700	,720	.740	.860	.740	.700
BUN (mg/100ml)	19.20	19.80	19.60	18.40	19.80	17.40
Sugar (mg/100ml)	96.0	110.0	177.4	203.4	196.0	178.4
SGOT (SGOT units)	34.8	30.6	34.6	39.0	31.6	29.6
Cholesterol (mg/100ml)	190.8	214.0	186.8	189.2	189.4	190.0
Phosphorous	4.14	3.78	4.46	3.94	3.52	3.66
Uric Acid (mg/100ml)	7.66	7.86	7.20	8.10	7.40	7.18
Osmolarity (mosm/L)	301.6	292.8	297.8	306.6	305.3	300.2
Strength:						
Retract (lb/sq. in.)	17.5	14.6	15.6	13.5	12.8	14.2
Extend (lb/sq. in.)	23.3	18.0	18.8	19.5	18.3	21.6
Coordination (min)	.398	.422	.485	.417	.526	.436

Table 6. Recovery Treatment Means for Five Men

	No Fluid	Water	A.R.F.	Olympade	Coca-Cola	Gatorade
Blood:						
Sodium (mEq/L)	140.8	141.2	139.2	141.8	140.8	141.6
Potassium (mEq/L)	4.36	4.40	3.90	4.12	3.72	3.96
Chloride (mEq/L)	104.6	100.4	102.4	103.0	103.4	103.0
CO_2 (mEq/L)	27.2	28.1	28.4	27.4	25.4	26.8
T. P. (gm/100ml)	7.74	7.80	7.64	8.04	7.72	7.42
Albumin (gm/100ml)	4.84	4.74	4.80	5.06	4.84	4.70
Calcium (mg/100ml)	10.36	10.32	10.12	10.70	10.20	9.92
Alk. Phos. (KA units)	11.00	9.60	11.40	13.00	11.20	10.70
Bilirubin (mg/100ml)	.700	.620	.780	.840	.680	.660
BUN (mg/100ml)	20.40	20.20	19.20	18.80	19.80	18.00
Sugar (mg/100ml)	101.6	103.8	155.6	197.0	174.0	139.0
SGOT (SGOT units)	36.6	30.2	33.0	35.6	29.6	24.0
Cholesterol (mg/100ml)	190.4	208.4	179.2	181.2	184.0	191.2
Phosphorous (mg/100ml)	4.08	3.88	4.120	3.96	4.00	3.96
Uric Acid (mg/100ml)	7.74	7.90	7.12	8.08	7.66	6.88
Osmolarity	300.6	290.8	297.0	304.0	300.0	295.0
Urine:						
Sodium (mEq/L)	86.8	75.6	86.6	72.6	140.2	100.5
Potassium (mEq/L)	146.0	129.8	126.8	128.8	90.8	116.2
Strength:						
Retract (lb/sq. in.)	17.2	16.2	15.4	16.3	14.8	16.3
Extend (lb/sq. in.)	21.8	18.2	18.8	21.0	22.5	23.5
Coordination (min)	.416	.385	.419	.403	.423	.444

APPENDIX V

MEANS FOR OTHER PARAMETERS

Throughout Appendix V the following treatments will be denoted by the symbol given:

No replacement	○
Water	□
Athletes Replacement Fluid	◇
Olympade	▽
Coca-Cola	◸
Gatorade	⬡

