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The Effects of Sodium Bicarbonate Ingestion
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Gary R. Hunter

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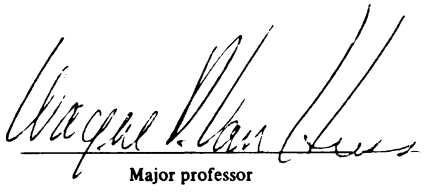

Major professor

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THE EFFECTS OF SODIUM BICARBONATE INGESTION ON ACID-BASE PARAMETERS ASSOCIATED WITH EXHAUSTIVE WORK

By

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ABSTRACT

THE EFFECTS OF SODIUM BICARBONATE INGESTION ON ACID-BASE PARAMETERS ASSOCIATED WITH EXHAUSTIVE WORK

By

Gary R. Hunter

This study was designed to determine the effects of different amounts of ingested sodium bicarbonate upon acid-base balance and relative aerobic and anaerobic metabolism and performance in a high-intensity treadmill run of about two-minutes duration. Four fit male subjects (age 29-31 years) were exercise tested twice under each of four conditions (placebo, .065 grams $NaHCO_3$/kg body weight, .130 grams $NaHCO_3$/kg body weight, and .260 grams $NaHCO_3$/kg body weight. The exercise test consisted of running on the treadmill at nine miles/hour nine-percent grade until exhausted. Gas collection took place during the run and during a fifteen minute recovery utilizing the Douglas bag method. Arterialized capillary blood was sampled before exercise and five, ten, and fifteen minutes following exercise. The blood was analyzed for pH, BE, pCO_2 and lactate.

The mean pre-exercise pH and BE values for the three $NaHCO_3$ supplement levels were all higher than the placebo-supplement level, with the low $NaHCO_3$ supplement level yielding the highest pH and BE values. A priori planned comparison F tests yielded significance only for BE between the pre-exercise placebo condition and a combination of the low, medium, and high treatment conditions.

All three $NaHCO_3$ treatment levels had larger pre-exercise to postexercise changes in arterialized capillary blood pH, BE, and lactate than the placebo treatment level. The largest changes were observed under the low $NaHCO_3$ condition. A priori planned comparison F tests between the placebo and the low $NaHCO_3$ level for the changes in lactate and BE were significant ($P<.05$). The contrast between the placebo and the low, medium, and high treatments combined for the change in BE was also significant ($P<.05$).

$NaHCO_3$ ingestion did not affect maximum VO_2, ventilation, respiration rate, or heart rate significantly. However, the maximum oxygen uptake was negatively related to pH and the oxygen uptake during the run was significantly lower (sign test $P<.05$) when the pre-exercise arterial blood pH was elevated above 7.45.

Nonsignificant increases in performance time were observed under each of three $NaHCO_3$ treatment levels. The largest increase was found with the low $NaHCO_3$ level. These increases in performance time paralleled the increases in anaerobic metabolism.

Two of the subjects (MP and KF) who were relatively alkaline when ingesting placebo also consumed a high-carbohydrate low-fat diet (fat<30%). Therefore, a small companion study was conducted to determine the effects of diet upon acid-base balance. Seven subjects were placed on a high-fat and protein or a high-carbohydrate diet for three day periods. Each subject went on each diet two times. Dietary recall indicated that the subjects consumed 59.5 percent carbohydrate, 24.5 percent fat, and 16 percent protein under the high-carbohydrate diet, and 19.5 percent carbohydrate, 49.5 percent fat, and 31.0 percent protein under the high fat-protein diet. There

was a significant .05 level decrease in BE under the fat-protein diet and nonsignificant decrease in pH.

DEDICATION

To my wife, Becky

ACKNOWLEDGEMENTS

Appreciation is extended to both Dr. W. D. Van Huss and W. W. Heusner for their guidance throughout my graduate study.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION TO THE PROBLEM

The effects of altering the buffer reserves in the body's extracellular fluid upon work performance have received relatively little attention in the research literature. Dennig (29) used sodium and potassium bicarbonate ingestion to produce alkalosis and ammonium chloride to produce acidosis. He found that work performance of greater than 20-minutes duration was markedly enhanced in alkalosis with an increased oxygen debt capacity, whereas both oxygen debt capacity and performance were lowered in the acidotic state. More recently, Jones et al. (56) and Sutton, Jones, and Toews (100) studied the effects of manipulating the acid-base balance of the extracellular fluid prior to exhaustive exercise of relatively short duration (five minutes). In the acidotic condition the antecubital venous blood lactate concentration was relatively low and the performance time was relatively short, whereas in the alkalotic condition the lactate concentrations were relatively high and the performance times were relatively long. Atterbom (10) increased the base excess (BE) 4.1 mEq per liter in the extracellular fluid shortly before short-duration high-intensity exhaustive work (about 2.5 minutes) using .13 gram/kg bodyweight orally ingested $NaHCO_3$. Nonsignificant but expected increased loss in base excess and increase in performance time were observed.

These studies indicate that exercise performance may be enhanced by an increase in the alkalinity of the extracellular fluid and suggest that anaerobic glycolysis, as measured by changes in blood lactate concentrations and extracellular BE, may be facilitated when this medium is more alkaline than normal. Under controlled conditions it has been shown that the conversion of glucose to lactate is rapid in a relatively alkaline medium (34,35,40,64). In isolated rat diaphragms subjected to severe hypoxia under various pH conditions, lactate production was shown to rise with alkalinity (34).

The following is a plausible explanation for the increase in anaerobic metabolism found in an alkaline medium. Hermansen proposes that in all-out work low pH may limit the rate of glycolysis. He found that in repeated bouts of maximal work the pH of the exercising muscle cell immediately after each bout was almost identical (43). One explanation for the pH dependence of the muscle cell's glycolytic pathway may be that phosphofructokinase (40,67,73,103), a known rate-limiting enzyme in glycolysis (Figure 1.1), is inhibited at low pH. If glycolysis is occurring at a sufficiently fast rate, a buildup of $NADH_2$ in the cytoplasm of the cell would be observed because the individual's aerobic processes are functioning at capacity. Lactic acid does not stay in the undissociated form very long. Since its pk is 3.86, $lactate^-$ and H^+ are formed rapidly. If a buildup of H^+ does decrease glycolytic activity and more buffer were available in the cell, glycolysis should be able to continue for a longer time before H^+ concentration slows down the activity of the pertinent enzymes. An increase in intracellular buffer has been shown to take place about one hour after ingestion of $NaHCO_3$ (80).


GLYCOLYTIC PATHWAY
Glycogen
Phosphorylase
Glucose 1-Phosphate
Glucose 6-Phosphate
Fructose 6-Phosphate
Phosphofructokinase
Fructose 1,6-Diphosphate
Glyceraldehyde 3-Phosphate
Glyceraldehyde-3P
Dehydrogenase
1,3-Diphosphoglycerate
3-Phosphoglycerate
2-Phosphoglycerate
Phosphoenolpyruvate
Phosphoenolpyruvate
Carboxykinase
Pyruvate
Lactate
Oxaloacetate
Tricarboxylic Acid Cycle

Figure 1.1

Blood lactic acid concentration, changes in acid-base balance of the blood and oxygen debt have all been used to determine the amount of anaerobic metabolism. In one study in which muscle lactate concentrations were measured at the end of various bouts of repeated maximal work of between one and seven minutes duration, no time-dependent differences in lactate concentrations were found (60). Increased values of blood lactate are felt to reflect increased muscle lactate concentration and the degree of anaerobic glycolysis achieved. An almost linear relationship has been observed between the highest concentrations of blood lactate and muscle lactate immediately after work (60). Since the decrease in blood pH following exercise reflects the muscle cell pH (43) and is highly related to maximum values of arterialized capillary blood lactate at the end of exercise (13,84), both blood lactate and blood pH are used to estimate anaerobic activity.

A decrease in the buffering capacity of the blood occurs when H^+ concentration of the blood is elevated. Therefore, BE of the blood is recognized as a measure of the total buffering capacity of the blood and loss of BE is recognized as a measure of anaerobic activity (13,84).

It is important that the same subjects be used when studying the limiting factors of physical performance since there are large differences in the anaerobic and aerobic capacities of different individuals (41,43). This may be partially explained by the large intersubject differences found in human muscle fiber composition (32). Human skeletal muscle is made up of either highly aerobic slow-twitch fibers or largely anaerobic fast-twitch fibers (32,37,48). The percentage of slow-twitch fibers in the gastrocnemius muscle has been

reported to vary from 25 to 80% in highly trained sprinters and distance runners, respectively (32).

It appears likely that aerobic metabolism may be reduced in alkalosis (71). When the pH is elevated, reductions in the activity of cytochrome c (88) and decreases in the conversion of lactate to glucose in the kidney (5,6) and liver (102) have been observed. No exercise studies in man have been found in which changes in aerobic metabolism have been related to acid-base balance.

The changes in anaerobic activity, aerobic activity, and exercise performance observed under various degrees of alkalosis could be of practical significance. In exercising man no study of altered acid-base balance has been found in which arterial blood parameters (lactate, pH, P_{CO_2}) and oxygen consumption have been obtained simultaneously. It was felt that additional insight into the problem could be gained by the study of the interrelationships among those parameters. Therefore, a study was designed to determine what effects changing the pre-exercise acid-base balance would have on anaerobic metabolism, aerobic metabolism and performance of fit young men in high-intensity short-duration work.

Statement of the Problem

The purpose of this study was to determine the effects of different amounts of pre-exercise ingested sodium bicarbonate upon acid-base balance, performance, anaerobic metabolism and aerobic metabolism in fit young men during and after an exhaustive high-intensity treadmill run of about two-minutes duration.

Since the results from the primary experiment indicated that diet may affect pre-exercise acid-base balance, the effects that

high-carbohydrate or high-protein and fat diets have on pre-exercise acid-base balance were determined.

Rationale

Improved performance in exhaustive work of about two-minutes duration, which is principally anaerobic in nature, was expected on the basis of previous studies (10,29,56,100). With pre-exercise pH increases of over .05 and base excess increases of over +5 mEq per liter, greater capacity to buffer lactic acid was expected (10,56).

Further, it was expected that the changes in base excess during the run would be related to exercise performance times, blood lactate, and oxygen debt. Different amounts of sodium bicarbonate were administered to determine if there is a linear or nonlinear relationship between the ingested dose on the one hand and pre-exercise acid-base balance, performance, aerobic metabolism, and anaerobic metabolism on the other. The tests were conducted in Latin-square order in a single-blind protocol.

Limitations

1. The results of this study can be applied only to young men with characteristics similar to those of the subjects used.

2. The results should be limited to exhaustive work of about two-minutes duration and are especially applicable to running.

3. Although standard precautions were taken, psychological and physiological fatigue may be concomitant variables in any repeated-measures study involving exhaustive work.

4. The results of the companion study comparing the effects that diet has on pre-exercise acid-base balance should be limited to subjects ingesting the respective diets for about three days.

Definitions

Anaerobic Glycolysis.--The metabolic breakdown of glucose to lactic acid is anaerobic glycolysis. It is the only pathway within which high energy phosphate bonds can be generated without the immediate utilization of oxygen (Figure 1.1).

Anaerobic Metabolism.--The production of energy without the utilization of oxygen is referred to as anaerobic metabolism. It includes the energy available in the endogenous high-energy phosphagens (adenosine triphosphate and creatine phosphate) and energy that can be obtained from anaerobic glycolysis. After exercise the body must remove the end product of anaerobic glycolysis (lactate) and replenish its high energy phosphate stores by an elevated oxygen utilization (oxygen debt).

Base Excess (BE).--The base concentration of whole blood as measured by its titration to pH 7.40 at a PCO_2 of 40 mm Hg is BE. It is equal to buffer base minus normal buffer base; therefore, normal BE is equal to zero.

Bicarbonate-Carbon Dioxide System.--Bicarbonate is the most important buffer in the blood. Bicarbonate acts as a buffer to decrease H^+ via the following reaction: $H^+ + HCO_3^- \rightleftarrows H_2CO_3 \rightleftarrows CO_2 + H_2O$. Only a very small amount of the combined $H^+ + HCO_3^-$ remains as H_2CO_3. Most of the H_2CO_3 is converted to CO_2 and water at equilibrium. Increased lung ventilation removes carbon dioxide and causes the reaction to move to the right. This allows increased amounts of hydrogen ion to be excreted. Decreased lung ventilation does the

reverse. Carbon dioxide is elevated causing an indirect increase in hydrogen ion concentration.

Gross Oxygen Debt.--The total amount of oxygen utilized during recovery from work is gross oxygen debt.

Lactate.--The salt of lactic acid is lactate.

Lactic Acid.--The end product of anaerobic metabolism is lactic acid (Figure 1.1).

Maximum Oxygen Uptake (Max VO_2).--The maximum amount of oxygen that can be taken up during work per unit of time (usually one minute) is defined as the subject's maximum oxygen uptake.

Oxygen Debt.--After work oxygen utilization is elevated above resting level to repay the deficit incurred during work. This elevated oxygen utilization, which is related to the anaerobic processes during work, is called oxygen debt.

Oxygen Debt Capacity.--The maximum oxygen debt that can be incurred by an individual following maximal work (usually of two to four minutes duration) is referred to as the subject's oxygen debt capacity.

Oxygen Uptake (VO_2).--The uptake of oxygen by the body per unit of time (usually one minute) is called oxygen uptake.

CHAPTER II

REVIEW OF LITERATURE

The purpose of this study was to determine the effects of three different doses of $NaHCO_3$ on acid-base balance of the blood, exercise performance, anaerobic metabolism, and aerobic metabolism. The review of literature pertinent to this problem has been organized into six main sections: (a) energy sources of work, (b) limiting factors in anaerobic glycolysis, (c) acid-base balance and anaerobic metabolism, (d) acid-base balance and aerobic metabolism, (e) measurement of anaerobic metabolism, and (f) the effects of sodium bicarbonate supplementation on acid-base balance, anaerobic metabolism, aerobic metabolism, and high-intensity work performance.

Energy Sources of Work

Skeletal muscle tissue in man is able to function both aerobically and anaerobically. Aerobic energy usually is derived from the oxidation of fats and carbohydrates. For short periods of time energy also can be obtained anaerobically by: (a) the splitting of high-energy phosphate bonds of the endogenous phosphagens (adenosine triphosphate and creatine phosphate), and (b) the breakdown of endogenous glycogen through anaerobic glycolysis.

The immediate sources of energy for muscle contraction are the high-energy phosphate bonds. During exercise of very high intensity, virtually all energy needs are derived from adenosine triphosphate

(ATP) and creatine phosphate (CP) (Figure 2.1-A and B). These high-energy bonds will be exhausted after a short period of time (about ten seconds at the highest work loads) unless they are replenished. At work loads in which exhaustion occurs in ten seconds or less, there is insufficient time to allow significant amounts of other energy sources to contribute to the replenishment of ATP and CP.

At relatively low work intensities (below 70 to 80 percent of maximum oxygen uptake), all energy needs for the regeneration of ATP and CP are met by oxidative metabolism (excluding the energy needed while the oxygen uptake is readjusted from a resting metabolic level to a higher one) (Figure 2.1-C). Fat and carbohydrate are the primary fuels used in the aerobic resynthesis of these high-energy phosphate bonds (8). Hermansen (41) has hypothesized that aerobic metabolism predominates in work of about ten-minutes duration and longer.

At work levels higher than 70 to 80 percent of maximum oxygen uptake (especially when work intensity exceeds 100 percent of aerobic capacity), anaerobic glycolysis (Figure 2.1-D) also comes into use (20). Anaerobic glycolysis can help to maintain ATP and CP levels for periods of up to several minutes during high-level work. In this pathway glycogen is broken down into pyruvic acid and then lactic acid. In exhaustive work of one- to two-minutes duration, Hermansen (41) has proposed that the production of energy by anaerobic glycolysis predominates.

During recovery from heavy work, oxygen uptake is elevated above normal (O_2 debt). This elevated oxygen uptake is due to: (a) regeneration of muscle ATP and CP levels to normal during repayment of the alactic portion of the debt (Figure 2.1-A and B), and

SCHEMATIC REPRESENTATION OF THE VARIOUS ENERGY SOURCES FOR MUSCULAR WORK

A, B, C and D correspond to the different reactions as indicated in the modified Lohmann scheme (20).

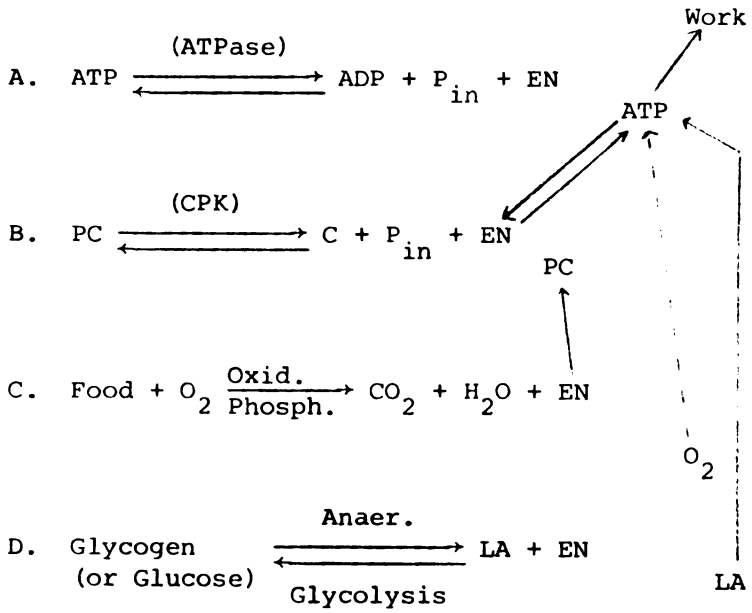

Figure 2.1

(b) utilization of lactate for energy and for the regeneration of glycogen (Figure 2.1-D). Lactate is metabolized in heart muscle, skeletal muscle, liver, and kidney (18,44,57).

The O_2 debt an individual will incur depends on the intensity and duration of the work that is performed. A bout of exercise in which exhaustion is reached after two to five minutes usually will elicit an individual's maximal O_2 debt (8,41,68). However, subject motivation is of utmost importance in establishing this maximal value (8,41,68).

There are large differences in the anaerobic and aerobic capacities of different individuals (41,43,89). These differences, at least in part, may be due to variations in muscle-fiber types (32). Human skeletal muscle is made up of two basic types of muscle fibers: fast-twitch fibers (that are largely dependent upon anaerobic metabolism) and slow-twitch fibers (that are primarily dependent upon aerobic metabolism) (38). It has been estimated from selected muscle biopsies that the composition of the gastrocnemius muscle may vary from 20 to 80 percent fast-twitch fibers in different subjects (32). It would appear that an individual with a large proportion of fast-twitch fibers would have a relatively high capacity for anaerobic glycolytic activity. In fact, it has been reported that athletes who are highly successful in short-duration high-intensity events do have large proportions of fast-twitch fibers (38,62).

Limiting Factors in Anaerobic Glycolysis

Several factors have been hypothesized to be limiting for anaerobic glycolysis. Glyclogen depletion, high concentrations of lactate in the blood and muscle cells, increased blood H^+, and

increased intracellular H^+ all have been proposed. A short discussion of each of these factors follows.

Glycogen depletion may limit relatively high-intensity work of long duration and may even limit anaerobic work of short duration if the glycogen stores are low at the beginning of the work. However, if glycogen levels are normal before the commencement of work, glycogen depletion is not a limiting factor in exercise to exhaustion of up to two- to five-minutes duration (4,22,53).

Lactate has been proposed as a limiting factor in short-term exercise (45). Though the highest cellular lactate concentrations have been found at the highest work levels and these concentrations are approximately the same with repeated work bouts to exhaustion (60), no causal relationship has been found between muscle fatigue and muscle lactate. Hirche, Langohr, and Walker (47) have shown that there is an increase in lactate output from working dog skeletal muscle when $NaHCO_3$ is infused into the blood. Jones et al. (56) used biopsies and obtained increased muscle lactate output following $NaHCO_3$ ingestion in humans. Since HCO_3^- concentration seems to affect lactate concentrations in maximal work, it would appear that lactate concentration does not directly limit short-duration work to exhaustion.

Cerretelli (21) hypothesized that increased blood H^+ is the immediate cause of fatigue in exercise of two- to five-minutes duration. Since both the ability to incur a lactate debt and blood HCO_3^- are reduced at altitude, he suggested that anaerobic glycolysis is dependent on the alkali reserve of the blood. However, when subjects perform repeated bouts of exercise to exhaustion, there is a substantial drop in blood pH after each of the exercise bouts is terminated

(43,84). These data make it appear that blood pH is an unlikely limiting factor in exhaustive exercise.

A decrease in muscle pH is the most probable cause of the exhaustive fatigue that occurs in short-duration high-intensity work. Repeated work periods to exhaustion have been shown to produce very small changes in intracellular pH as compared to the changes that are seen in blood pH (84). No differences have been found in the terminal exercise pH between various work periods (84).