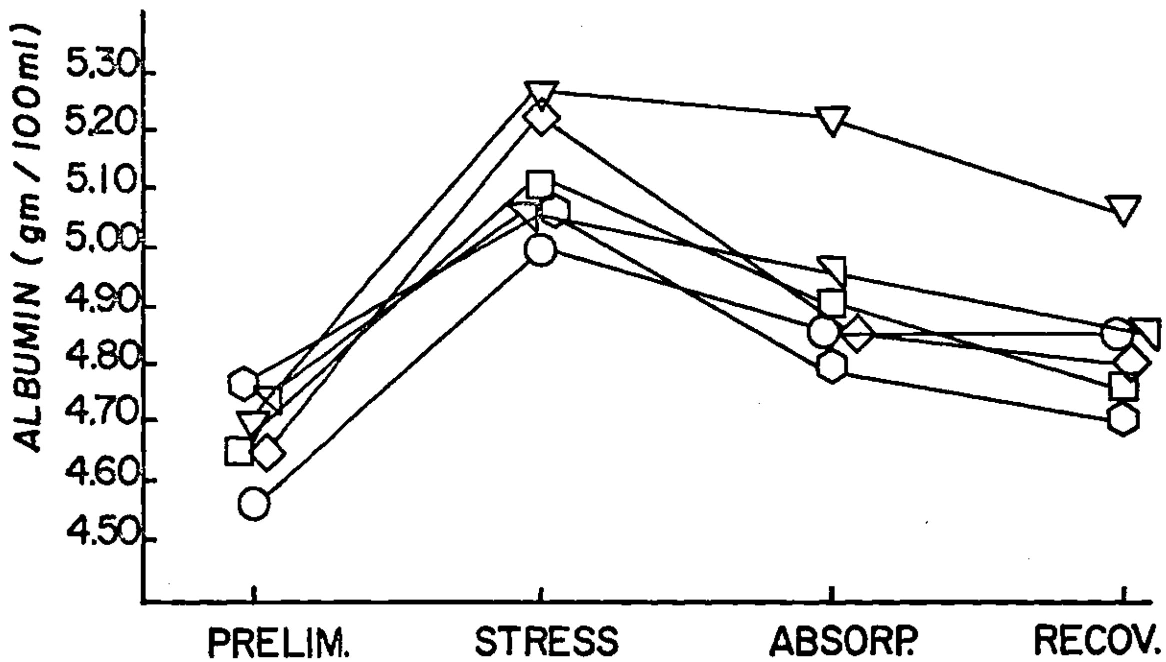

Figure 16. Mean Serum Albumin Concentrations for Five Men
Under Six Treatment Conditions

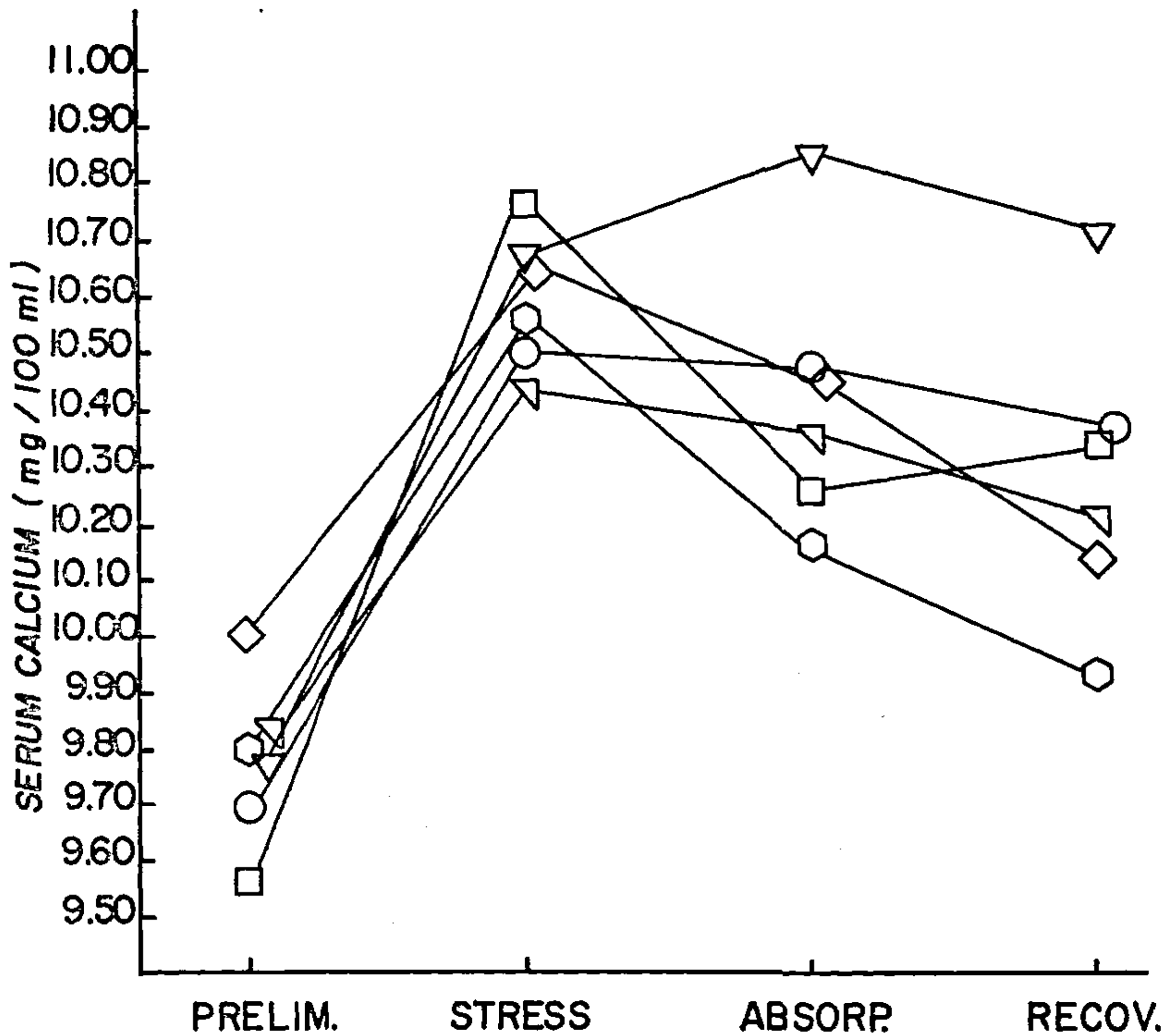

Figure 17. Mean Serum Calcium Concentrations for Five Men Under Six Treatment Conditions