Acid-Base Balance and Anaerobic Metabolism

Numerous investigators have shown that an increase in lactate production occurs in an alkaline environment and a decrease occurs in an acidotic environment. Presumably these variations are due, respectively, to increased and decreased glycolytic metabolism (34,35,103). Some investigators feel that alterations in glycolytic metabolism may be caused by the pH dependence of some of the enzymes in the glycolytic pathway (67,87,90,103). Phosphofructokinase, glyceraldehyde-dehydrogenase, and phosphorylase activities all have been shown to be inhibited by high concentrations of H^+ in the extracellular fluid (67,87,103). Phosphofructokinase and glyceraldehyde-3p-dehydrogenase are considered to be rate-limiting enzymes in glycolysis (12,63,87,90) (Figure 1.1 shows the glycolytic pathway). It does seem possible that pH dependence may be responsible, at least in part, for the exhaustion that occurs in highly anaerobic work.

The cell appears to be affected by elevated extracellular pH in at least two ways: (a) there is an increase in buffer base caused by diffusion of HCO_3^- across the cell membrane; and (b) there is an increase in cell membrane permeability to lactic acid.

1. Bicarbonate ions are known to be freely diffusible between the blood and the interstitial fluid with equilibrium being reached within fifteen minutes after $NaHCO_3$ is injected into the blood (15,91). When a dose of 1.3 mEq/kg of body weight is infused into normal subjects, calculations indicate that sixteen percent of the HCO_3^- enters the tissue cells within one hour (the amounts lost from the lungs and kidneys and the amounts in equilibrium in the blood, irterstitial fluid, and erythrocytes are subtracted to determine the amount entering the tissues) (80,98). Similar results have been obtained from both *in vivo* and *in vitro* calculations of intracellular penetrations of HCO_3^- (101,106).

2. Permeability of the muscle cell membrane seems to be increased for lactic acid in an alkaline environment. Hirche, Wangor, and Wacker (47) demonstrated that lactate output from the muscle cells of dogs was increased when the interstitial fluid had an increased concentration of HCO_3^-. The total amount of lactate production was not increased. Gesser (34) found a marked increase in lactate excretion from isolated rat diaphragm muscle when the pH of the extracellular fluid was raised from 6.90 to 7.40. However, only relatively small increases in lactate production were found. It is uncertain whether lactic acid diffuses out of the cell as lactic acid or as lactate ion (34,46), but diffusion in either form would tend to limit the increase in cellular H^+. Diffusion as lactic acid could participate directly as the H^+ would be carried in combination with the lactate. Dissociation of most of the lactic acid would occur quite rapidly once it was out of the cell since lactic acid has a pK of 3.86 which favors lactate at an alkaline pH (lactic acid $\rightleftarrows$ $lactate^- + H^+$). If lactate diffuses out of the cell in the ionic

form, H^+ diffusion from the cell would have to be increased in order for the cell to maintain its membrane potential.

Acid-Base Balance and Aerobic Metabolism

It is possible that aerobic production of energy is decreased at an elevated pH. Experiments on isolated pigeon hearts have demonstrated that small increases in alkalinity within the pH range of 6.5 to 7.5 cause a decrease in oxidation and a buildup of NADH concentration (71). Decreases in pH cause the reverse. This apparent dependence of aerobic metabolism on pH may be explained in part by either or both of two mechanisms.

Cytochrome c has been reported to reduce its ability to participate in oxidation-reduction reactions with an increase in pH (88). Brandt et al. reported that the decrease in oxidation-reduction potential of cytochrome c in an alkaline pH is evidently due to a pH-dependent change in the conformation of the cytochrome protein. If a partial block of oxidation does occur in the electron transport system, a buildup of the intermediates of the citric acid cycle would be expected. This buildup does occur in the measurable citric acid cycle substrates (1,2,87,97).

It is possible that conversion of lactate to glycogen is inhibited in the kidney and liver (6,97) as well as in skeletal muscle and heart muscle (30,59) when the extracellular H^+ concentration is elevated. This conversion utilizes oxygen and thus elevates O_2 uptake. The phosphoenolpyruvate carboxykinase (PEPCK) reaction catalyzes the first step in the conversion of pyruvate to phosphoenolpyruvate in gluconeogenesis (Figure 2.2). This reaction bypasses the irreversible pyruvate-kinase reaction. Therefore, a block here

would limit the oxidation of lactate to glucose (87). PEPCK activity has been found, at least in the kidney, to be pH dependent and to exhibit less activity as intracellular pH goes up (5,6,102). Eggleton and Evans (30) perfused oxygenated mammalian skeletal muscle *in vitro* and found an increase in lactate removal as the H^+ concentration increased. Kamm et al. (59) found an increase in muscle glycogen when extracellular H^+ concentration was increased. As stated previously, it is well established that lactate removal can occur in non-exercising skeletal muscle, liver, kidney, and heart muscle during mild exercise as long as the arterial blood is well oxygenated. This phenomenon would be very difficult to detect when large volumes of lactate are diffusing into the blood from working muscles because quantitatively the removal of lactate would be quite small compared to the influx of lactate. If the removal does occur in non-exercising tissue and the removal is inhibited by an increase in pH, it may help to explain the apparent decrease in aerobic metabolism mentioned earlier.

Measurement of Anaerobic Metabolism

In the early 1930s Margaria (75) proposed that the total O_2 debt measured during recovery from exercise is actually reflective of two separate mechanisms: an alactic acid mechanism and a lactic acid mechanism. He stated that the initial rapid fall in O_2 consumption is due to the alactic restoration of the high-energy phosphates in muscle. The subsequent slower decline in O_2 consumption was attributed to the oxidation of lactic acid. Consequently, he concluded that venous and arterial blood lactate concentrations are good measures of anaerobic metabolism and exertion in short-duration high-intensity work.

Huckabee (50,51) introduced the concept of "excess lactate" (XL) because he felt that a variety of conditions other than hypoxia (e.g., extracellular alkalosis, increased blood glucose, and catecholamine injections) can produce increased concentrations of lactate in the body. Consequently, he concluded that it is unwarranted to use alterations in body lactate as an indication of oxygen deficiency of the tissues. Since changes in pyruvate may affect lactate production as much as hypoxia, Huckabee felt that pyruvate must be considered in evaluating increased lactate concentrations. Therefore, he devised a formula for calculating XL from the ratio of lactate to pyruvate concentrations. He concluded that the value of XL is a much better measure of hypoxia and thus a better measure of anaerobic metabolism than is lactate.

This XL concept has been challenged by a number of investigators. DeCoster et al. (26) failed to find elevated arterial lactate concentrations with extracellular alkalosis. Of more importance is the fact that higher correlations have been found between oxygen debt and arterial lactate (3,26) than between oxygen debt and XL (26,76). Furthermore, several investigators have found very high relationships between work intensity and arterial lactate (19,76,86).

Since pyruvate is multiplied by the expected lactate/pyruvate ratio, normal XL has a value of zero. This has led to reports of negative values for XL during recovery from submaximal exercise even when there are decreases in arterial buffer base and significant amounts of oxygen debt (26,107).

Karlson (60) has found an almost linear relationship in humans between the highest arterial lactate concentration during recovery from work and muscle lactate concentration immediately following work,

whereas Dawson, Nadel, and Horvath (25) have reported that, in swimming rats, changes in muscle and arterial lactates parallel each other very closely. Arterial blood lactate concentrations range between 11 and 14 mM/l for young, moderately trained individuals (8). This value can be much higher (20 mM/l) in highly trained, highly motivated, middle-distance athletes (8).

The use of arterial blood is recommended in the study of the metabolic acidosis of exercise because it is difficult to estimate what happens to the lactate and acid-base balance of the blood as it passes through the capillaries of nonexercising limbs (18,26,49,75). Since lactate uptake may occur in skeletal muscle, a marked arterial-venous difference may occur. If lactate is metabolized by nonexercising skeletal muscle, the alkalinity of the venous blood in the nonexercising limbs could be increased since metabolism of lactate decreases H^+ (lactate + H^+ + $3O_2$ → $3CO_2$ + $3H_2O$).

Acid-base balance of the blood frequently is used to detect anaerobic metabolism. Osnes and Hermansen (84) and Bouhuys et al. (13) found an almost linear relationship between arterialized capillary blood lactate and arteriolized capillary blood H^+ concentration in exercising humans. Hermansen and Osnes (42) reported a very high relationship between arterialized capillary blood pH and muscle biopsy pH in exercising humans. Average arterial pH after one bout of maximal exercise of two to five minutes duration was found to be 7.19 to 7.25 (13,41,42).

Base excess of arterial blood is also very highly related to the lactate concentration in arterial blood (13,84). Bouhuys et al. (13) reported an average after exercise BE value of -14 mEq/l in a group

of twenty-seven 22- to 30-year-old male subjects. The change in BE (pre-exercise to postexercise) was 15.6 mEq/l.

Sodium Bicarbonate Supplementation

Several investigators have reported that a small increase in the amount of bicarbonate in the blood may improve an athlete's ability to buffer lactic acid and thus increase his potential for high-intensity work (10,28,56,75,100). All of these authors hypothesized that an increase in glycolytic activity in the exercising muscle cells is the factor responsible for the increases in performance with alkalosis.

Oral administration of various amounts of $NaHCO_3$ was used in several investigations to increase the bicarbonate of the blood. Dennig (28) used ten grams forty-eight hours before exercise and another ten grams twenty-four hours before exercise. Margaria (75) and Sutton, Jones, and Toews (100) used about twenty grams approximately three hours before exercise.

With $NaHCO_3$ ingestion, increases in alkalinity appear to be quite rapid up to pH changes of about .05 units. Additional amounts of $NaHCO_3$ achieve little additional change in pH. An average change of .055 pH units was observed with nine grams of $NaHCO_3$ supplementation (10), whereas increases in pH of only .05 units were observed with supplements of twenty grams of $NaHCO_3$ (100).

Of the studies reporting enhanced exercise performance following $NaHCO_3$ supplementation, only one reported statistical significance. Sutton, Jones, and Toews (100) found a mean increase in performance time of 2.25 minutes ($P<.01$) on a cycle ergometer ride to exhaustion. Since the results of the other investigators who reported no

significance were in the expected direction, it appears likely that they were actually in the statistical range of no decision.

Jones et al. (56), Sutton, Jones, and Toews (100), and Margaria (75) all reported increased amounts of lactic acid in the blood after exercise to exhaustion in an alkalotic state. Jones et al. (56) performed some additional experiments that did not terminate in exhaustion but in which increases in muscle lactate were found with sodium bicarbonate ingestion. They proposed that the increases in lactate were due to increased anaerobic metabolism. Dennig et al. (29) and Atterbom (10) demonstrated an increased before-to-after exercise change in the pH of the blood under alkalotic conditions. Atterbom also found increased changes in the HCO_3^- and BE of the blood.

CHAPTER III

RESEARCH METHODS

The methods and procedures described in this chapter were used to investigate the effects of pre-exercise ingestion of selected dosages of sodium bicarbonate on performance in exhaustive high-intensity work of about two-minutes duration. Primary attention was given to acid-base balance and to various parameters of energy metabolism for clues regarding underlying mechanisms. Secondarily, as a small companion study, attention is focused on the effect that diet has on the acid-base balance of arterialized capillary blood.

Research Design

A Latin-square design with four subjects and four treatments with replication was used for the primary experiment (Figure 3.1). The treatments consisted of oral doses of sodium bicarbonate or placebo which were administered blind in two equal parts, twelve and two hours prior to the exhaustive exercise test. Timing of administration was determined from pilot experiments, the data for which are shown in Appendix A. The dietary supplements used were: (a) .100 gram of dextrose per kilogram (kg) of body weight (placebo), (b) .065 gram of sodium bicarbonate ($NaHCO_3$) per kg of body weight, (c) .130 gram of $NaHCO_3$ per kg of body weight, and (d) .260 gram of $NaHCO_3$ per kg of body weight.

EXPERIMENTAL DESIGN

Sequence of treatments is depicted by the numbers in boxes.

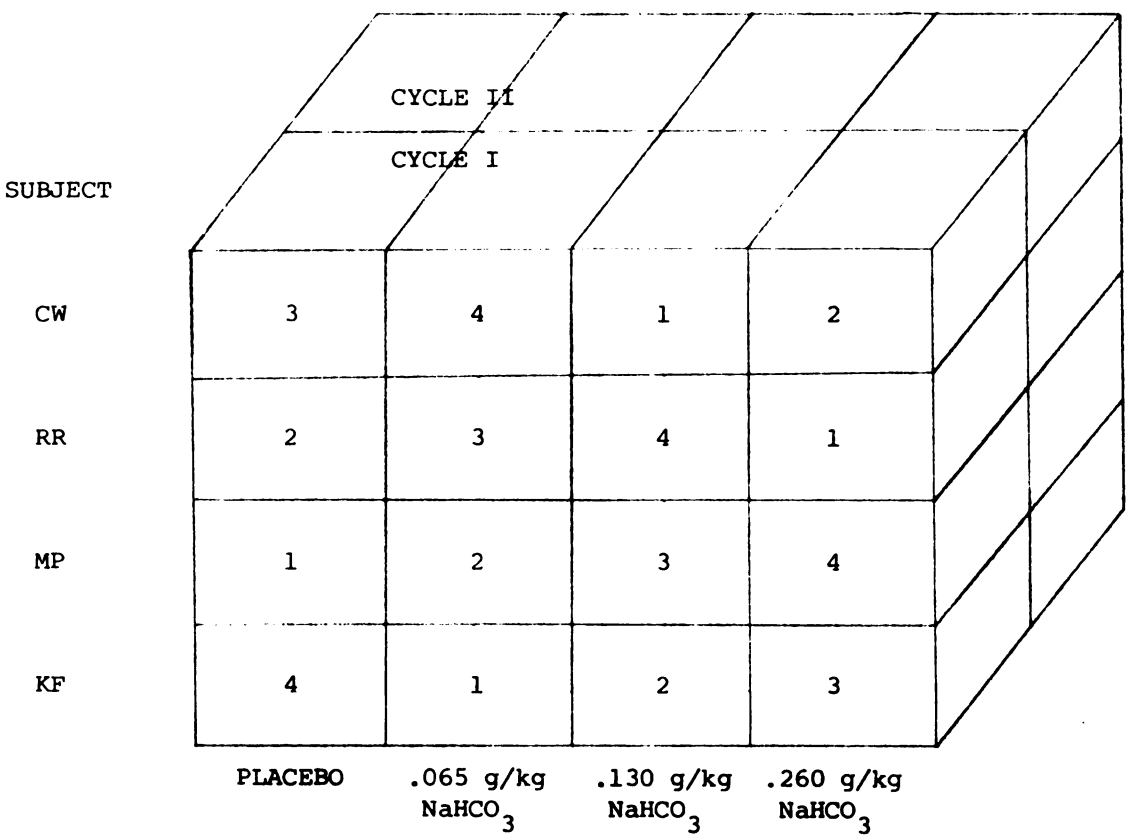

Figure 3.1

Subjects

The subjects were four physically fit males, ages 29-31 years, who had recent medical approval for participation in strenuous physical activity. Two of the subjects were distance runners; the other two were basketball players.

Prior to any exhaustive testing, informed consent was obtained from each subject. A personal history was obtained, and a stress test utilizing a modified Bruce protocol (16) was used in which the treadmill speed and grade were increased every three minutes (see Appendix B for details). Resting and exercise electrocardiograms and blood pressures were monitored.

Established criteria for the termination of stress tests were followed (31). In addition, the level of physical fitness for endurance performance was determined prior to exhaustive testing by obtaining the heart rate responses of each subject during a six miles/hour, zero-percent grade treadmill run. The average maximum pulse rate in this test for untrained subjects of college age is over 160 beats/minute while well-trained marathon runners have maximum pulse rates on this test of under 140 beats/minute (see Figure 3.2 for typical responses). Since the subjects of this study all exhibited a pulse rate of 150 beats/minute or less (Figures 3.3 through 3.6), they were considered to be reasonably fit.

Exercise Test

The exercise test consisted of a high-intensity treadmill run at a speed of nine miles/hour and a grade of nine percent. The speed and grade were selected to achieve a maximal performance duration of about two to two and one-half minutes. The post-run recovery period

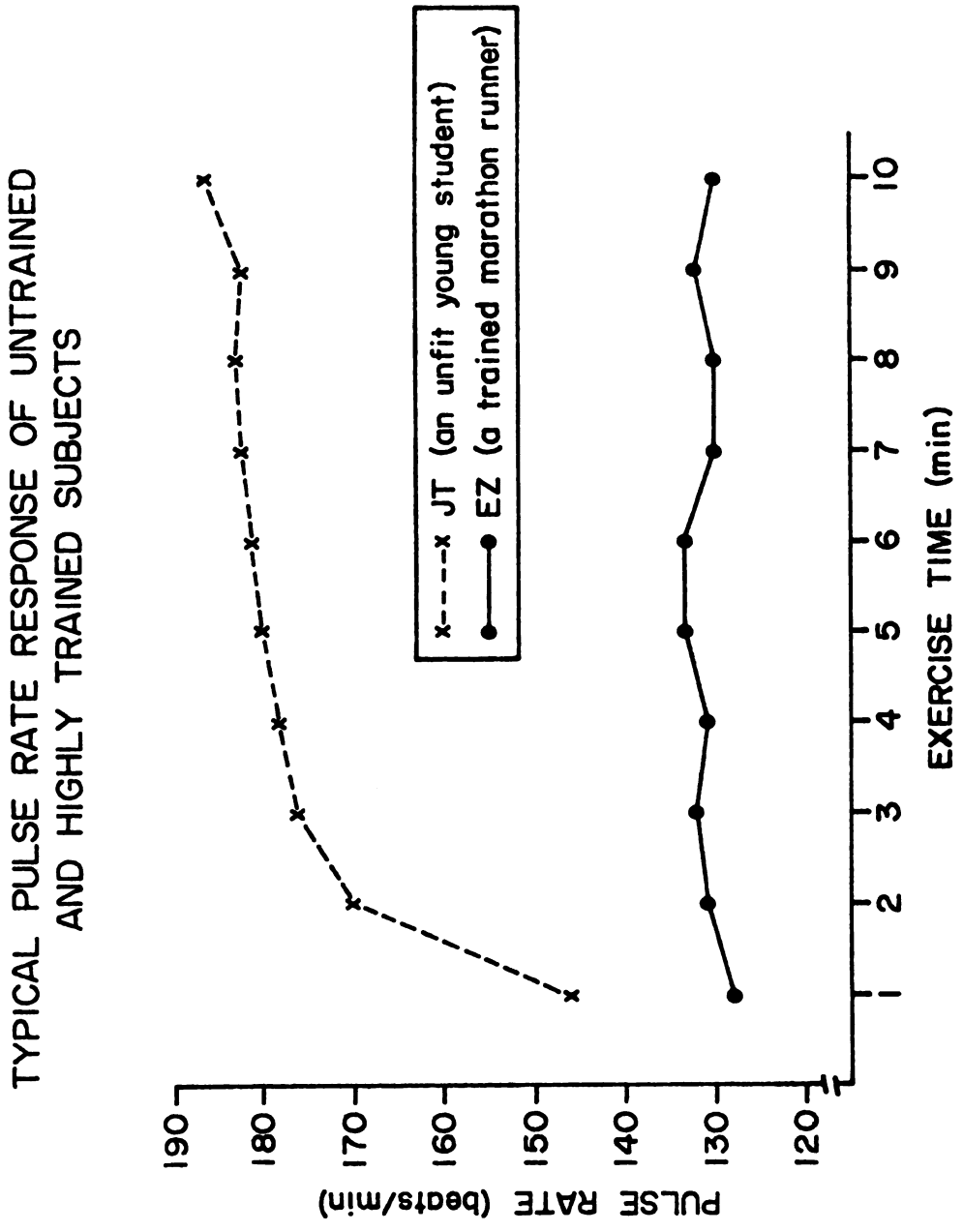
TYPICAL PULSE RATE RESPONSE OF UNTRAINED AND HIGHLY TRAINED SUBJECTS
x---x JT (an unfit young student)
EZ (a trained marathon runner)
PULSE RATE (beats/min)
190
180
170
160
150
140
130
120
1
2
3
4
5
6
7
8
9
10
EXERCISE TIME (min)