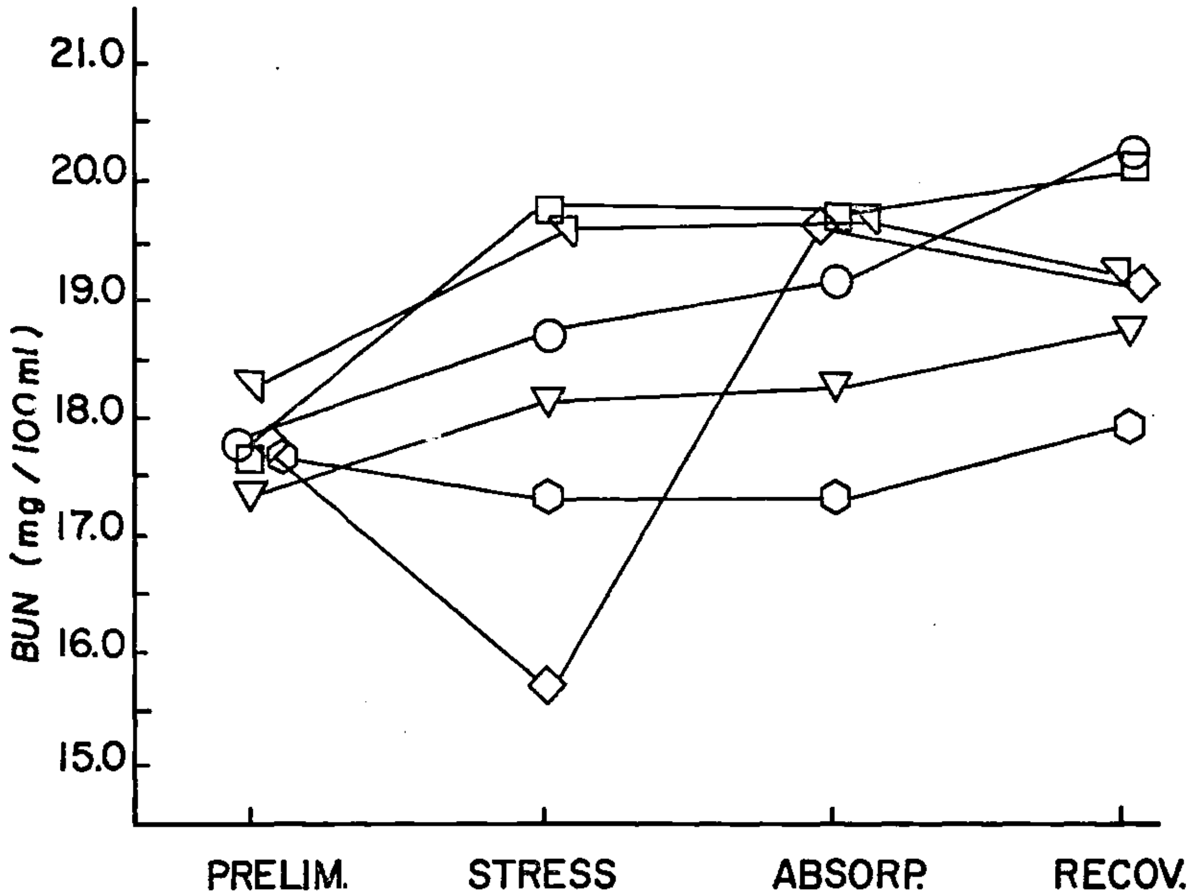

Figure 18. Mean Blood Urea Nitrogen Concentrations for Five Men Under Six Treatment Conditions

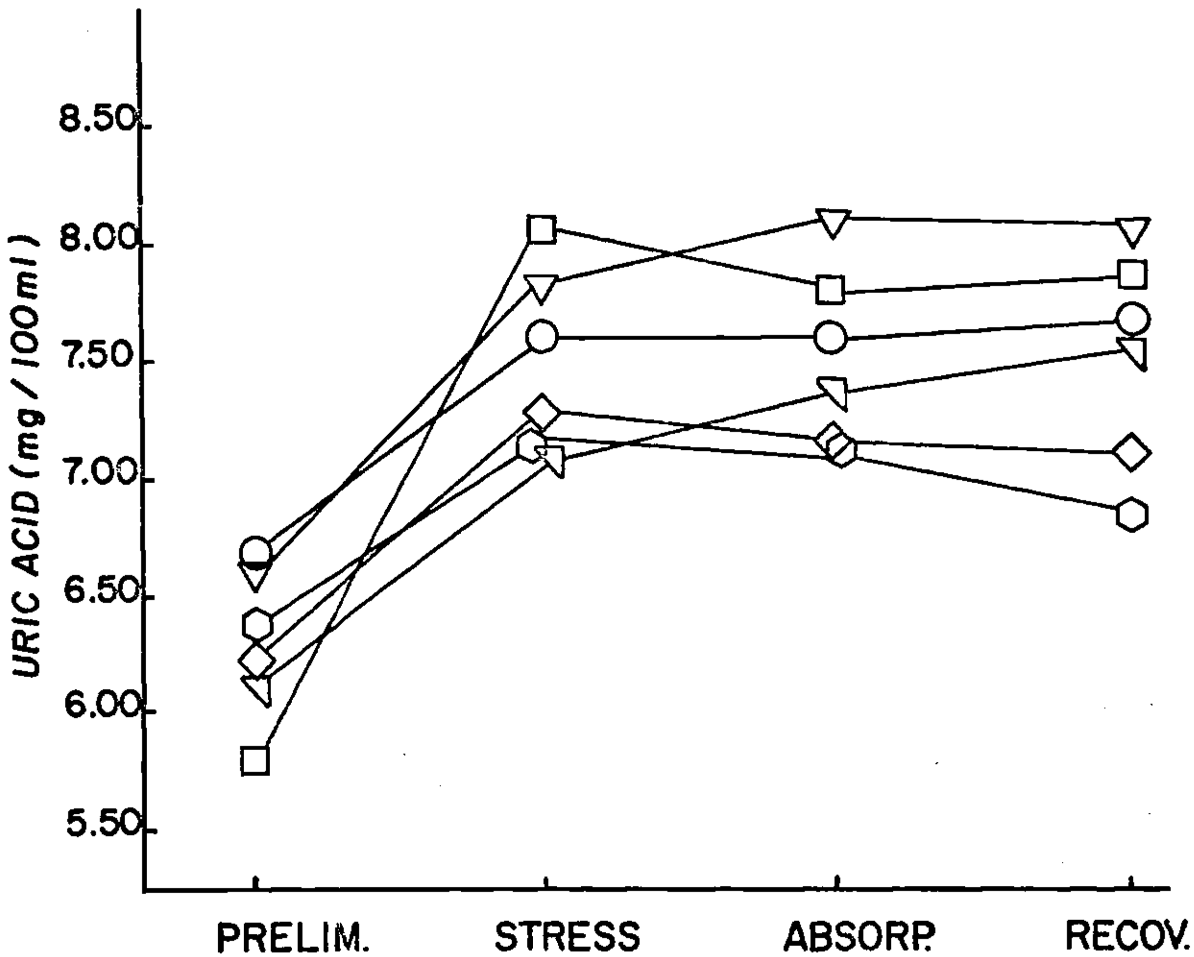

Figure 19. Mean Serum Uric Acid Concentrations for Five Men
Under Six Treatment Conditions