Figure 3.2

PULSE RATE RESPONSE OF THE SUBJECTS TO A 10 MINUTE, 6 MPH, 0% GRADE RUN

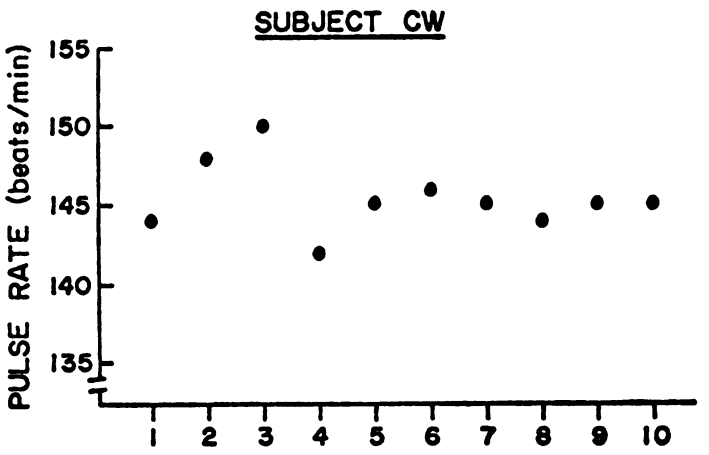

Figure 3.3

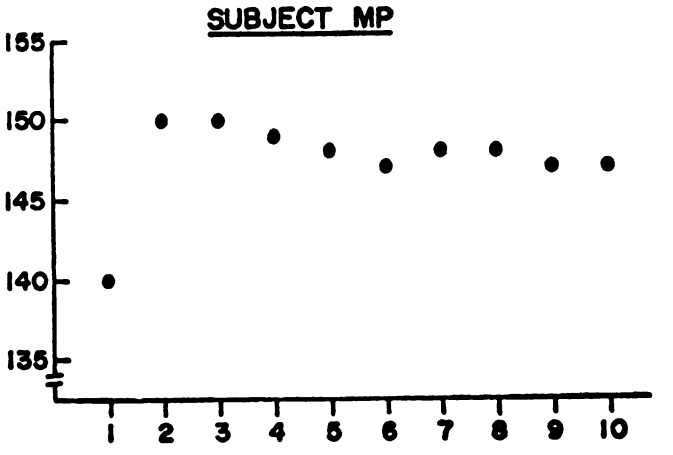

Figure 3.4

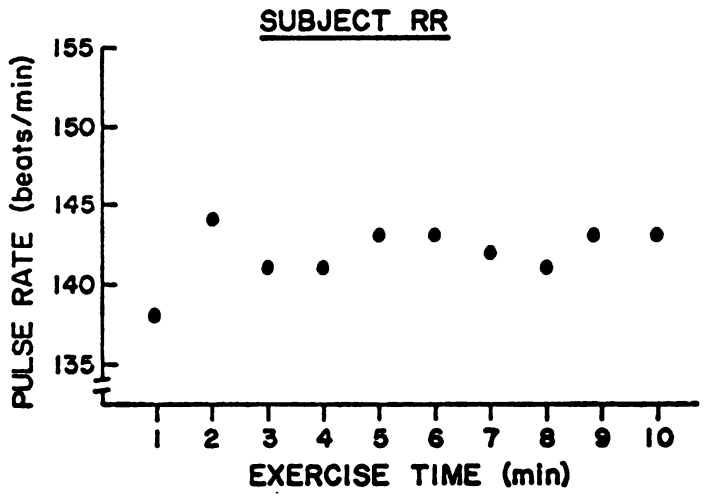

Figure 3.5

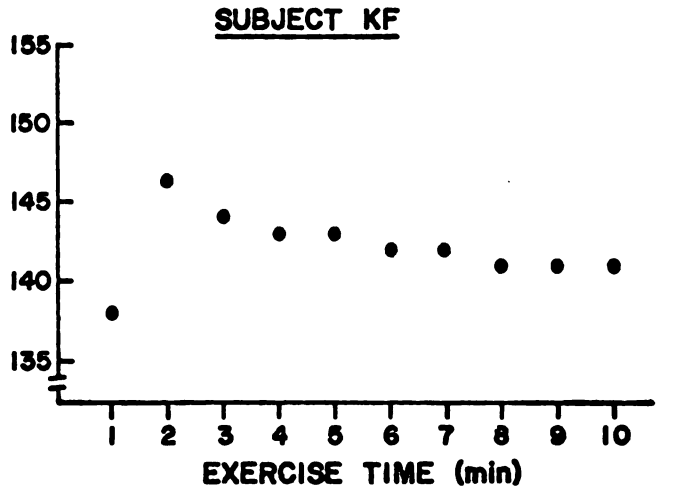

Figure 3.6

was standardized at fifteen minutes. A lightweight safety harness was worn by the subjects to prevent them from falling and to make them feel more secure in running to exhaustion at a nine-percent grade. A description of the procedures used in measuring the dependent variables before, during, and following the exercise follows.

Measurement Procedures

Heart Rate. Disposable electrodes[1] were placed on the subject in a single bipolar V5 electrocardiograph configuration (31) (Figure 3.7) with the results recorded on a Cambridge 3030 ECG unit.[2] Heart rate was recorded once every 30 seconds during the run and every minute during recovery. The recordings were made directly from a readout of the ECG unit's R wave to R wave calculation of heart rate. Each of these recordings was viewed as a separate variable.

Respiration Rate. Respiration rate was detected using a Sanborn pressure transducer (Model 268A) connected by plastic tubing to an Otis-McKerrow respiratory valve.[3] The output from the pressure transducer was recorded on a Sanborn Twin-Viso Recorder[4] once every minute for ten seconds. Average respiration rate was computed for each treadmill run.

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[1] 3M Red Dot Electrodes, Minnesota Mining and Manufacturing Company, 3M Company, 3M Center, St. Paul, Minnesota.

[2] Cambridge Instrument Co., Inc., 73 Spring Street, Ossining, New York.

[3] Otis McKerrow, Warren Collins Company.

[4] Sanborn Company, Cambridge, Massachusetts.

THIS FIGURE SHOWS ELECTRODE PLACEMENTS WHICH CONFORM TO A SINGLE BIPOLAR V5 CONFIGURATION.

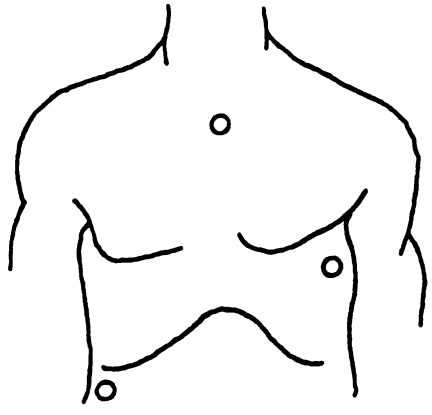

Figure 3.7

Energy Metabolism. The expired gas was collected using the standard Douglas bag method (23). A lightweight Otis McKerrow respiratory valve was used with a minimum of hose between the subject and collection bag (circuit resistance was less than 20 mm H_2O at a flow rate of 227 liters per minute). The collection bags were neoprene weather balloons[5] (33).

During exercise, bags were changed every thirty seconds. During recovery, bags were changed each minute for the first three minutes, once every two minutes for the next six minutes, and once every three minutes during the final six minutes.

Percent CO_2 in expired air was determined on a Beckman Medical Gas Analyzer (Model LB2); percent O_2 was analyzed on a Beckman Oxygen Analyzer (Model OM-11).[6] An American Meter Company Dry Gas Meter (Model DTM-11)[7] was used to determine gas volumes. Helium was used to set the zero points of the analyzers. Room air and a known standard gas sample (17.78% O_2 and 4.31% CO_2) were used to calibrate the analyzers. Oxygen and carbon dioxide concentrations of the standard gas sample were determined using a Haldane Chemical Analyzer.[8] All energy metabolism calculations were made as described by Consolazio, Johnson, and Pecora (23) (Appendix C). Energy metabolism variables consisted of the ventilation, O_2 uptake, and RQ computed from analyses of each expired gas bag that was collected during both exercise and

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[5]Darex Balloons, W. R. Grace and Company, Cambridge, Massachusetts.

[6]Beckman Instruments Inc., 3900 River Road, Schiller Park, Illinois.

[7]Singer, American Meter Company.

[8]Arthur H. Thomas Company, Philadelphia, Pennsylvania.

recovery. The maximum oxygen uptake and total exercise and recovery oxygen consumptions also were computed.

Blood. Two hundred twenty microliters (µl) of anaerobic arterialized capillary blood were taken from the fingertip before each exercise period and five, ten, and fifteen minutes after the exercise period (9,93,94,95). The detailed procedures are described in Appendix D.

Lactate Analysis. Of the 220 µl of total blood sampled, 100 µl were collected in an unheparinized capillary tube. This sample was used in the determination of blood lactate by the enzymatic method (81). A Sigma lactic acid chemical kit[9] was used for the enzymatic reaction and a Bausch and Lomb Spectrophotometer (Spectronic 20)[10] was used for the analysis of NADH (Appendix E). The blood lactate variables included lactate concentrations before exercise, at five, ten, and fifteen minutes after exercise, and the change in lactate which was calculated to be the difference between the before-exercise lactate concentration and the maximum lactate concentration after exercise.

pH, Partial Pressure Carbon Dioxide, Bicarbonate Concentration, and Base Excess. One hundred twenty microliters of blood were collected in heparinized capillary tubes and were used in determining pH directly. The PCO_2, HCO_3^-, and BE were determined by using the Astrup Equilibration Method for acid-base balance variables

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[9]Sigma Chemical Company, P.O. Box 14508, St. Louis, Missouri.

[10]Bausch and Lomb, Rochester, New York.

(9,94,95,96) (Appendix F). A Radiometer pH meter 27 and a Radiometer Microtonometer[11] were used in the determination of pH, PCO_2, and BE. Each of these acid-base measurements was viewed as a separate variable for each blood sample. Change in pH and BE (the difference between the before-exercise value and the lowest value after exercise) also were computed.

Subject Protocol

Pretest Procedure. Two tests per week (either a Monday and Thursday or a Tuesday and Friday schedule) were used. All subjects were tested at approximately the same time of day, either late morning or early afternoon. The subjects were requested to keep their diets, activity levels, and amounts of sleep as constant as possible during the twenty-four hour period before each test. Twelve hours before the scheduled test, each subject was requested to take one-half of a designated, but unlabeled, dietary supplement. Two hours before test time, the rest of the supplement was taken.

Laboratory Procedures. The subject came to the laboratory dressed in tennis shoes and track shorts. The ECG electrodes were attached to the subject, and a pre-exercise blood sample was taken. The subject was weighed and allowed to warm up in his own manner (usually about five minutes of running at six miles/hour and zero-percent grade). The electrode leads, harness, and Otis McKerrow respiratory valve were attached about five minutes after the warmup. The subject then performed the exercise test until exhausted. At this time the subject would grasp the iron railings on the sides of

[11] Radiometer, 72 EMDRUPVEJ, Copenhagen NV, Denmark.

the treadmill and straddle the treadmill belt until it was stopped. The harness was removed, and the subject sat down. Heart rate was monitored at one-minute intervals, and expired gas was collected continuously. At one minute into recovery, the subject placed his finger in 45°C water to arterialize the finger tip capillaries. The first post-exercise blood sample was taken at five minutes into recovery. The subject then placed his finger back in the warm water, and at ten minutes and fifteen minutes the blood was sampled again. The experiment was terminated after the fifteen-minute blood sample was drawn.

Data Collection Procedures. Heart rate and respiration rate were recorded as the experiment proceeded. The gas analyses took place as soon as the bags were collected. All blood to be used in the determination of acid-base variables was stored at 0-3°C and samples were analyzed within 2.5 hours. The blood used in the lactate determinations was used to obtain a protein-free supernatant which was stored at 0-3°C for up to six days before analysis (Appendix D).

Diet and Acid-Base Balance

The effects of diet on acid-base balance of the arterial blood were determined in a small companion study designed as a followup to the primary experiment. Seven subjects were placed on regulated diets for three-day periods. The diets consisted of either high-carbohydrate or high-fat and protein (Table 3.1 lists the instructions the subjects were given under each dietary regimen). Each regulated diet was followed two times with each subject consuming either a high-carbohydrate or a high-fat and protein diet for three days during each week. Young male undergraduate physical education students were

Table 3.1

Instructions to Subjects Under Each Dietary Regimen

Foods to be Eaten on the High-Carbohydrate Diet

Foods that can be consumed in any amounts:

Fruit (except cranberries, plums, prunes)
Vegetable (except corn and lentils)
Bread
Cereal
Potatoes, Rice, Macaroni
Margarine
Sugar
Skim Milk (no more than 3 servings of whole milk)
Cottage Cheese
Lettuce
Pancakes

No more than one serving of any combination of the following can be consumed each day:

Meat
Egg
Fish
Nuts (including peanut butter)
Corn, Lentils
Cranberries, Plums, Prunes
Cakes and Cookies, plain
Butter

AN EFFORT MUST BE MADE TO KEEP YOUR TOTAL CALORIC INTAKE RELATIVELY CONSTANT. A BODY WEIGHT LOSS OR GAIN DURING THE CONTROLLED DIET PERIOD COULD AFFECT THE EXPERIMENTAL RESULTS.

Foods to be Eaten on the High-Fat, High-Protein Diet

Foods that can be consumed in any amounts:

Meat
Fish
Fowl
Eggs
Nuts
Peanut Butter
Bacon
Butter
Corn
Lentils
Cranberries
Lettuce
Margarine

Table 3.1 (continued)

AT LEAST 3 SERVINGS OF ANY COMBINATION OF MEAT, FISH, AND FOWL MUST BE CONSUMED EACH DAY.

No more than 3 servings of any combination of the following can be consumed each day:

- Fruit
- Vegetables
- Bread
- Cereal
- Potatoes, Rice, Macaroni
- Margarine
- Sugar
- Milk
- Cakes and Cookies, plain
- Pancakes

AN EFFORT MUST BE MADE TO KEEP YOUR TOTAL CALORIC INTAKE RELATIVELY CONSTANT. A BODY WEIGHT LOSS OR GAIN DURING THE CONTROLLED DIET PERIOD COULD AFFECT THE EXPERIMENTAL RESULTS.

used as subjects. A dietary recall was conducted to determine the foods the subjects consumed during the three days of regulated diet. Portion size also was determined by dietary recall procedures, and the data were recorded as shown in Table 3.2. Percent carbohydrate, protein, and fat were calculated for the two diets. Arterialized capillary blood was sampled using the procedures described previously. Finally, blood pH, PCO_2, and BE were determined as previously described.

Statistical Analyses

Correlations were computed between the obtained performance, respiratory rate, heart rate, energy metabolism, and blood data using a CDC 6500 computer and the Subprogram Scattergram of the Statistical Package for the Social Sciences (see Appendix G for a complete listing of all variables). Multiple correlations were computed for the performance, energy metabolism, and blood variables using a Hewlett-Packard 9810A Calculator and the Statistics Block program.

Three-way repeated-measures analysis of variance (AOV) tests (99,111) were calculated with supplement level, cycle, and subject as the independent variables. Separate analyses were performed for each of the dependent variables. Planned-comparison F-tests were computed for selected contrasts (99). The Michigan State University Statistic Series 4 AOV was used.

Finally, sign tests (92) were run comparing the five- and ten-minute BE values. Each measurement was treated as one observation for these sign tests. A sign test was also run comparing average values on the O_2 uptake curve with pH recorded as either above 7.45 or equal to and below 7.45.

Table 3.2

Dietary Recall Calculation Sheet

SUMMARY OF FOOD INTAKE OF AN INDIVIDUAL SUBJECT

Subject_____ Date ___/___/___ Age_____ Sex_____ Ht._____ Wt._____

Food	Per Day Number of Servings M	T	W	T	F	S	S	Total	Av.	gm Fat	gm Protein	gm Carbohydrate	Calories	Total	Av.
Milk															
Cheese															
Eggs															
Dried beans and peanut butter															
Meat, fish, etc.															
Tomatoes and citrus fruits															
Leafy, green, yellow vegetables															
Potatoes															
Other fruits and vegetables															
Whole grain or enriched bread															
Whole grain or enriched cereal															
Other bread and cereal*															

Table 3.2 (continued)

Food	Per Day Number of Servings M	T	W	T	F	S	S	Total	Av.	gm Fat	gm Protein	gm Carbohydrate	Calories	Total	Av.
Baked goods, pancakes, doughnuts, etc.															
Soda pop															
Candy, jelly, jam, syrup, sundae topping, etc.															
Tea, coffee															
									Total						

*Includes spaghetti, macaroni, plain rice, noodles, and popcorn.

Three-way repeated-measures AOV tests were used to analyze the data from the companion study. Diet, subject, and cycle were the independent variables with separate analyses performed for each of the dependent variables. The dependent variables were percent carbohydrate, fat, and protein in the regulated diets and the resting pH and BE of the subject's arterialized capillary blood. Subprogram Multivariate of the Statistical Package for the Social Sciences was used.

CHAPTER IV

RESULTS AND DISCUSSION

The results are presented in five main sections: (a) the effects of the three sodium bicarbonate supplementation levels upon acid-base balance before exercise; (b) habitual exercise and/or diet and resting acid-base balance; (c) the effects of supplementation and degree of alkalosis upon anaerobic glycolytic activity; (d) the relationship of supplementation level and degree of alkalosis to aerobic metabolism and heart rate; and (e) the relationship of work performance to supplement level, acid-base balance before exercise, anaerobic metabolism, and aerobic metabolism.

Supplement Level and Acid-Base Balance Before Exercise

Elevated pre-exercise values of PCO_2, pH, and base excess (BE) in arterial blood would be expected with $NaHCO_3$ supplementation (10,28,80). The partial pressures of carbon dioxide were increased slightly as $NaHCO_3$ ingestion increased (Table 4.1). These changes were in the direction expected, but they were relatively small and not statistically significant ($F=0.27$, $P>.05$). Although the mean pH and BE values were noticeably different between the placebo and lowest $NaHCO_3$ treatments (Tables 4.2 and 4.3), little difference was observed between the three $NaHCO_3$ levels, and there was no overall statistical significance found for either pH ($F=1.06$, $P>.05$) or BE ($F=1.54$, $P>.05$). However, the a priori planned-comparison F-tests

Table 4.1

Pre-Exercise Values PCO_2
(mm Hg)

Subject	Treatment			
	Placebo	$NaHCO_3$ Low	$NaHCO_3$ Medium	$NaHCO_3$ High
CW	34.5	36.5	42.5	39.0
	38.5	38.0	39.5	40.5
$\bar{X}_{CW}$	36.5	37.3	41.0	39.8
RR	35.0	39.0	36.0	41.0
	39.0	39.0	36.0	36.0
$\bar{X}_{RR}$	37.0	39.0	36.0	38.5
MP	36.0	37.5	36.0	36.0
	40.0	36.0	41.5	37.5
$\bar{X}_{MP}$	38.0	36.8	38.8	36.8
KF	43.0	42.5	36.5	40.5
	42.0	41.0	42.0	42.5
$\bar{X}_{KF}$	42.5	41.8	39.3	41.5
$\bar{X}$	38.5	38.7	39.0	39.2
	F=0.27	P>.05		

Table 4.2

Pre-Exercise Values pH

Subject	Treatment			
		$NaHCO_3$		
	Placebo	Low	Medium	High
CW	7.45	7.49	7.41	7.48
	7.41	7.45	7.44	7.51
$\bar{X}_{CW}$	7.43	7.47	7.43	7.50
RR	7.38	7.47	7.51	7.46
	7.44	7.41	7.48	7.46
$\bar{X}_{RR}$	7.41	7.45	7.50	7.46
MP	7.47	7.47	7.48	7.46
	7.42	7.46	7.43	7.45
$\bar{X}_{MP}$	7.45	7.47	7.46	7.46
KF	7.45	7.47	7.43	7.46
	7.43	7.47	7.44	7.45
$\bar{X}_{KF}$	7.44	7.47	7.44	7.46
$\bar{X}$	7.43	7.46	7.45	7.47
	F=1.06	P>.05		

Table 4.3

Pre-Exercise Values BE
(mEq/l)

Subject	Treatment			
		$NaHCO_3$		
	Placebo	Low	Medium	High
CW	+0.9	+4.8	+1.5	+5.3
	-2.1	+2.7	+2.0	+7.3
$\bar{X}_{CW}$	-0.6	+3.8	+1.8	+6.3
RR	-3.9	+4.5	+5.5	+1.1
	+2.4	+0.3	+4.9	+5.8
$\bar{X}_{RR}$	-0.8	+2.4	+5.2	+3.5
MP	+2.9	+3.8	+3.3	+2.6
	+2.1	+1.9	+3.9	+2.4
$\bar{X}_{MP}$	+2.5	+2.8	+3.6	+2.5
KF	+4.8	+4.7	+1.0	+4.8
	+3.0	+6.3	+3.8	+5.8
$\bar{X}_{KF}$	+3.9	+5.5	+2.4	+5.3
$\bar{X}$	+1.3	+3.6	+3.2	+4.4
	F=1.54	P>.05		

between means (99) for BE demonstrated significant differences ($P<.05$) between the placebo treatment and the three $NaHCO_3$ levels combined (Table 4.4). This was not found for pre-exercise pH. No significant increases in either pH or BE were observed between the placebo and the low $NaHCO_3$ conditions or between the low $NaHCO_3$-high $NaHCO_3$ conditions.

Table 4.4

Planned Comparison Tests Between Pre-Exercise Means

	Significance
Comparisons for pH	
1. Placebo vs. Low, Medium, and High combined	NS
2. Placebo vs. Low	NS
3. Low vs. High	NS
Comparisons for BE	
1. Placebo vs. Low, Medium, and High combined	S
2. Placebo vs. Low	NS
3. Low vs. High	NS

$\alpha=.05$

There was no increase in pH and only a minimal increase in BE between the low $NaHCO_3$ level and the high $NaHCO_3$ level even though there was a four-fold increase in $NaHCO_3$ ingestion. It appears, at least for the levels of $NaHCO_3$ and the ingestion times used in this study, that after small increases in pH and BE are achieved it is difficult to further increase pH and BE with larger doses of $NaHCO_3$.

Habitual Exercise and/or Diet and Resting Acid-Base Balance

When the subjects were selected for the study, the level of physical fitness for endurance performance was determined prior to exhaustive testing by obtaining the exercise heart rate during a six miles/hour, zero-percent grade treadmill run. The subjects selected all exhibited excellent endurance with heart rates throughout the run of less than 150 beats/minute. With no precedent this method of equating subjects appeared adequate. However, on the basis of the data, it is evident that the habitual exercise and dietary habits of the subjects merit examination prior to presentation of the main body of the results. Two of the subjects who responded similarly on the six mile/hour run were endurance runners and two were active basketball players.

The two distance runners (MP and KF) had pre-exercise arterialized blood which was more alkaline than that of the two basketball players (CW and RR) under placebo conditions (Table 4.5). This was especially apparent in terms of pre-exercise BE since the average BE of MP and KF was +3.2 mEq/l after ingesting the placebo while that of CW and RR was -0.7 mEq/l. The arterial blood of MP and KF did not increase in pH and BE nearly as much as did that of CW and RR. For example, the average BE of CW and RR increased 3.8 mEq/l after the ingestion of .065 g/kg $NaHCO_3$, but that of MP and KF increased only 0.9 mEq/l following the same dosage. The lesser response in MP and KF may have been due to the fact that their arterial blood was already slightly alkaline.

In addition to the obvious difference in sports, it was found that the dietary habits of MP and KF varied greatly from those of CW

Table 4.5

Intrasubject Acid-Base Balance (Means and S.E.)

Subject	Placebo	$NaHCO_3$ Low	$NaHCO_3$ Medium	$NaHCO_3$ High
		pH by Treatment Level		
CW & RR	7.42±.016	7.46±.017	7.46±.022	7.48±.012
MP & KF	7.45±.011	7.47±.003	7.45±.012	7.46±.003
		BE by Treatment Level (mEq/l)		
CW & RR	-0.7±1.4	+3.1±1.0	+3.5± .9	+4.9±1.3
MP & KF	+3.2± .6	+4.1± .8	+3.0± .7	+3.9± .8

and RR. MP and KF followed a relatively high-carbohydrate, low-fat diet (fat estimated to be below 30%) while CW and RR followed a relatively high-fat, high-protein diet (fat estimated to be above 40%). Since previous pilot work (Appendix H) had indicated that a high-carbohydrate diet (80% carbohydrate) has an alkalizing effect on the arterial blood and a high-fat diet (80% fat) has an acidifying effect, it was felt that acid-base balance should be observed under dietary conditions that more closely duplicated the four primary subjects' dietary habits.

A small companion study was conducted to investigate the effects of these dietary differences on acid-base balance. Seven male undergraduate students were chosen as subjects and were asked to go on either a high-carbohydrate diet similar to that of MP and KF or a high-fat, high-protein (fat-protein) diet similar to that of CW and RR for three-day periods. Each subject went on each diet twice. A

diet recall was conducted each day to determine what percent of the ingested calories of the previous 24 hours were carbohydrate, protein, and fat (Table 4.6). A statistically significant difference in BE ($F=7.6$, $P<.05$) and a nonsignificant difference in pH ($F=3.6$, $P>.05$) were observed between the high-carbohydrate and the fat-protein diets (Table 4.7).

Table 4.6

Companion Study: Percentages of Carbohydrate, Fat, and Protein Under Fat-Protein and High-Carbohydrate Diets (Means and S.E.)

Diet	% Carbohydrate	% Fat	% Protein
High fat-protein	19.5±2.1	49.5±1.8	31.0±3.5
High carbohydrate	59.5±1.8	24.5±1.7	16.0±1.9
	F=160.0	F=279.3	F=40.8
	P<.00001	P<.00001	P<.0007

Table 4.7

Companion Study: pH and BE With Fat-Protein and High-Carbohydrate Diets (Means and S.E.)

Diet	pH	BE
High fat-protein	7.43±.006	-1.6±.4
High carbohydrate	7.46±.008	+0.8±.4
	F=3.6 P<.10	F=7.6 P<.03

On the basis of these data it is likely that the relative alkalinity observed in the blood of MP and KF, at least in part, was diet related. This difference in diet also may help to explain the relative

insensitivity of MP and KF to $NaHCO_3$ ingestion in that they already had reached a degree of alkalinity which is difficult to increase.

It also is possible that the acid-base balance of the blood is different in subjects with different kinds of fitness (24). Even though they display similar pulse rate responses on a submaximal standard treadmill run, MP and KF trained for middle distance running whereas CW and RR played basketball. The differences observed in their acid-base balances might be attributed to their habitual training regimens.

Since evidence of sufficient relevance is not available, it is impossible at this time to determine whether the observed differences in pre-exercise blood acid-base balance were due to diet, training, a combination of diet and training, or to some as yet undetermined cause.

Supplementation Level, Degree of Alkalosis, and Anaerobic Metabolism

The four variables that permit estimation of anaerobic glycolysis, specifically gross O_2 debt and changes in pH, BE, and lactate (13,25, 60), were inspected first in relation to supplement level (the changes in pH, BE, and lactate represent the largest changes from the pre-exercise values to either the five-minute or the ten-minute post-exercise values). Next, these anaerobic indicators were correlated with the pre-exercise acid-base balance measures. Since each subject completed eight treadmill runs and large differences between subjects were evident, the correlations were computed separately for each subject.

Supplementation Level and Anaerobic Metabolism. Low, medium, and high levels of $NaHCO_3$ supplementation all produced greater changes in pH, BE, and lactate than did the placebo treatment (Tables 4.8 through 4.10, Figure 4.1). Though only the change in lactate exhibited overall statistical significance ($F=2.44$, $P<.05$), the fact that all changes were larger with the supplements than with the placebo would seem to be important. A priori planned-comparison F-tests (99) were run for each of the dependent variables contrasting: (a) the placebo vs. the low treatment, (b) the placebo vs. the low, medium, and high treatments combined, and (c) the low treatment vs. the high treatment (Table 4.11). The contrasts between the placebo and the low treatment for the changes in lactate and BE proved to be significant ($P<.05$) as did the contrast between the placebo and the low, medium, and high treatments combined for the change in BE.

Surprisingly small differences were observed in gross oxygen debt (Table 4.12). On the basis of the significant lactate and BE measures, it appears that there is an increase in anaerobic glycolytic activity with the ingestion of $NaHCO_3$. The fact that significant lactate differences were not reflected in the debt measure is puzzling and unexplained by the data.

Every indicator of anaerobic metabolism was highest following the low $NaHCO_3$ treatment (Figure 4.1). Furthermore, none of the low vs. high treatment contrasts were significant (Table 4.11). Therefore, it appears that after an initial increase in anaerobic capacity is achieved with $NaHCO_3$ ingestion, increasing amounts of $NaHCO_3$ do not further facilitate anaerobic metabolism.

Table 4.8

Change in pH: Pre-Exercise to Postexercise (pH Units)

Subject	Treatment			
		$NaHCO_3$		
	Placebo	Low	Medium	High
CW	.26	.28	.18	.28
	.22	.26	.18	.22
$\bar{X}_{CW}$	.24	.27	.18	.25
RR	.16	.30	.32	.22
	.21	.22	.25	.25
$\bar{X}_{RR}$	.19	.26	.29	.24
MP	.24	.19	.26	.18
	.17	.23	.24	.27
$\bar{X}_{MP}$	.21	.21	.25	.23
KF	.26	.29	.23	.20
	.31	.34	.24	.25
$\bar{X}_{KF}$	.29	.32	.24	.23
$\bar{X}$	.23	.26	.24	.24
	F=.83	P>.05		

Table 4.9

Change in BE: Pre-Exercise to Postexercise (mEq/l)

Subject	Treatment			
		$NaHCO_3$		
	Placebo	Low	Medium	High
CW	18.4	18.3	15.4	19.0
	15.4	18.2	15.9	20.6
$\bar{X}_{CW}$	16.9	18.3	15.7	19.8
RR	12.5	18.7	24.7	15.3
	16.6	14.5	21.6	20.1
$\bar{X}_{RR}$	14.5	16.6	23.2	17.7
MP	16.1	15.8	16.1	12.7
	13.3	16.6	18.7	19.0
$\bar{X}_{MP}$	14.7	16.2	17.4	15.9
KF	19.4	20.9	15.3	15.3
	23.1	25.5	17.0	20.1
$\bar{X}_{KF}$	21.3	23.2	16.5	17.7
$\bar{X}$	16.8	18.6	18.1	17.8
	F=1.59	P>.05		

Table 4.10

Change in Lactate: Pre-Exercise to Postexercise (mmoles/l)

Subject	Treatment			
		$NaHCO_3$		
	Placebo	Low	Medium	High
CW	14.1	13.0	14.0	12.8
	12.6	14.1	12.0	15.4
$\bar{X}_{CW}$	13.4	13.6	13.0	14.1
RR	12.0	15.6	15.8	14.1
	10.7	12.0	14.6	13.5
$\bar{X}_{RR}$	11.4	13.8	15.2	13.8
MP	11.2	14.1	11.6	11.2
	10.3	13.7	12.6	13.6
$\bar{X}_{MP}$	10.8	13.9	12.1	12.4
KF	12.6	15.4	12.0	11.1
	15.0	17.1	14.4	13.6
$\bar{X}_{KF}$	13.8	16.2	13.2	12.5
$\bar{X}$	12.3	14.4	13.4	13.2
	F=2.44	P<.05		

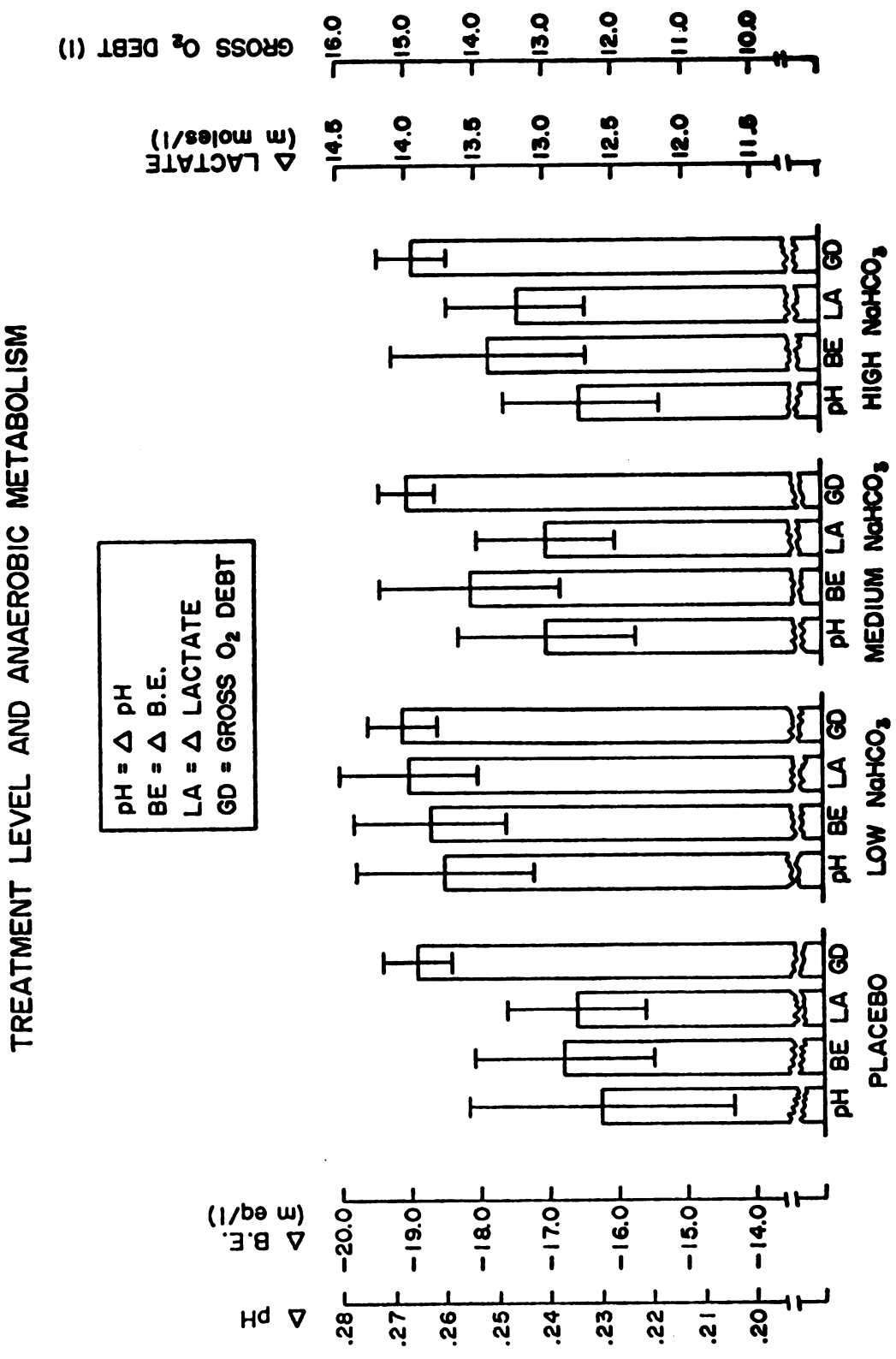

TREATMENT LEVEL AND ANAEROBIC METABOLISM
pH = Δ pH
BE = Δ B.E.
LA = Δ LACTATE
GD = GROSS O_2 DEBT
Δ pH
Δ B.E. (∓ eq/l)
Δ LACTATE (∓ moles/l)
GROSS O_2 DEBT (l)
PLACEBO
LOW $NaHCO_3$
MEDIUM $NaHCO_3$
HIGH $NaHCO_3$
pH BE LA GD

Figure 4.1

Table 4.11

Planned Comparison Pre-Exercise to Postexercise Changes

Comparison	Significance
Change in pH	
1. Placebo vs. Low	NS
2. Placebo vs. Low, Medium, and High combined	NS
3. Low vs. High	NS
Change in BE	
1. Placebo vs. Low	S
2. Placebo vs. Low, Medium, and High combined	S
3. Low vs. High	NS
Change in Lactate	
1. Placebo vs. Low	S
2. Placebo vs. Low, Medium, and High combined	NS
3. Low vs. High	NS
Gross O_2 Debt	
1. Placebo vs. Low	NS
2. Placebo vs. Low, Medium, and High combined	NS
3. Low vs. High	NS

α=.05

Table 4.12

Gross O_2 Debt (liters O_2)

Subject	Treatment			
	Placebo	$NaHCO_3$ Low	$NaHCO_3$ Medium	$NaHCO_3$ High
CW	15.5	15.9	14.0	14.6
	15.3	15.4	15.3	15.1
$\bar{X}_{CW}$	15.4	15.7	14.7	14.9
RR	13.6	15.3	15.4	15.3
	14.2	13.8	14.2	14.9
$\bar{X}_{RR}$	13.9	14.6	14.8	15.1
MP	15.2	12.8	14.0	12.6
	13.2	13.9	14.3	16.0
$\bar{X}_{MP}$	14.2	13.4	14.2	14.3
KF	15.3	15.7	16.7	13.5
	16.9	17.6	15.6	16.3
$\bar{X}_{KF}$	16.1	16.7	16.2	14.9
$\bar{X}$	14.9	15.1	14.9	14.8
	F=0.05	P>.05		

Pre-Exercise Acid-Base Balance and Anaerobic Metabolism. If $NaHCO_3$ ingestion results in both an increase in alkalinity of the pre-exercise arterialized capillary blood and an increase in anaerobic activity during exercise, it would seem that indicators of anaerobic activity should be related to measures of pre-exercise acid-base balance. All four indicators of anaerobic glycolytic activity had relatively good correlations with the pre-exercise blood pH and BE in the basketball players, CW and RR. These correlations were consistently lower in the distance runners, MP and KF. Table 4.13 contains the complete intrasubject correlation matrices. Graphs showing these relationships may be found in Appendix I.

The relatively low relationships between the measures of pre-exercise acid-base balance and the indicators of anaerobic metabolism for MP and KF can be explained by their previously mentioned lack of response to $NaHCO_3$ ingestion. The minimal intrasubject variabilities observed in their pre-exercise pH and BE values precluded any possibility of obtaining high correlations with these variables. In fact, due to the differences in intersubject pre-exercise pH and BE values under placebo conditions, low correlations for MP and KF can be viewed as being consistent with relatively high correlations for CW and RR. Overall, these correlational results appear to be supportive of the thesis that was to be tested by this investigation.

The Relationship of Supplement Level and Degree of Alkalosis to Aerobic Metabolism

Aerobic Metabolism. There were no significant differences observed in maximum oxygen uptake between the different levels of ingested $NaHCO_3$ (Table 4.14). However, there were low-to-moderate

Table 4.13

Intrasubject Correlation Matrices

	PERF	BEBEF	PHBEF	CHBE	CHPH	LACT	DEBT
			Subject CW				
PERF	1.000						
BEBEF	+.400						
PHBEF	+.420	+.910					
CHBE	+.420	+.800	+.919				
CHPH	+.491	+.330	+.510	+.722			
LACT	+.585	+.420	+.374	+.553	+.570		
DEBT	+.023	+.150	+.340	+.150	+.515	+.308	
$MAXVO_2$	+.431	-.371	-.242	-.402	-.080	-.425	+.528
			Subject RR				
PERF	1.000						
BEBEF	+.540						
PHBEF	+.592	+.872					
CHBE	+.660	+.921	+.914				
CHPH	+.695	+.866	+.877	+.814			
LACT	+.833	+.605	+.775	+.701	+.824		
DEBT	+.451	+.576	+.746	+.390	+.695	+.582	
$MAXVO_2$	+.065	-.187	-.024	-.101	-.187	-.278	.008
			Subject MP				
PERF	1.000						
BEBEF	+.005						
PHBEF	+.121	+.203					
CHBE	+.864	+.434	+.043				
CHPH	+.833	+.382	+.289	+.847			
LACT	+.342	+.205	+.215	+.532	+.367		
DEBT	+.880	+.100	+.051	+.810	+.893	+.192	
$MAXVO_2$	+.810	-.058	-.300	+.748	+.751	+.164	+.789
			Subject KF				
PERF	1.000						
BEBEF	+.009						
PHBEF	+.008	+.783					
CHBE	+.790	+.521	+.352				
CHPH	+.889	+.693	+.218	+.967			
LACT	+.855	+.375	+.268	+.886	+.898		
DEBT	+.940	-.134	+.194	+.668	+.79	+.706	
$MAXVO_2$	+.584	-.448	-.590	-.209	-.276	-.369	+.631

Table 4.14

Maximum VO_2

Subject	Placebo		Low		Medium		High	
	l/min	ml/kg/min	l/min	ml/kg/min	l/min	ml/kg/min	l/min	ml/kg/min
CW	4.88	63	5.14	67	4.70	62	4.50	58
	5.06	67	5.34	70	5.28	69	4.68	61
$\bar{X}_{CW}$	4.97	65	5.24	69	4.99	66	4.59	60
RR	4.64	60	4.76	62	4.64	60	4.82	64
	4.74	63	4.86	64	4.90	64	4.84	63
$\bar{X}_{RR}$	4.69	62	4.81	63	4.77	62	4.83	64
MP	4.84	69	4.34	62	4.66	67	4.56	65
	4.56	65	4.90	70	5.20	74	5.16	74
$\bar{X}_{MP}$	4.70	67	4.62	66	4.93	71	4.86	70
KF	5.40	75	5.74	83	6.04	87	5.34	77
	5.96	86	5.68	82	5.92	86	5.98	87
$\bar{X}_{KF}$	5.68	81	5.71	83	5.98	87	5.66	82
$\bar{X}$	5.01	69	5.10	70	5.17	71	4.99	69
	F=.608		P>.05					

negative correlations between BE before exercise and maximum VO_2 for all four subjects (Table 4.13 and Figure 4.2). The pH before exercise also was negatively related to maximum VO_2 for all four subjects (Table 4.13 and Figure 4.3).