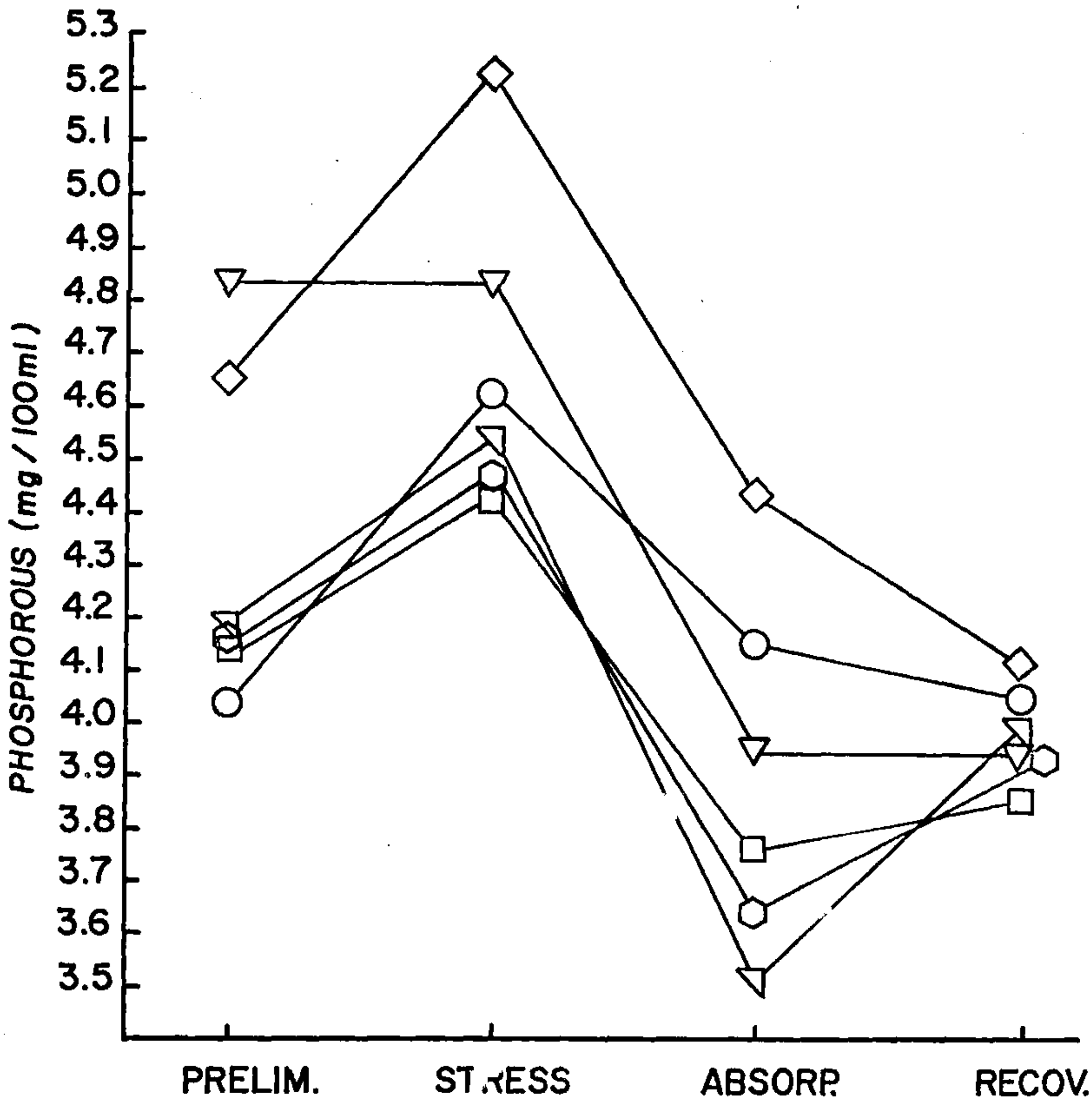

Figure 20. Mean Serum Phosphorous Concentrations for Five Men Under Six Treatment Conditions