Inspection of Figure 4.3 suggests that when the pre-exercise blood pH value was above a level of approximately 7.45, there was a drop in the maximum VO_2 during the subsequent bout of exercise. The mean maximum VO_2 was equal to 4.89 l/minute when the pre-exercise pH was above 7.45 and was equal to 5.23 l/minute when the pH was 7.45 or less (Table 4.15). Figure 4.4 shows that greater oxygen uptakes were

Table 4.15

Maximum VO_2 (l/min) Dichotomized by Pre-Exercise Arterialized Capillary Blood pH ($\leq$7.45 vs. >7.45) (Mean and S.E.)

Subject	pH $\leq$7.45		pH >7.45	
	l/min	ml/kg/min	l/min	ml/kg/min
CW	5.05±.27**	66±3.6	4.77±.33*	64±4.4
RR	4.77±.10*	63±1.3	4.78±.11**	63±1.4
MP	4.97±.36*	71±5.1	4.66±.22**	66±3.1
KF	5.86±.36**	87±5.2	5.59±.21*	83±3.0
$\bar{X}$	5.23	73	4.89	68

*Contains 3 observations.

**Contains 5 observations.

achieved by the subjects throughout the exercise when the pre-exercise pH was 7.45 or less and that smaller oxygen uptakes were achieved when the pH was greater than 7.45. Although the differences were small, they were consistent for each of the four subjects. In 14 of the 18

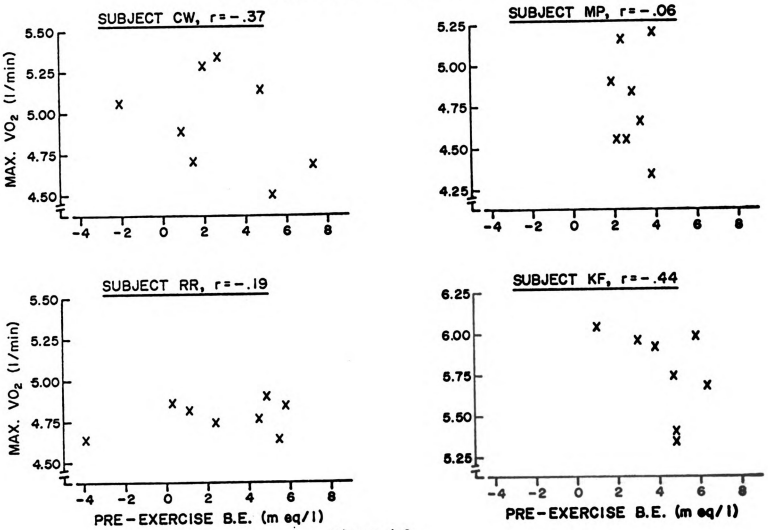

INTRASUBJECT CORRELATIONS BETWEEN
PRE-EXERCISE B.E. AND MAX. VO_2
SUBJECT CW, r=-.37
SUBJECT MP, r=-.06
SUBJECT RR, r=-.19
SUBJECT KF, r=-.44
MAX. VO_2 (l/min)
PRE-EXERCISE B.E. (m eq/l)

Figure 4.2

INTRASUBJECT CORRELATIONS BETWEEN
PRE-EXERCISE pH AND MAX. VO_2

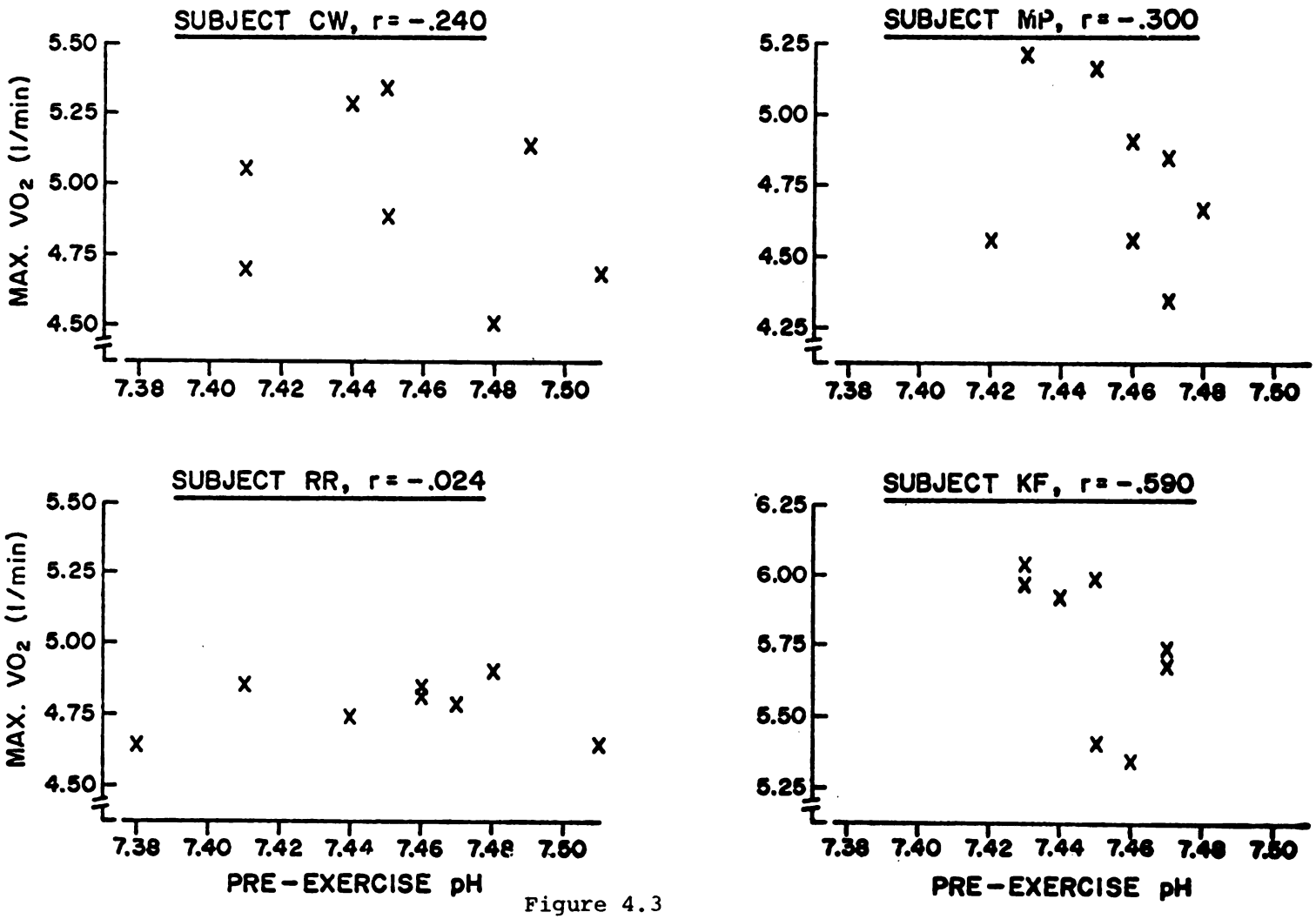


Figure 4.3

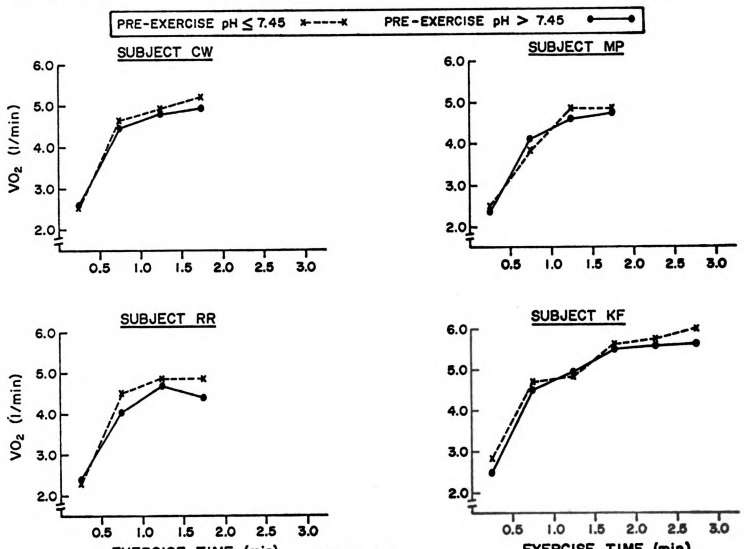

INTRASUBJECT OXYGEN UPTAKE DURING EXERCISE WITH pH ≤ 7.45 AND pH > 7.45
PRE-EXERCISE pH ≤ 7.45
PRE-EXERCISE pH > 7.45
SUBJECT CW
SUBJECT MP
SUBJECT RR
SUBJECT KF
VO2 (l/min)
EXERCISE TIME (min)

Figure 4.4

comparisons of VO_2 values shown in Figure 4.4, the oxygen uptake was higher when the pre-exercise pH was 7.45 or less (sign test $P<.05$).

Ventilation, Respiration Rate, and Heart Rate. No significant differences were found in maximum ventilation during exercise (Table 4.16). Dichotomizing the observations by pre-exercise blood pH (≤ 7.45 vs. >7.45) showed that slightly lower values of maximum ventilation were obtained when the pH was high (Table 4.17). With the differences observed in maximum VO_2 and the known relationship of ventilation to oxygen uptake, these differences were expected.

No significant differences were found in maximum respiration rate during exercise, though all three supplement levels produced slightly higher respiration rates than did the placebo (Table 4.18). A dichotomy of observations by pre-exercise blood pH yielded a difference of only two respirations per minute (Table 4.19).

Maximum heart rate during exercise was not significantly affected by $NaHCO_3$ supplementation and was not related to varying degrees of pre-exercise alkalosis (Tables 4.20 and 4.21).

It would appear from the data presented that high degrees of alkalosis may hinder aerobic metabolism in some as yet undetermined manner. Several *in vitro* investigations have shown that decreases in aerobic metabolism accompany alkalosis (14,87,88,97). This may be due to decreases in electron transport activity (14,88) and/or to decreases in oxidation of lactate in non-exercising tissue (6,87,97). It is clear that aerobic metabolism was negatively related to pre-exercise acid-base measures during the short-duration, high-intensity run used in this study.

Table 4.16

Maximum Ventilation (l/min)

Subject	Treatment			
	Placebo	$NaHCO_3$ Low	$NaHCO_3$ Medium	$NaHCO_3$ High
CW	60.1	62.0	65.0	56.0
	65.0	66.2	60.8	58.8
$\bar{X}_{CW}$	62.6	64.1	62.5	57.4
RR	57.5	55.0	60.9	56.0
	56.3	54.7	58.9	55.0
$\bar{X}_{RR}$	56.9	54.9	59.9	55.5
MP	57.6	55.0	60.0	57.7
	62.2	65.2	68.8	63.1
$\bar{X}_{MP}$	64.1	63.3	65.2	61.9
KF	75.1	75.0	73.9	72.2
	80.1	72.8	73.7	76.8
$\bar{X}_{KF}$	77.6	73.9	73.8	74.5
$\bar{X}$	64.2	63.2	65.2	62.0
	F=.70	P>.05		

Table 4.17

Maximum Ventilation (l/min) Dichotomized by Pre-Exercise Arterialized Capillary Blood pH ($\leq$7.45 vs. >7.45) (Mean and S.E.)

Subject	pH $\leq$7.45	pH >7.45
CW	63.7±3.1**	59.7±3.9*
RR	56.9±1.2*	56.7±1.3**
MP	62.2±4.0*	60.4±2.3**
KF	76.8±4.1**	75.1±2.5*
$\bar{X}$	64.9	62.6

*Contains 3 observations.
**Contains 5 observations.

Table 4.18

Maximum Respiration Rate (Respirations/min)

Subject	Treatment			
	Placebo	$NaHCO_3$ Low	$NaHCO_3$ Medium	$NaHCO_3$ High
CW	45	48	48	42
	48	45	45	45
$\bar{X}_{CW}$	47	47	47	44
RR	42	42	45	48
	45	48	45	42
$\bar{X}_{RR}$	44	45	45	45
MP	48	51	60	60
	48	60	54	57
$\bar{X}_{MP}$	48	56	57	59
KF	39	48	57	51
	45	51	42	48
$\bar{X}_{KF}$	42	50	50	50
$\bar{X}$	45	50	50	50
	F=1.33	P>.05		

Table 4.19

Maximum Respiration Rate (Respirations/min) Dichotomized by Pre-Exercise Arterialized Capillary Blood pH (≤7.45 vs. >7.45) (Mean and S.E.)

Subject	pH ≤7.45	pH >7.45
CW	46.2±0.96**	45.0±1.76*
RR	45.0±1.76*	44.4±1.47**
MP	53.0±3.35*	55.8±2.47**
KF	46.2±1.76**	50.0±3.82*
$\bar{X}$	47.3	49.1

*Contains 3 observations.
**Contains 5 observations.

Table 4.20

Maximum Heart Rate

Subject	Treatment			
	Placebo	$NaHCO_3$ Low	$NaHCO_3$ Medium	$NaHCO_3$ High
CW	175	185	168	190
	179	176	174	176
$\bar{X}_{CW}$	177	181	171	183
RR	175	176	174	180
	184	178	177	182
$\bar{X}_{RR}$	180	177	176	181
MP	177	172	180	170
	172	166	176	175
$\bar{X}_{MP}$	175	169	178	173
KF	187	190	191	185
	192	195	191	193
$\bar{X}_{KF}$	190	193	191	189
$\bar{X}$	180	180	179	181
	F=.50	P>.05		

Table 4.21

Maximum Heart Rate Dichotomized by Pre-Exercise Arterialized Capillary Blood pH (≤7.45 vs. >7.45) (Mean and S.E.)

Subject	pH ≤7.45	pH >7.45
CW	174±2.0**	183±3.5*
RR	180±2.0*	177±1.6**
MP	174±1.1*	173±3.2**
KF	191±1.3**	190±2.5*
$\bar{X}$	180	181

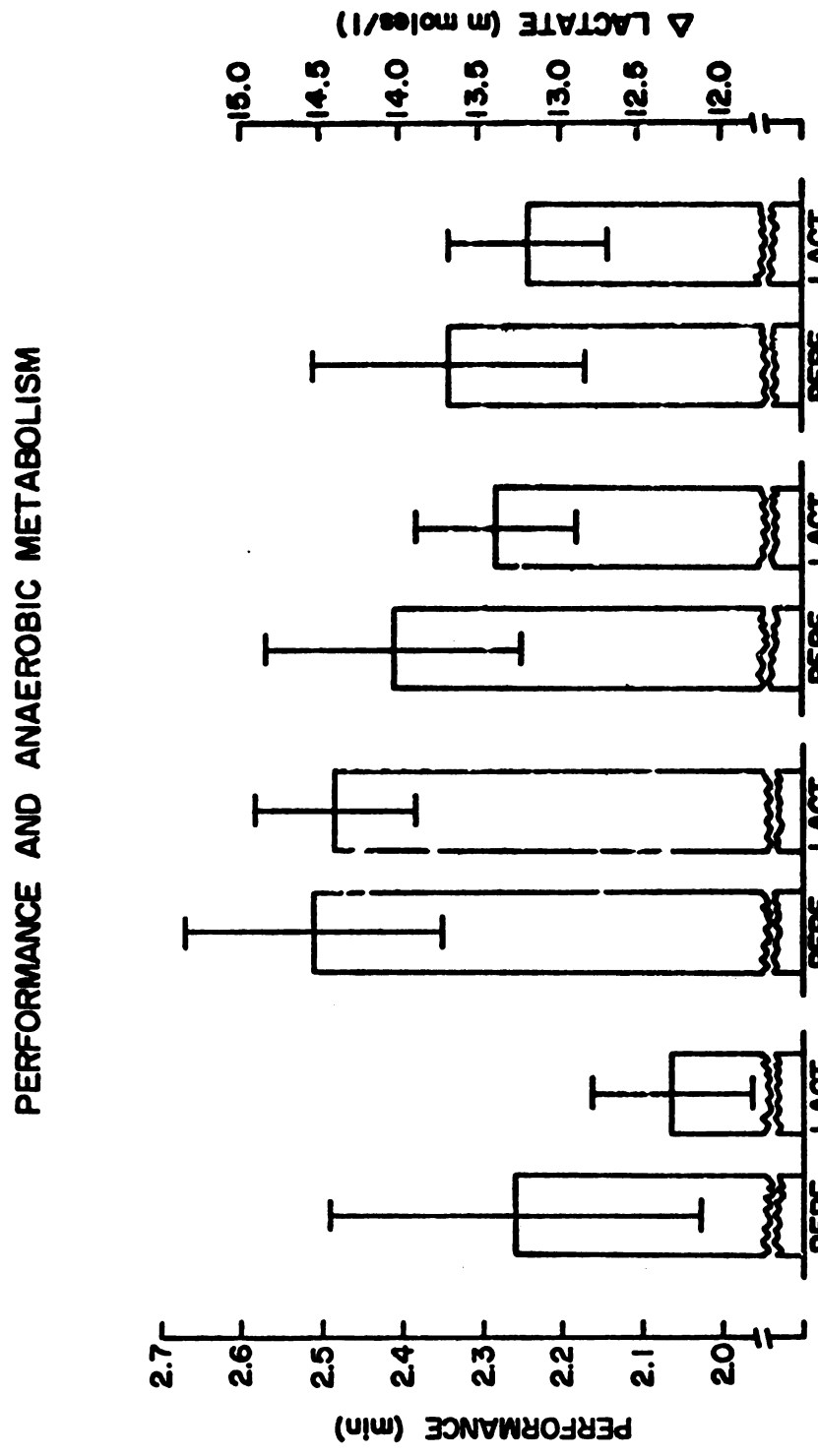
*Contains 3 observations.
**Contains 5 observations.

Relationship to Work Performance

Performance and Supplement Level. There were expected, but statistically nonsignificant, increases in performance time with different supplement levels. The largest increase in performance time was observed under the low $NaHCO_3$ condition; the high $NaHCO_3$ condition yielded the smallest increase in performance time. These improvements in performance time paralleled the increases in anaerobic metabolism found under the respective treatment conditions (Figures 4.1 and 4.5), but the greatest change in performance (low $NaHCO_3$ vs. placebo) was only 15 seconds (Figure 4.5).

Although the levels of supplementation used in the present investigation were similar to those used by Atterbom (10), Jones et al. (56), Sutton, Jones, and Toews (100), and Dennig (28), the improvements in performance with $NaHCO_3$ supplementation observed in this study were lower than the values reported by these other investigators (performance times and supplement levels are compared in Table 4.22). The studies of Jones et al., Sutton, Jones and Toews, and Dennig are not exactly comparable to the present investigation even though the supplementation levels used were similar. Dennig exercised his subjects at work loads which produced exhaustion at about 20 minutes. In each of the other two studies, the exhaustive test was preceded by two 20-minute work periods at approximately 30% and 70% of maximum VO_2.

Atterbom (10), Jones et al. (56), and Sutton, Jones, and Toews (100) all used the cycle ergometer rather than the treadmill as an exercise mode. That difference is not considered to be a major factor. The most comparable study is that of Atterbom, where the work intensity was similar and the treatment corresponded to the medium treatment



Lactate was chosen as a representative measure of anaerobiosis, see fig. 4.1 to see how lactate varies with the other measures of anaerobic metabolism.

Figure 4.5

Table 4.22

Performance and Supplement Level Comparisons

Study	Supplement Level	Performance Time (min) Placebo	Supplement	% Increase
Atterbom (10)*	.13 gm/kg	2.47	3.01	21.9
Jones (56)**	.26 gm/kg	4.50	7.30	62.2
Sutton (100)**	.26 gm/kg	3.69	5.94	62.5
Dennig (28)* ***	.13 gm/kg	20.00	42.00	110.0
Hunter*	.065 gm/kg	2.26	2.51	11.0
	.130 gm/kg	2.26	2.41	6.6
	.260 gm/kg	2.26	2.34	3.5

*Used a sugar placebo.

**Used calcium carbonate placebo.

***Was not blind.

level used in this study. Although Atterbom reported a larger increase in performance than was found in this study, it was more comparable than the very large increases reported by the other investigators (Table 4.22).

For the two subjects in this study who were somewhat alkaline under pre-exercise placebo conditions, supplementation increased blood alkalinity in rather small amounts. This, in itself, would have depressed the observed changes in performance due to $NaHCO_3$ supplementation.

No mention of subject fitness level was made by any of the earlier investigators. It is possible that unfit subjects were used. If that

were the case, it may be that unfit subjects with low aerobic capacity are relatively unaffected by the decrease in aerobic metabolism found with alkaline arterial blood. The subjects in this study all had relatively high maximum VO_2 capacities of over 62 ml/kg.

Performance and Pre-Exercise Acid-Base Balance. Pre-exercise pH and BE were moderately related to performance in the two subjects who responded well to $NaHCO_3$ supplementation but were very poorly related in the two subjects who were alkalotic under control conditions (Table 4.23). The correlations increased only slightly when pre-exercise pH and BE were combined in a multiple correlation analysis.

Table 4.23

Intrasubject Correlations of Pre-Exercise pH and BE with Performance

Subject	Pre-Exercise BE vs. Performance	Pre-Exercise pH vs. Performance	Pre-Exercise BE and pH vs. Performance
	r	r	r
CW	.40	.42	.49
RR	.54	.59	.67
MP	.01	.12	.14
KF	.01	.00	.02

The two subjects (MP and KF) who exhibited the lowest relationships between performance time and pre-exercise acid-base measures also demonstrated the highest levels of aerobic fitness. (Aerobic fitness was evaluated from maximum oxygen uptake and recovery from all-out work.) Since MP and KF were trained middle-distance runners

whereas the other two subjects (RR and CW) were conditioned basketball players, the two pairs of subjects might be expected to exhibit different types of fitness.

If there is, as hypothesized, a decrease in aerobic capacity with alkalosis, it is possible that the subjects with relatively high aerobic capacity may have their aerobic metabolism affected more than subjects with relatively low aerobic capacity. This may be one explanation for the low relationships between pre-exercise acid-base balance and performance that were found in MP and KF. Whether the differences in performance responses to change in pre-exercise acid-base balance were due to acid-base balance alone or to an interaction between kind of fitness and acid-base balance is not clear at this time.

Performance and Anaerobic Metabolism. The relationships between performance and changes in pH, BE, and lactate were moderate to high (Table 4.24). As expected, there seemed to be a strong relationship between anaerobic activity and the amount of high-intensity work that each individual could tolerate. Table 4.13 shows that gross O_2 debt was highly related to performance for MP and KF (r=.88 and .94, respectively). The relationship was low to moderate for CW and RR (r=.02 and .45, respectively).

The differences in the relationships between O_2 debt and performance may have been due to the relatively fast recovery by MP and KF. Much of the total gross O_2 debt in these two subjects was measured within the fifteen-minute recovery time; thus, a high relationship with performance resulted.

Table 4.24

Intrasubject Correlations: Changes in BE and pH with Performance

Subject	Change in BE with Performance	Change in pH with Performance	Change in Lactate with Performance
	r	r	r
CW	.42	.49	.59
RR	.66	.70	.83
MP	.86	.83	.34
KF	.79	.89	.86

Despite the fact that CW and RR exhibited virtually the same amount of total anaerobic activity as MP and KF (Figure 4.6), the following factors indicate a slower recovery for CW and RR:

1. Table 4.25 shows that CW and RR exhibited lower BE values after ten minutes of recovery than after five minutes of recovery 12 out of 13 times (sign test $P<.05$), whereas MP and KF exhibited lower BE values after five minutes 13 out of 14 times ($P<.05$). It appears that a net output of acid from the cells was still occurring during the period between five and ten minutes into recovery for CW and RR but not for MP and KF. This observation is further demonstrated by the fact that CW and RR averaged a 0.9 mEq/l decrease in BE between five and ten minutes of recovery, whereas MP and KF averaged a 1.3 mEq/l increase in BE during the same interval of time (Figure 4.7).

2. The change in BE during the period between five and fifteen minutes of recovery for CW and RR averaged only a 1.2 mEq/l increase in BE as opposed to the 4.1 mEq/l increase for MP and KF (Figure 4.7).

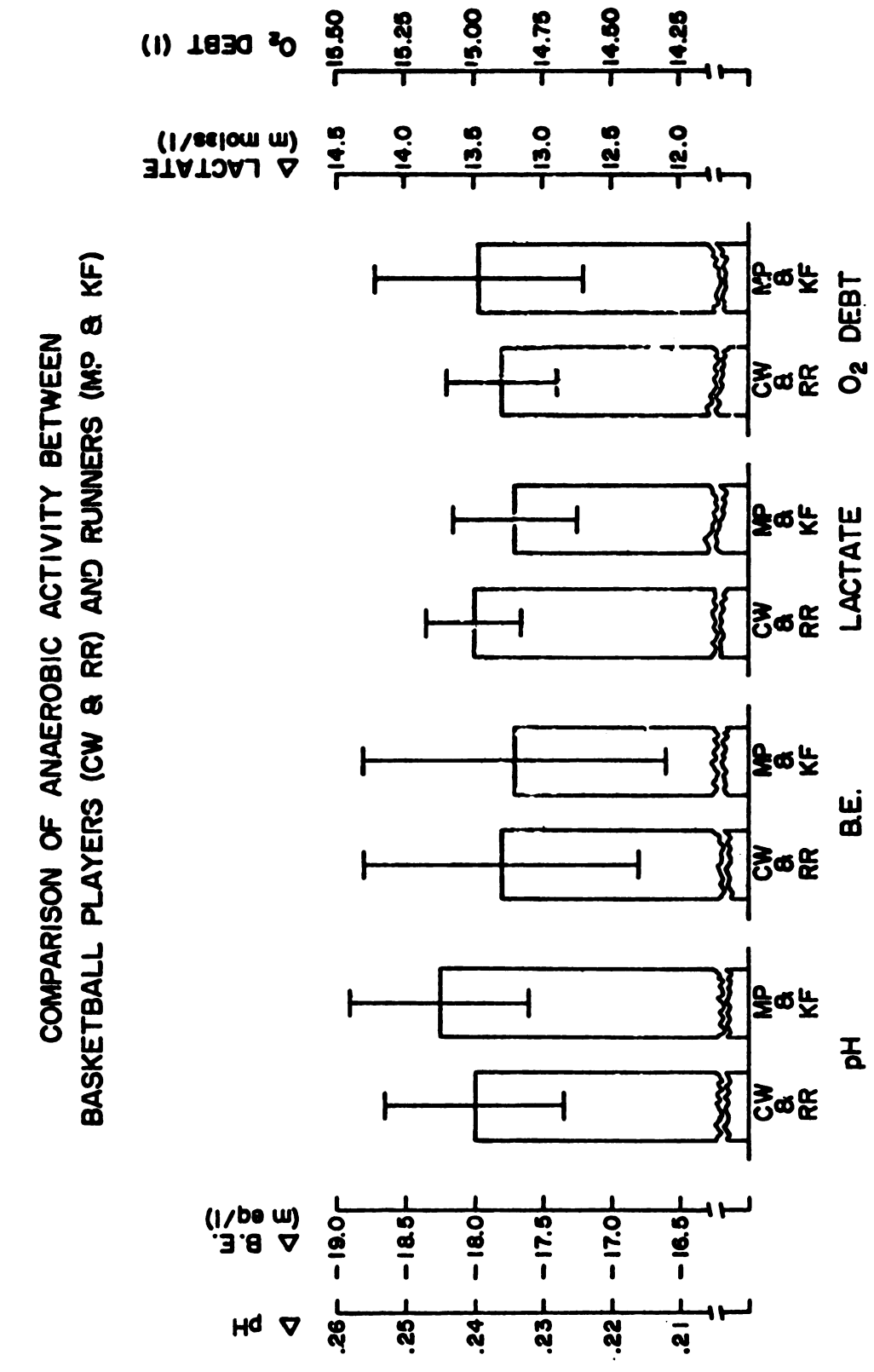

COMPARISON OF ANAEROBIC ACTIVITY BETWEEN
BASKETBALL PLAYERS (CW & RR) AND RUNNERS (MP & KF)
Δ pH
Δ B.E. (m eq/l)
Δ LACTATE (m moles/l)
O2 DEBT (l)
.26
.25
.24
.23
.22
.21
-19.0
-18.5
-18.0
-17.5
-17.0
-16.5
14.5
14.0
13.5
13.0
12.5
12.0
15.50
15.25
15.00
14.75
14.50
14.25
CW & RR
MP & KF
pH
B.E.
LACTATE
O2 DEBT

Figure 4.6

COMPARISON OF POST EXERCISE pH, B.E. AND LACTATE BETWEEN BASKETBALL PLAYERS (CW & RR) AND RUNNERS (MP & KF)

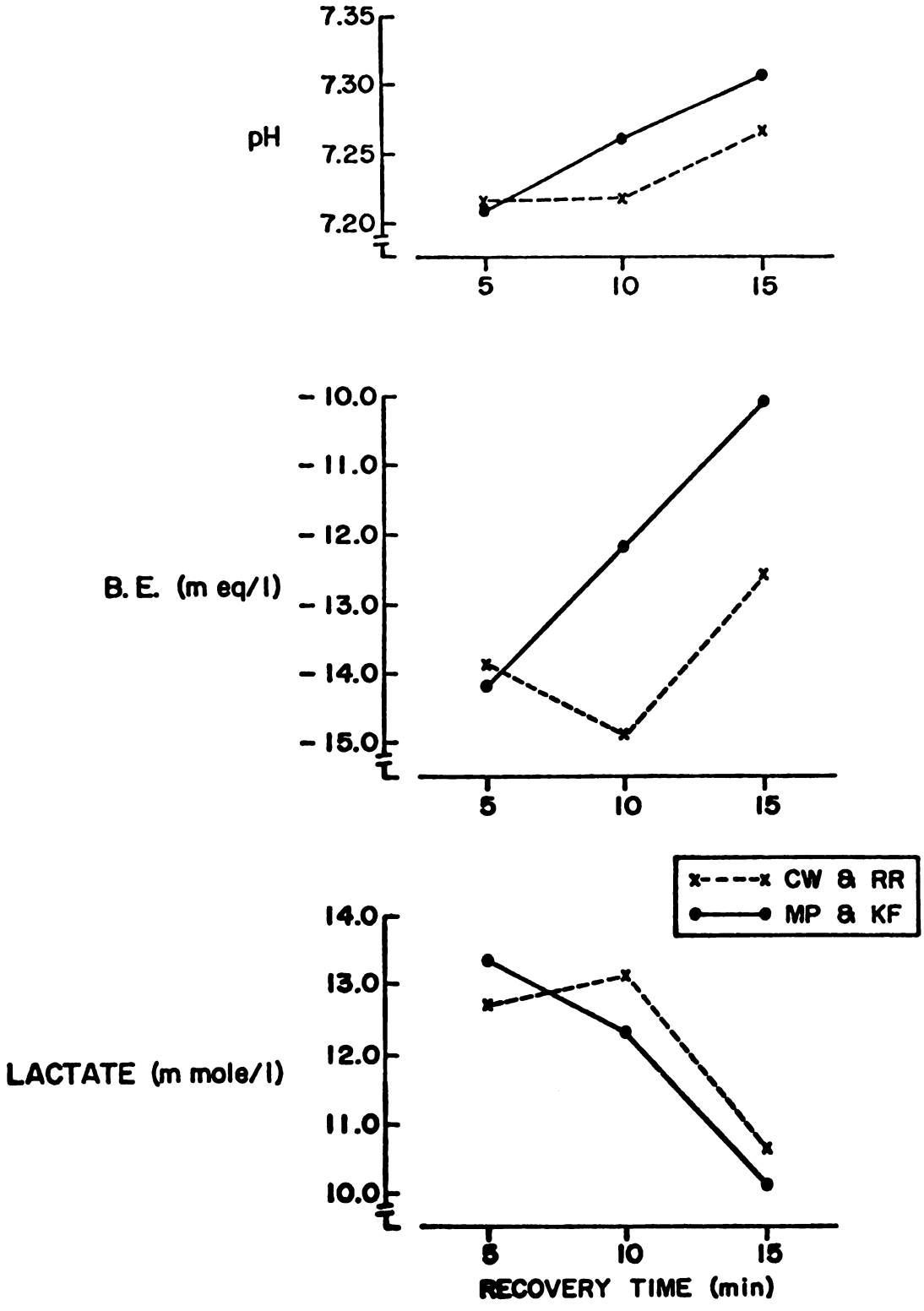


Figure 4.7

Table 4.25

Comparison of Five and Ten Minute Postexercise BE Values (mEq/l)
(When difference between matched pairs is zero that contrast
is not counted in the analysis)

Subject	Five Minute	Ten Minute	Sign Test	Subject	Five Minute	Ten Minute	Sign Test
CW	-11.8	-11.9	+	MP	-13.2	*	
	-15.5	-17.5	+		-12.0	-10.8	-
	-12.5	-13.5	+		-12.8	-11.0	-
	-15.8	-16.4	+		-08.1	-07.2	-
	-12.0	-15.3	+		-11.2	-09.8	-
	-14.5	-17.6	+		-14.7	-11.8	-
	-15.5	-15.5	0		-14.8	-12.5	-
	-09.1	-06.3	-		-18.6	-12.3	-
RR	-14.2	-14.3	+	KF	-15.8	-15.8	0
	-16.2	-19.2	+		-10.5	-08.3	-
	-10.9	-12.2	+		-14.6	-14.2	-
	-15.2	-15.3	+		-16.2	-15.3	-
	-14.2	-14.2	0		-13.2	-12.4	-
	-15.4	-16.7	+		-14.3	-13.2	-
	-15.2	-16.3	+		-18.3	-20.1	+
	-15.1	-15.1	0		-19.2	-18.7	-
	$\bar{X}$=-13.9	-14.8			-14.2	-12.9	

*Missing value.

The same pattern was observed in pH and lactate, though some recovery generally was seen at ten minutes for CW and RR (Figure 4.7).

3. MP and KF utilized more oxygen during the early minutes of recovery than CW and RR, but after three minutes the runners' recovery curve became much steeper than the basketball players' (Figure 4.8). Throughout the last ten minutes of recovery, MP and KF used less oxygen than CW and RR. At the end of the fifteen-minute recovery period MP and KF probably were not fully recovered but their O_2 uptakes were closer to resting values than were those of CW and RR.

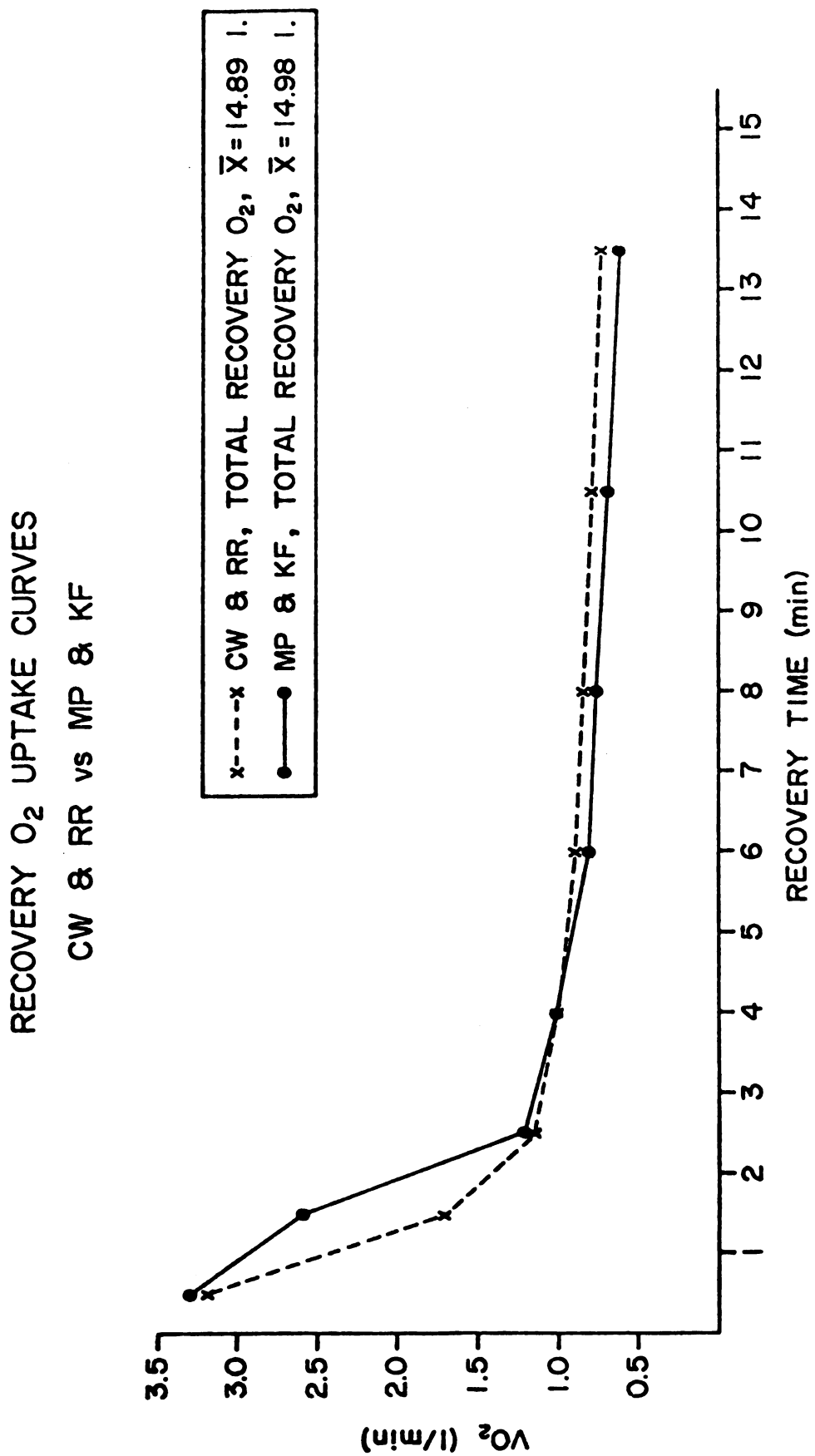

RECOVERY O_2 UPTAKE CURVES
CW & RR vs MP & KF
x----x CW & RR, TOTAL RECOVERY O_2, $\bar{X}$ = 14.89 l.
●——● MP & KF, TOTAL RECOVERY O_2, $\bar{X}$ = 14.98 l.
VO_2 (l/min)
3.5
3.0
2.5
2.0
1.5
1.0
0.5
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
RECOVERY TIME (min)

Figure 4.8

All these factors were interrelated and, taken together, they demonstrated a faster recovery for MP and KF than for CW and RR. More lactate was metabolized by MP and KF in the early minutes of recovery, which created a greater need for oxygen during this period (see Figure 4.8). When lactate is metabolized, HCO_3^- is formed, and the BE and pH are both increased.

Since CW and RR removed less lactate than MP and KF after five minutes of recovery (especially between five and ten minutes) but were actually using more oxygen during this same period of time, the previous discussion relating to increased oxygen uptake in recovery to lactate removal may appear faulty. It must be remembered, though, that there is a time delay for values of lactate, pH, and BE in the blood. It takes time for cellular values to be reflected in the blood. Maximum values for lactate and minimum values for acid-base balance are usually reported to be between three to ten minutes after the short duration all-out exercise used in this study. Thus, the values of lactate, pH, and BE in arterialized capillary blood for ten minutes are probably reflective of cell values shortly after exercise.

The reason why MP and KF had a faster recovery from the lactic acidosis of exercise than CW and RR is impossible to ascertain from the present data. However, several investigators have shown increased activity of oxidative enzymes in the muscles of trained endurance athletes (48,60). Hermansen (43) and others (18,55) have shown that during exercise lactate uptake may occur in the liver, kidney, heart, and nonexercising muscles. Perhaps the trained runners (MP and KF) had a greater ability to metabolize lactate than did the basketball players (CW and RR).

Performance and Aerobic Metabolism. Table 4.13 shows that maximum VO_2 was moderately to highly related with performance in three of the subjects (CW, r=+.43; MP, r=+.81; KF, r=+.58), while in one subject little relationship was exhibited (RR, r=+.07). The maximum VO_2 of RR varied very little during his eight treadmill runs. RR also exhibited the highest relationship between performance and pre-exercise acid-base balance. The fact that maximum O_2 uptake is negatively related to pre-exercise blood alkalosis may help to account for the relatively moderate relationship between acid-base balance of the blood before exercise and performance time.

Multiple Correlational Analysis. A series of multiple correlations were computed to determine the relationships between performance time and various pairs of independent variables. Maximum VO_2 and either pre-exercise pH or BE proved to have moderate to high correlations with performance time (Table 4.26). It appears that maximum oxygen uptake and measures of pre-exercise acid-base balance could be combined to yield reasonably good predictions of performance time to exhaustion.

Maximum VO_2 also was paired with each of the measures of anaerobic glycolysis. All of these combinations produced at least moderately high correlations with performance. Maximum VO_2 and change in lactate proved to be the best combination (Table 4.27) with intrasubject coefficients of determination (CW, R^2=.85; RR, R^2=.71; MP, R^2=.67; KF, R^2=.83), indicating that large amounts of variability in performance were accounted for. It is evident that some combination of aerobic and anaerobic metabolism measures could yield excellent predictions of performance time on the treadmill.