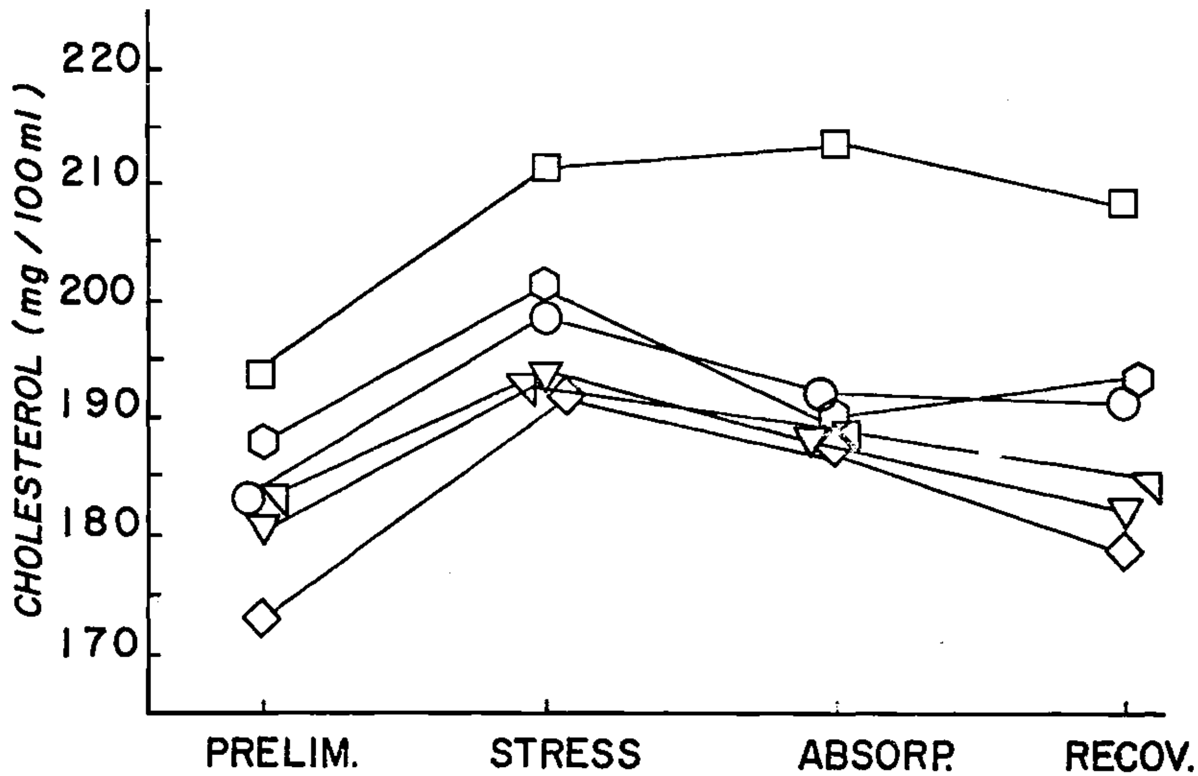

Figure 21. Mean Serum Cholesterol Concentrations for Five Men Under Six Treatment Conditions