Table 4.26

Intrasubject Correlations: Max VO_2 and Pre-Exercise pH and BE with Performance

Subject	Max VO_2 and Pre-Exercise pH with Performance	Max VO_2 and Pre-Exercise BE with Performance
	R	R
CW	.46	.45
RR	.60	.69
MP	.82	.81
KF	.72	.65

Table 4.27

Intrasubject Multiple Correlations: Max VO_2 and Change in pH, BE, Lactate, and Gross O_2 Debt with Performance

Subject	Max VO_2 and Change in pH with Performance	Max VO_2 and Change in BE with Performance	Max VO_2 and Change in Lactate with Performance	Max VO_2 and Gross O_2 Debt with Performance
	R	R	R	R
CW	.44	.62	.92	.44
RR	.70	.66	.84	.46
MP	.86	.90	.82	.90
KF	.96	.92	.91	.94

When the four variables of anaerobiosis were combined into pairs of independent variables, all combinations were found to be correlated with performance time (Table 4.28). Change in lactate and O_2 debt proved to be the best combination. A comparison of the simple correlations in Table 4.13 with the multiple correlations in Table 4.28 shows that change in lactate and gross O_2 debt, as predictors of performance time, may be somewhat unrelated to each other. In other words, they may measure, in part, different components of anaerobiosis. Numerous investigators (20,66,75,77) have indicated that O_2 debt can be broken into alactate and lactate components. Since the lactate component should be accounted for by the measure of change in lactate, it would seem that any increase in correlation found when lactate and gross O_2 debt are combined might be due to variability in the alactate portion of the gross O_2 debt. No one has indicated that the alactate portion of the debt is variable, but these relationships suggest that the possibility of a changing alactic debt should not be ruled out.

Discussion

Ingestion of $NaHCO_3$ significantly increased pre-exercise acid-base balance as measured by BE; however, the pH and BE of arterialized capillary blood did not increase in a linear fashion as the levels of ingested $NaHCO_3$ were raised. Noticeable increases in pH and BE were produced by the lowest $NaHCO_3$ treatment level (.065 g/kg), but then only minimal additional increases were found with higher doses of $NaHCO_3$ (.13 g/kg and .26 g/kg). Two of the subjects (MP and KF) exhibited relatively high pH and BE values under placebo conditions and responded less to the $NaHCO_3$ treatments than did the other two subjects (CW and RR). Probably MP and KF already had reached a degree of alkalosis that is difficult to increase. Since MP and KF normally

Table 4.28

Intrasubject Multiple Correlations: Estimators of Anaerobic Metabolism with Performance

Subject	ΔpH and ΔBE vs. Performance	ΔpH and Gross O_2 Debt vs. Performance	ΔpH and ΔLactate vs. Performance	ΔBE and Gross O_2 Debt vs. Performance	ΔBE and ΔLactate vs. Performance	Gross O_2 Debt and ΔLactate vs. Performance
	R	R	R	R	R	R
CW	.52	.56	.62	.24	.59	.69
RR	.71	.70	.84	.69	.87	.86
MP	.88	.88	.82	.92	.90	.90
KF	.94	.97	.89	.97	.86	.98

ingested a relatively low-fat diet which has been found to have an alkalizing effect, it is possible that diet may have been the cause of their alkalosis. However, the chance that their alkalinity was in some way related to their training as middle-distance runners should not be ruled out.

The observed changes in pH, BE, and lactate all indicate that anaerobic metabolism is increased by $NaHCO_3$ supplementation. The greatest differences were produced by the low $NaHCO_3$ treatment level. The two subjects (CW and RR) that responded well to $NaHCO_3$ treatment also exhibited a strong relationship between pre-exercise acid-base balance and anaerobic metabolism. Conversely, the two subjects who did not vary much in their pre-exercise acid-base balance did not exhibit a strong relationship between anaerobic metabolism and pre-exercise acid-base balance. For some unexplained reason, gross oxygen debt did not increase with $NaHCO_3$ ingestion.

Aerobic metabolism was decreased ($P<.05$) when the subjects were relatively alkalotic (pH >7.45). This observation may help to explain why the correlations between pre-exercise acid-base balance and exercise performance time were not higher, especially in the two subjects who had the highest aerobic capacity (CW and KF). That is, a supplement-related decrease in aerobic capacity may have acted in opposition to any intrinsic beneficial effects of the $NaHCO_3$ treatments on performance time.

If anaerobic metabolism is facilitated and aerobic metabolism is inhibited at all exercise durations by $NaHCO_3$ supplementation, it would seem that an increased acid-base balance could have a marked positive effect on exercise performance only during highly anaerobic work of relatively short duration. It also would seem that any

performance improvements produced by $NaHCO_3$ ingestion should decrease as the duration of all-out exercise is increased, since aerobic metabolism becomes more of a factor as exercise time is prolonged. This line of reasoning makes the results reported by Dennig (28), Jones et al. (56), and Sutton, Jones, and Toews (100) all the more puzzling. Their exercise durations were longer than the durations in this study, but their experimental treatments yielded much larger increases in performance time.

There were differences in recovery following the all-out treadmill run. As compared to the two basketball players (CW and RR), the two subjects who were trained runners (MP and KF) had a steeper O_2 recovery curve, a more rapid decrease in their arterial blood lactate, and a more rapid increase in their arterial blood acid-base balance. It appeared that the runners had removed a large amount of their arterial blood lactate after fifteen minutes of recovery and thus had paid back a large portion of their gross O_2 debt. If the basketball players were unable to pay back a corresponding proportion of their gross O_2 debt during the same period of time, the low relationship that was observed between gross O_2 debt and performance time in these subjects was to be expected.

CHAPTER V

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Summary

This study was designed to determine the effects of different amounts of ingested sodium bicarbonate upon acid-base balance and relative aerobic and anaerobic metabolism and performance in a high-intensity treadmill run of about two-minutes duration. Four fit male subjects (age 29-31 years) were exercise tested under four conditions (placebo, .065 grams $NaHCO_3$/kg body weight, .130 grams $NaHCO_3$/kg body weight, and .260 grams $NaHCO_3$/kg body weight). Each subject was tested under each condition two times. The exercise test consisted of running on the treadmill at nine miles/hour nine-percent grade until exhausted. Gas collection took place during the run and during a fifteen minute recovery utilizing the Douglas bag method. Arterialized capillary blood was sampled before exercise and five, ten, and fifteen minutes following exercise. The blood was analyzed for pH, BE, PCO_2 and lactate using the Astrup method.

The mean pre-exercise pH and BE values for the three $NaHCO_3$ supplement levels were all higher than the placebo-supplement level, with the low $NaHCO_3$ supplement level yielding the highest pH and BE values. A priori planned comparison F-tests yielded significance only for BE between the pre-exercise placebo condition and a combination of the low, medium, and high treatment conditions.

All three $NaHCO_3$ treatment levels had larger pre-exercise to postexercise changes in arterialized capillary blood pH, BE, and lactate than the placebo treatment level. The largest changes, surprisingly, were observed under the low $NaHCO_3$ condition. A priori planned comparison F-tests between the placebo and the low $NaHCO_3$ level for the changes in lactate and BE were significant ($P<.05$). The contrast between the placebo and the low, medium, and high treatments combined for the change in BE was also significant ($P<.05$).

$NaHCO_3$ did not affect maximum VO_2, ventilation, respiration rate, or heart rate significantly. However, the maximum oxygen uptake was negatively related to pH and the oxygen uptake during the run was significantly lower (sign test $P<.05$) when the pre-exercise arterial blood pH was elevated above 7.45.

Nonsignificant increases in performance time were observed under each of three $NaHCO_3$ treatment levels. The largest increase was found with the low $NaHCO_3$ level. These increases in performance time paralleled the increases in anaerobic metabolism.

Relatively high relationships were found between the indicators of anaerobic metabolism and performance for all four subjects. This was not the case for gross O_2 debt and performance for CW and RR. It was felt that this may be related to a slow recovery from the exercise for these two subjects (a small proportion of the total O_2 debt was recovered, thus a low correlation between gross O_2 debt and performance). This slow recovery was indicated by a slow removal of lactate, thus a slow regeneration of BE and a flatter O_2 uptake curve throughout most of the recovery.

Two of the subjects (MP and KF), who were relatively alkaline when ingesting placebo, also consumed a high-carbohydrate low fat

diet (fat <30%). Therefore, a small companion study was conducted to determine the effects of diet upon acid-base balance. Seven subjects were placed on high-fat and protein or a high-carbohydrate diet for three-day periods. Each subject went on each diet two times. Dietary recall indicated that the subjects consumed 59.5 percent carbohydrate, 24.5 percent fat, and 16 percent protein under the high-carbohydrate diet, and 19.5 percent carbohydrate, 49.5 percent fat, and 31.0 percent protein under the high fat-protein diet. There was a significant .05 level decrease in BE under the fat-protein diet and a nonsignificant decrease in pH.

The two subjects (MP and KF) who were relatively alkaline after ingesting placebo also exhibited a very low multiple correlation for pre-exercise pH and BE vs. performance (R=.14 and R=.02, respectively). The two subjects who were not already alkaline under the placebo conditions exhibited multiple correlations that were relatively high for pre-exercise pH and BE vs. performance (R=.49 and R=.67). Since the acid-base balance of MP and KF varied little across the four treatment levels, it is not surprising that the relationship between acid-base balance and performance is low.

Conclusions

1. The pH and BE are increased with small amounts of $NaHCO_3$ ingestion.
2. Anaerobic metabolism as measured by changes in lactate, pH, and BE is increased with $NaHCO_3$ ingestion and moderate levels of alkalosis.
3. Aerobic metabolism as measured by oxygen uptake during the short-duration high-intensity treadmill run is

decreased when the alkalinity of the arterial blood is above a pH of 7.45.

4. The arterial blood was more alkaline under the high carbohydrate diet (>60%) and more acid under the high fat-protein diet (about 50% fat and 30% protein).

Recommendations

1. Testing of longer duration than the two to four minutes used in this study should be done with both aerobic metabolism and performance observed very closely under varying degrees of alkalosis.
2. Diet and $NaHCO_3$ ingestion should be studied simultaneously to determine their relative effects on pre-exercise acid-base balance, anaerobic metabolism, aerobic metabolism, exercise performance time, and any interactions that may occur.
3. A large number of highly trained subjects with different "fitnesses" should be observed and their various responses to all-out activity should be recorded, including aerobic capacity, anaerobic capacity, and speed of recovery from exercise.

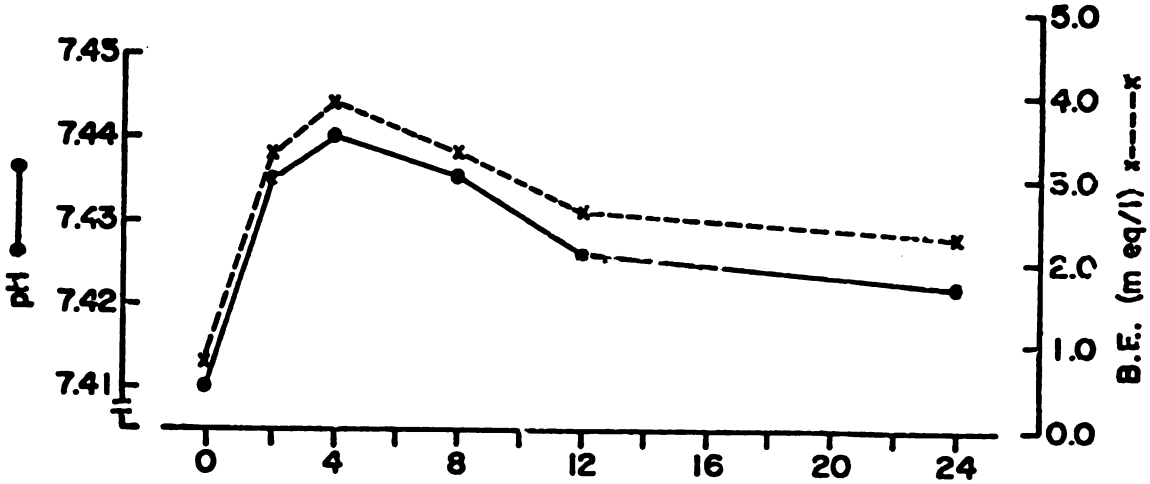
APPENDICES

APPENDIX A

TIMING OF SUPPLEMENTATION

It was not evident from the literature how long prior to exercise $NaHCO_3$ ingestion would produce maximum alterations in blood acid-base balance. An oral dose of .065 gram $NaHCO_3$ per kilogram body weight produced maximum changes in blood pH and BE after two to four hours with the pH and BE gradually decreasing after reaching its maximum value until only half of the increase was evident at twelve hours (Figure A.1). If another equal dose was given about twelve hours following the first dose, a slightly greater increase in alkalinity was achieved (Figure A.2).

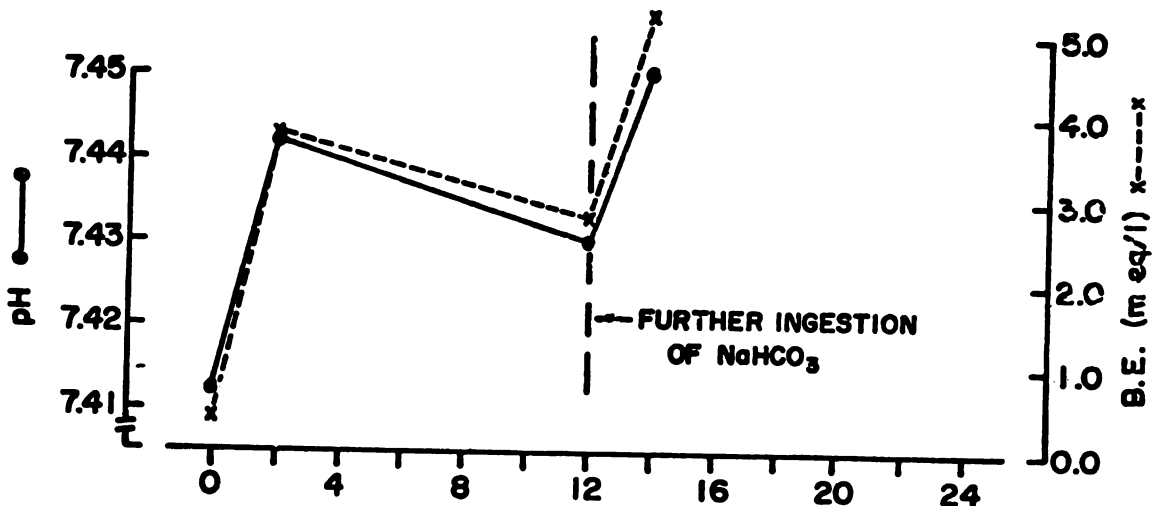
EFFECT OF ORAL $NaHCO_3$ INGESTION ON ARTERIAL BLOOD pH AND BASE EXCESS



TIME (hr) AFTER INGESTION OF $NaHCO_3$ (.065 gm/kg of bodyweight). EACH DATA POINT REPRESENTS THE MEAN OF THREE SUBJECTS.

Figure A.1

EFFECT OF TWO DOSES OF $NaHCO_3$ ON ARTERIAL BLOOD pH AND BASE EXCESS



TIME (hr) AFTER INGESTION OF $NaHCO_3$ (.065 gm/kg of bodyweight). A SECOND DOSE (.065 gm/kg) WAS INGESTED AT 12 HOURS. EACH DATA POINT IS THE MEAN OF TWO SUBJECTS.

Figure A.2

APPENDIX B

EXERCISE STRESS TEST

Certain individuals exhibit abnormalities in electrocardiogram (ECG) and blood pressure (BP) under the stress of exercise even though these abnormalities are not evident in a resting state. By using a graded exercise stress test where the intensity of the exercise increases gradually while the ECG and BP are monitored, a subject's ECG and BP response to exercise can be obtained in relative safety.

Adaptations in the Bruce protocol for graded exercise stress testing were made so that the test would stress the subjects adequately to insure a valid ECG and BP response at the high intensity of the experimental exercise.

Equipment and Materials

1. Disposable 3M Red Dot Monitoring Electrodes - Minnesota Mining Co., 3M Center, St. Paul, Minnesota 55101.
2. Cambridge 3030 EKG Unit, Cambridge Instrument Co., Inc., 73 Spring Street, Ossining, New York 10562.

Procedure

Electrodes were placed on the subject in a single bipolar V5 electrocardiograph configuration (Figure 3.5), a resting BP was taken

and a resting ECG was recorded. The subject then was exercised under the following conditions:

1. Level one - 3.5 miles/hour, 8% grade, 3 minutes duration.
2. Level two - 4.2 miles/hour, 12% grade, 3 minutes duration.
3. Level three - 6.0 miles/hour, 12% grade, 3 minutes duration.
4. Level four - 8.0 miles/hour, 12% grade, 1.5 minutes duration.

Blood pressure was measured immediately following the exercise at each level. The electrocardiogram was monitored throughout the test, and an ECG was recorded between exercise levels. The test was continued as soon as the BP and ECG were recorded.

The following criteria were used for terminating the stress test before all four levels were completed.

1. Systolic blood pressure over 220 mm Hg.
2. Diastolic blood pressure over 110 mm Hg.
3. Depression over 2 mm of the ST segment of the ECG.
4. Premature ventricular contractions (PVCs) in pairs or with increasing frequency.

None of the individuals used as subjects exhibited PVCs, any ST segment depression, or abnormal blood pressures.

APPENDIX C

CALCULATION OF OXYGEN, CARBON DIOXIDE, RESPIRATORY QUOTIENT, AND VENTILATION VARIABLES

Principle

The volume of expired gases must be corrected to standard temperature pressure dry (STPD) conditions. This can be accomplished using the following STPD correction factor:

$$\text{STPD correction factor} = \frac{P_B - P_{H_2O}}{760\ (1 + .00367\ T)} \qquad \text{(C.1)}$$

where: P_B = ambient barometric pressure,

P_{H_2O} = the water vapor tension in mm Hg at the temperature of the gasometer,

T = the temperature of the gasometer in degrees Centigrade,

.0367 = 1 divided by 273 (273 is the conversion factor for converting temperature in Centigrade to Kelvin).

This computation can be greatly simplified by using the line chart devised by R. C. Darling (Figure C.1) (23). The correction factor is then multiplied by the V_E ambient temperature saturated (ATPS) in order to obtain V_E (STPD). The volume of oxygen consumed can be found by obtaining the number of ml of oxygen consumed for every 100 ml of expired gas (true O_2) and multiplying the true O_2 by V_E (STPD). Expired gas volume does not equal inspired gas volume unless the

respiratory quotient (RQ) is equal to 1.00. The following formula for true O_2 corrects for this difference in the inspired and expired gas volume.

$$\text{TRUE } O_2 = \%\ N_2 \text{ in expired air X } .265 - \%\ O_2 \text{ in expired air} \quad \text{(C.2)}$$

$$\text{Where: } .265 = \frac{\%\ O_2 \text{ in ambient air}}{\%\ N_2 \text{ in ambient air}}$$

The same correction must be made in calculating RQ.

$$RQ = \frac{\%\ CO_2 \text{ in expired air} - .03}{\%\ N_2 \text{ in expired air X } .265} - \%\ O_2 \text{ in ambient air} \quad \text{(C.3)}$$

Where: .03 = solubility coefficient for CO_2 in human blood.

$$.265 = \frac{\%\ O_2 \text{ in ambient air}}{\%\ N_2 \text{ in ambient air}}$$

Both the above computations can be simplified by using the line chart (Figure C.2) by Dill (23).

Procedure

1. An STPD correction factor was obtained for each gas collection bag using the line chart in Figure F.1.
2. The STPD correction factor was multiplied by the total gas volume for the appropriate gas collection bag.
3. True O_2 and RQ were obtained from the line chart in Figure F.2.
4. True O_2 was multiplied by corrected V_E (STPD) and divided by 100 to get the volume of O_2 consumed in each gas collection bag.
5. Oxygen uptake per minute was obtained by dividing the O_2 consumed by the amount of time spent in collection of gas

for that bag (in fractions of a whole minute). The maximum O_2 uptake was considered to be the maximum value for O_2 uptake found in a 30-second bag during the run.

6. Oxygen uptake curves were constructed using the O_2 consumed from each gas collection bag for both exercise and recovery.
7. Gross O_2 debt was considered the sum of the oxygen uptake values for all of the recovery bags.

LINE CHART FOR DETERMINING FACTORS TO REDUCE SATURATED GAS VOLUMES TO DRY VOLUMES AT 0°C AND 760 MM HG

This figure is an example of a nomogram.