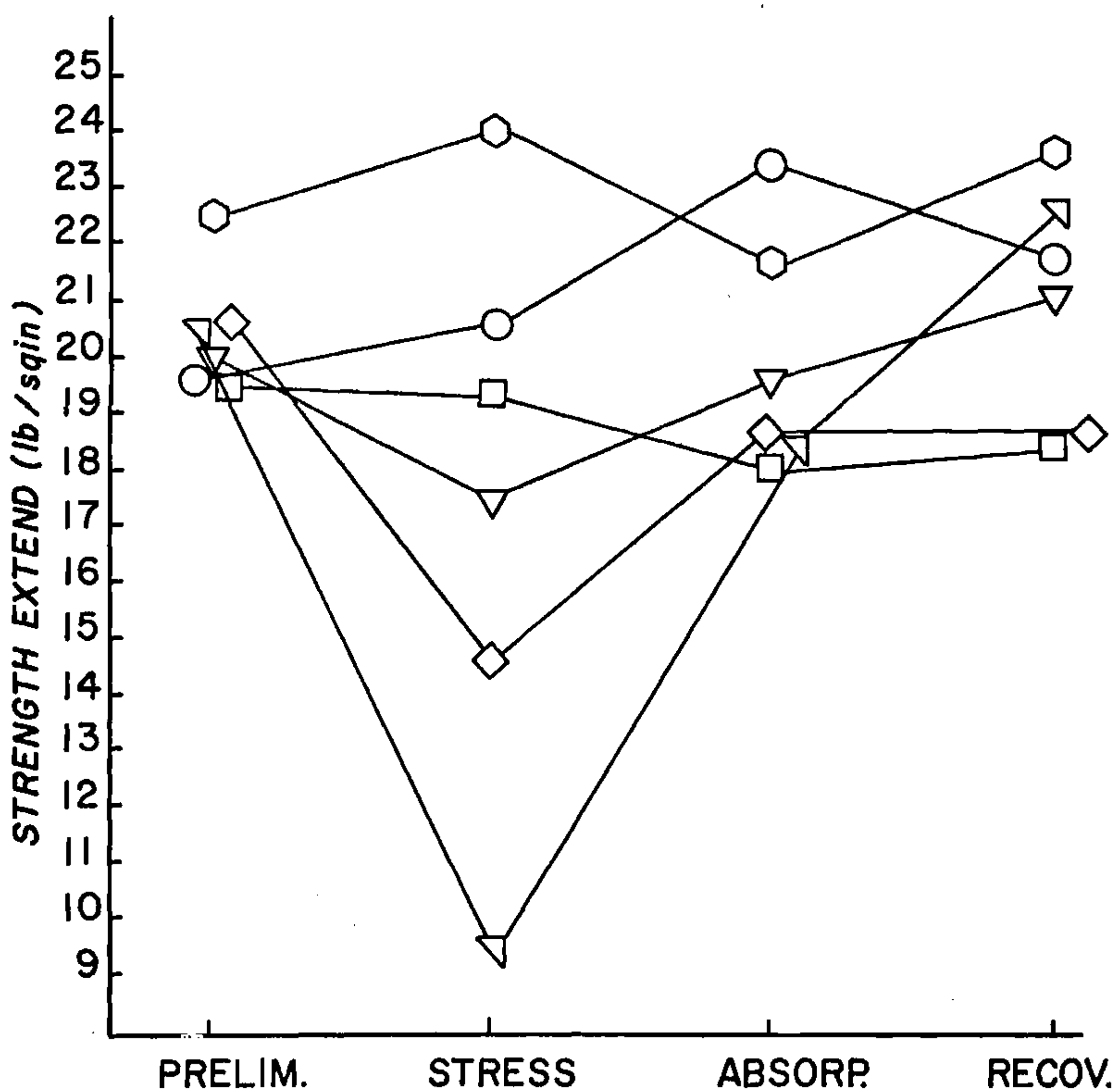

Figure 22. Mean Strengths Extend for Five Men Under Six Treatment Conditions

BIBLIOGRAPHY

1. Adolph, E. F. and Associates, Physiology of Man in the Desert, Hafner Publishing Co., New York, 1969.

2. Andersson, B., "Thirst--and Brain Control of Water Balance," American Scientist, 59 (4): 408-415, 1971.

3. Bell, C. R. and K. A. Provins, "Effects of High Temperature Environmental Conditions on Human Performance," Journal of Occupational Medicine, 4: 202-211, 1962.

4. Brouha, L., Physiology in Industry, Pergamon Press, Oxford, 1967.

5. Blyth, C. S. and J. J. Burt, "Effect of Water Balance on Ability to Perform in High Ambient Temperatures," Research Quarterly, 32: 301-307, 1961.

6. Cade, J. R., H. J. Free, A. M. de Quesada, D. L. Shires, and L. Roby, Changes in Body Fluid Composition and Volume During Vigorous Exercise by Athletes, unpublished, Department of Medicine, University of Florida Medical School, Gainesville, Florida, 1970.

7. Cade, R., G. Spooner, E. Schlein, M. Pickering, and R. Dean, Effect of Fluid, Electrolyte, and Glucose Replacement During Exercise on Performance, Body Temperature, Rate of Sweat Loss, and Compositional Changes of Extracellular Fluid, unpublished, Department of Medicine, University of Florida Medical School, Gainesville, Florida, 1971.

8. Eaves, C. G. W., Effects of Four Liquids on the Endurance of College Wrestlers Following Dehydration, unpublished dissertation, Ohio State University, 1968.

9. Edholm, O. G., The Biology of Work, McGraw-Hill Book Co., New York, 1967.

10. Fordtran, J. S. and B. Saltin, "Gastric Emptying and Intestinal Absorption During Prolonged, Severe Exercise," Journal of Applied Physiology, 23: 331-335, 1967.

11. Hicks, Charles R., Fundamental Concepts in the Design of Experiments, Holt, Rhinehart and Winston, New York, 1964.

BIBLIOGRAPHY (Continued)

12. Malawer, S. J., M. Ewton, J. S. Fordtran, and F. J. Ingelfinger, "Interrelation Between Jejunal Absorption of Sodium, Glucose, and Water in Man," Journal of Clinical Investigation, 44: 6, 1072, 196͏5.

13. Minard, D., H. S. Belding, and J. R. Kingston, "Prevention of Heat Casualties," Journal of the American Medical Assoc., Vol. 165, 1813-1818, December 7, 1957.

14. Morrison, D. F., Multivariate Statistical Methods, McGraw-Hill Book Co., New York, 1967.

15. Newburgh, L. H., Physiology of Heat Regulation and the Science of Clothing, W. B. Sanders Co., Philadelphia, 1949.

16. Olsen, W. A. and F. J. Ingelfinger, "The Role of Sodium in Intestinal Glucose Absorption in Man," Journal of Clinical Investigation, 47: 1133, May, 1968.

17. Pearcy, M., S. Robinson, D. Miller, J. Thomas, and J. Debrota, "Effects of Dehydration, Salt Depletion, and Pitressin on Sweat Rate and Urine Flow," Journal of Applied Physiology, 8: 621-626, 1956.

18. Pitts, G. C., R. E. Johnson, and F. C. Consolazio, "Work in the Heat as Affected by Intake of Water, Salt, and Glucose," American Journal of Physiology, 142: 253-259, 1944.

19. Poock, Gary K., Prediction of Elemental Motion Performance Using Personnel Selection Test, Report 115, The MTM Association for Standards and Research, Ann Arbor, Michigan, 1968.

20. Recci, B., Physiological Basis of Human Performance, Lea and Febiger, Philadelphia, 1967.

21. Robinson, S. and A. H. Robinson, "Chemical Composition of Sweat," Physiological Reviews, 34: 202-220, 1954.

22. Schamadan, J. L., W. R. Godfrey, and W. D. Snively, "Preliminary Communication: Evaluation of Potassium-Rich Electrolyte Solutions as Oral Prophylaxis for Heat Stress Disease," Industrial Medicine and Surgery, 37: 677-684, 1968.

23. Seedat, Y. K., "Effects of Potassium on Blood-Sugar and Plasma-Insulin Levels in Patients Undergoing Peritoneal Dialysis and Haemodialysis," The Lancet, 2: 1166-1168, 1968.

BIBLIOGRAPHY (Continued)

24. Taylor, H. L., A. Henschel, D. Mickelson, and A. Keys, "The Effect of Sodium Chloride Intake on the Work Performance of Man During Exposure to Dry Heat and Experimental Heat Exhaustion," American Journal of Physiology, 140: 439-451, 1943.

25. Williams, Robert H., ed., Textbook of Endocrinology, W. B. Saunders Co., Philadelphia, 1965.

26. Wintrobe, M. E., ed., Harrison's Principles of Internal Medicine, 6th edition, McGraw-Hill Book Co., New York, 1970.

27. Witten, C. X., The Effects of Three Liquids on Exhaustive Exercise and Absorption in College Men, unpublished dissertation, Ohio State University, 1969.