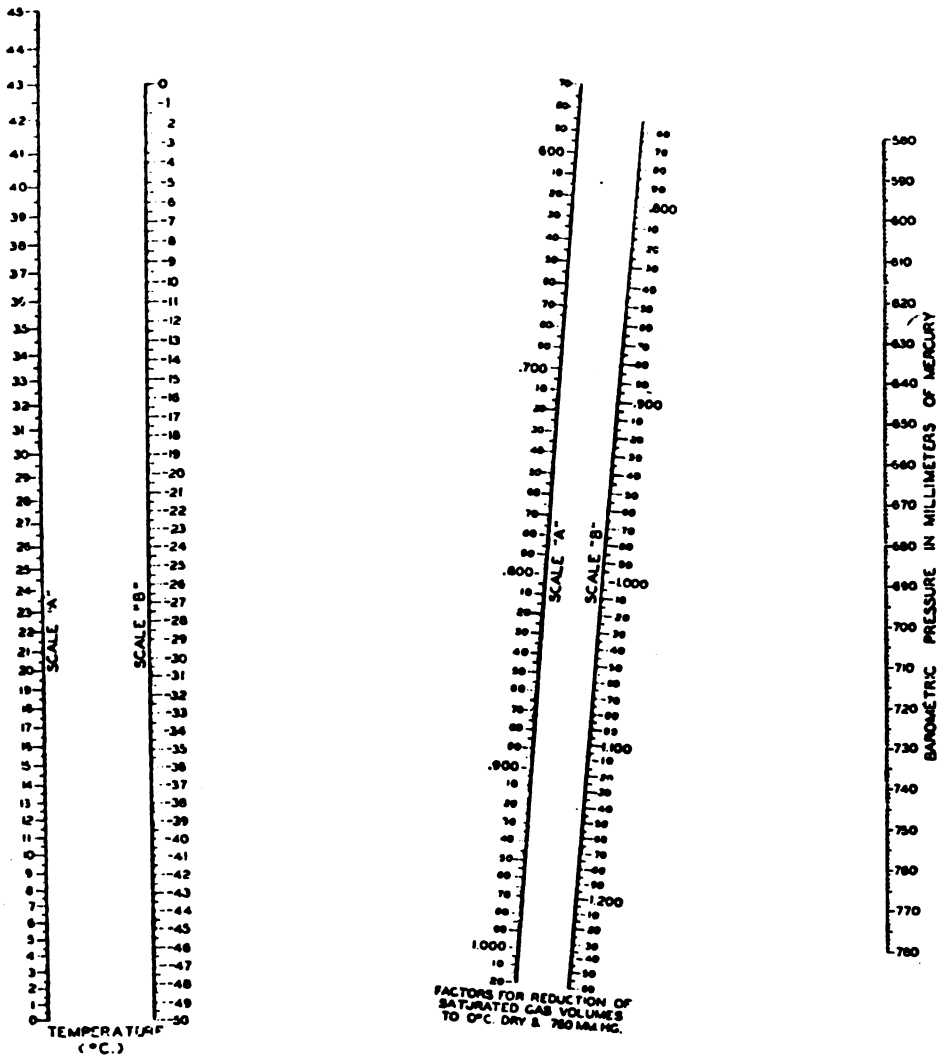


Figure C.1

LINE CHART FOR CALCULATING RQ AND TRUE OXYGEN
FROM ANALYSES OF EXPIRED AIR

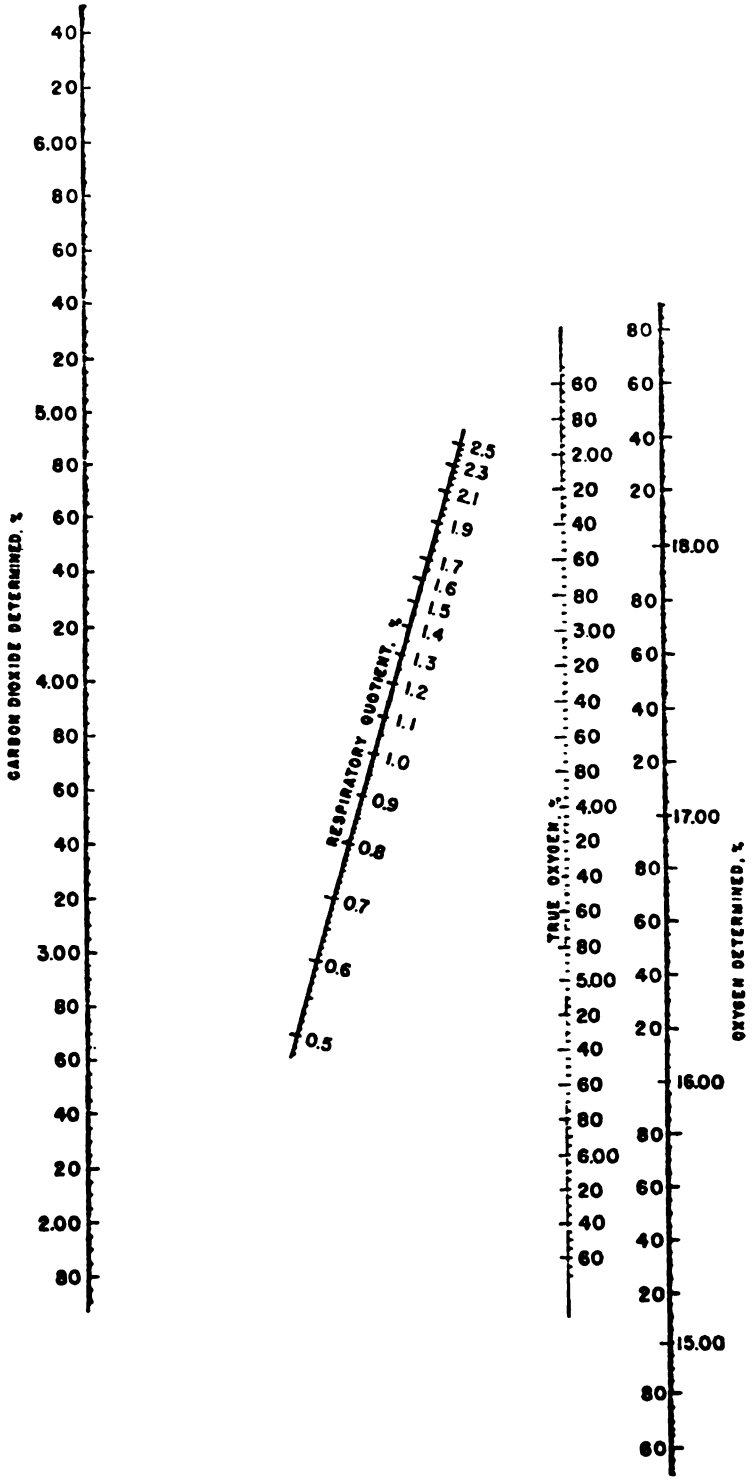


Figure C.2

APPENDIX D

BLOOD SAMPLING

Principle

It has been shown that arterialized capillary blood very closely approximates arterial blood gas composition. The finger or ear lobe must be warmed (in about 45°C water) to insure rapid flow of blood, and the blood must be taken from the middle of rapidly forming blood drops so that the sampled blood does not make contact with atmospheric air. Heparinized capillary tubes must be used to keep the blood from clotting.

Procedure

1. The finger was warmed for about two minutes in water (approximately 45°C).
2. The finger was cleaned with alcohol and wiped dry with a sterile gauze pad.
3. The finger was lanced with a long point microlance.
4. The first drop of blood formed was wiped away and then a large pool of blood was allowed to form.
5. The capillary tube was placed in the center of the blood pool and allowed to fill via capillary action insuring that the capillary tube did not take blood from the surface of the pool.

APPENDIX E

LACTATE DETERMINATION

Principle

NADH is formed when lactate is oxidized to pyruvate.

$$\text{Lactate}^- + \text{NAD} \rightleftharpoons \text{Pyruvate}^- + \text{NADH} \qquad \text{(E.1)}$$

By incubating the reaction in an alkaline environment and by trapping pyruvate with hydrazine, lactate can be completely oxidized. The equimolar formation of NADH then is measured at 340 nanometers (nm) to determine the lactate concentration.

Reagents

1. Lactic dehydrogenase enzyme (LDH) stock no. 826-6.
2. Glycine buffer (contains glycine and hydrazine pH 9.2) stock no. 826-3.
3. NAD preweighed vial stock no. 260-110.
4. Lactic acid standard solution, stock no. 826-10.
5. Sigma metabolite control, product no. s-3005.

The above reagents are from Sigma Chemical Company, P.O. Box 14508, St. Louis, Missouri 63178.

6. Perchloric acid, 70%.

Solutions

Perchloric Acid: 7 ml of 70% perchloric was diluted with 100 ml distilled water.

Lactic Acid Diluted Standard: 1.0 ml of lactic acid standard solution was diluted with 5.0 ml distilled water.

Specimen Collection and Preparation

1. One hundred microliters of blood was pipetted into centrifuge tube containing 200 µl of cold perchloric acid.
2. The mixture was centrifuged five to ten minutes at approximately 32 gs (International Chemical Centrifuge, Fisher Scientific Co.).
3. The protein free supernatant which was ready for use in the lactate determination was stored for up to six days at 0-3°C before analysis took place.
4. Sigma metabolite control was mixed with 5 ml distilled water. The metabolite control was treated the same as a pre-exercise sample (2.2 mM/l) and was used with each analysis batch.

Test Procedures

1. The number of NAD vials needed was determined.

$$\text{number of NAD vials} = \frac{\text{number of samples} + 2}{4}$$

2. Into each NAD vial the following was pipetted:

   2.0 ml glycine buffer
   4.0 ml distilled water
   .1 ml lactic dehydrogenase enzyme

   The vials were inverted several times to dissolve the NAD.

3. The solution from all the vials was mixed.
4. Into each test tube 1.4 ml solution from step 3 was pipetted and the test tubes were labeled blank through appropriate sample number.
5. To blank, .1 ml of perchloric acid was added.
6. To all samples taken before exercise, .1 ml of protein-free supernatant was added.
7. To all samples taken after exercise, .05 ml of protein-free supernatant and .05 ml of perchloric acid was added. Since the above solution is only accurate for lactate values of up to about 7 mM/l and postexercise values were expected to be over 10 mM/l, only 1/2 of the protein-free supernatant in the postexercise samples was used.
8. The test tubes were incubated at least 45 minutes at 25°C.
9. The absorbance was read at 340 nm on the Bausch and Lomb Spectronic 20.

Calibration Curve

Since the Bausch and Lomb Spectronic 20 exhibits a wide band width at 340 nm, a calibration curve was prepared. The standard lactate solutions were prepared using the following steps:

1. To each of three NAD vials, 2.0 ml glycine buffer was added.
2. The solutions were combined in one vial.
3. To the combined vial, .7 ml distilled water and .3 ml LDH enzyme was mixed.

4. The test tubes were prepared:

Test tube	Mixture from Step 3 (ml)	Water (ml)	Lactic acid diluted standard (ml)
1	1.0	2.0	0
2	1.0	1.9	.1
3	1.0	1.8	.2
4	1.0	1.7	.3
5	1.0	1.6	.4
6	1.0	1.5	.5

5. The solution was then incubated at least 45 minutes at 25°C.

6. The absorbance was read on the Bausch and Lomb Spectronic 20.

The following values were read for absorbance:

Test tube	Mixture from step 3 (ml)	Water (ml)	Lactic acid diluted standard (ml)	Absorbance	Lactate concentration
1	1.0	2.0	0	.30	0
2	1.0	1.9	.1	.47	1.33
3	1.0	1.8	.2	.54	2.66
4	1.0	1.7	.3	.62	4.00
5	1.0	1.6	.4	.69	5.33
6	1.0	1.5	.5	.77	6.66

The lactic acid calibration curve for this study then was calculated using the above standards (Figure D.1).

LACTATE STANDARD CONCENTRATION VALUES (MMOLES/L)

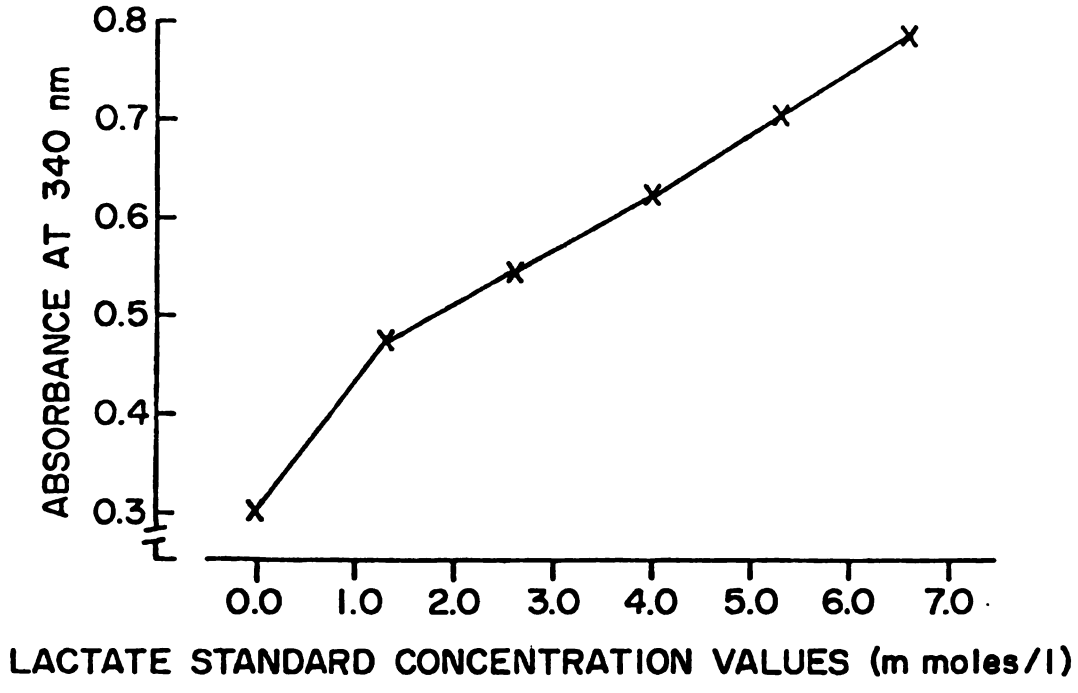


Figure D.1

APPENDIX F

pH, PARTIAL PRESSURE CARBON DIOXIDE, AND BASE EXCESS DETERMINATION

Principle

pH Determination. A Calomel electrode filled with saturated potassium chloride acts as a reference cell for the system. Blood is pulled into a pH sensitive glass electrode via a suction pump. A liquid junction is made in the system when the tip of the glass electrode containing blood or buffer is dipped into the Calomel electrode. The temperature throughout the system is kept at 38°C by a circulating water bath.

PCO_2 Determination, Indirect Method. PCO_2 can be estimated by dividing a blood sample into three parts. Two parts are used to determine the pH after the samples have been equilibrated with gases of known PCO_2. The third part of the sample is used to determine the actual pH of the sample. Since the relationship between pH and log PCO_2 is approximately a straight line relationship, a pH/log PCO_2 line for the blood sample can be drawn using the equilibrated parts of the sample. The slope of this line depends primarily on the hemoglobin of the blood. The actual pH of the sample is plotted as a point on a line connecting the equilibrated sample points and PCO_2 of the sample is read off the PCO_2 axis. Bicarbonate can then be determined by using the Hendersen-Hasselbalch equation:

$$pH = 6.1 + \log \frac{HCO_3^-}{PCO_2 \times .03} \qquad (F.1)$$

Siggaard-Andersen has developed a nomogram which was used to estimate PCO_2 and BE (Figure F.1) (11).

Equipment and Materials

1. pH meter Model 27, Radiometer.
2. Microtonometer, Radiometer.
3. Saturated potassium chloride.
4. 7.382 precision buffer ±.005 at 38°C.
5. 6.838 precision buffer ±.005 at 38°C.
6. .9% NaCl solution.

Procedure

1. Approximately 30 µl of the blood was put into two equilibration chambers of the microtonometer (one chamber equilibrated with 8.21% CO_2 and the other equilibrated with 2.69% CO_2). The samples were then allowed to equilibrate for at least three minutes.
2. While the equilibration was occurring, the rest of the blood sample was used to determine actual pH.
3. First, the pH meter was calibrated with both 7.382 and 6.838 precision buffer.
   a. The glass electrode was rinsed with .9% NaCl and filled with 7.382 precision buffer.
   b. The polyethylene glass electrode tip was placed into the saturated KCl pool in the Calomel cell.
   c. The buffer control knob on the pH meter was adjusted to 7.382.

pH, LOG PCO_2 NOMOGRAM FOR BLOOD

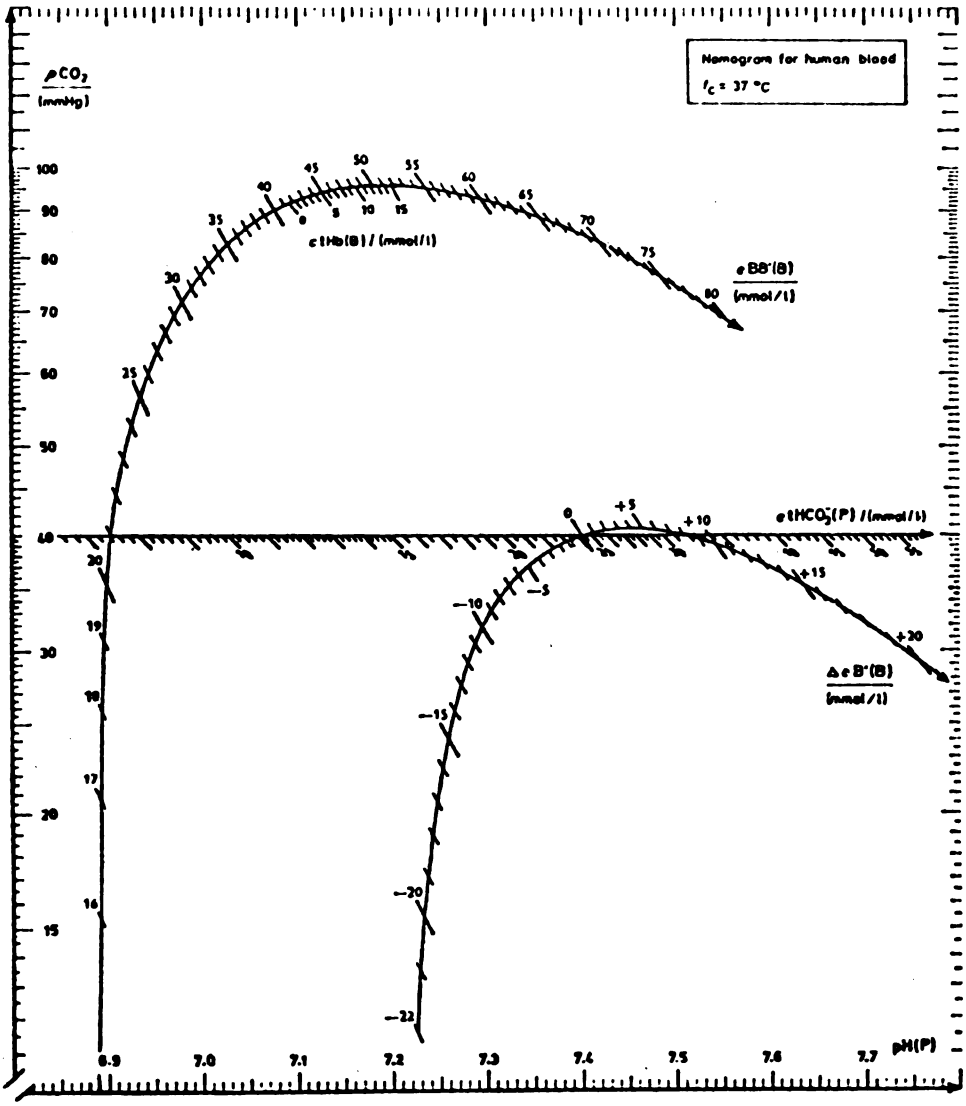


Figure F.1

d. Steps 3a-3c were repeated with the 6.838 precision buffer.

4. After the pH meter 27 was calibrated, the glass electrode was rinsed with saline and about 30 µl of blood was drawn into the glass electrode.
5. The polyethylene glass electrode tip was placed into the pool of saturated KCl.
6. The pH meter was read.
7. The glass electrode was rinsed with saline.
8. The pH meter was calibrated again with at least one precision buffer.
9. Steps 4 through 6 were repeated using the blood that had been equilibrated with 8.21% CO_2 and 2.69% CO_2.

Calculations

1. Determine the PCO_2 of the known equilibrating gases.

$$PCO_2 = \frac{\text{(barometric pressure - water vapor pressure)}}{100} \text{ X \% } CO_2 \quad \text{(F.2)}$$

2. The pH and PCO_2 values from the two equilibrated samples allow the investigator to plot two points on the Siggaard-Andersen nomogram.
3. In plotting actual pH on buffer curve sample PCO_2, HCO_3^-, and BE can then be obtained from the nomogram.

APPENDIX G

DEPENDENT VARIABLES

1. Exercise Performance Time
2. Average Respiration Rate During Exercise
3. Total Ventilation During Exercise
4. Maximum Minute Ventilation During Exercise
5. Total Ventilation During Exercise
6. Oxygen Uptake 1st 30 Seconds of Exercise
7. Oxygen Uptake 2nd 30 Seconds of Exercise
8. Oxygen Uptake 3rd 30 Seconds of Exercise
9. Oxygen Uptake 4th 30 Seconds of Exercise
10. Maximum Oxygen Uptake During Exercise
11. Oxygen Uptake 1st Minute of Recovery
12. Oxygen Uptake 2nd Minute of Recovery
13. Oxygen Uptake 3rd Minute of Recovery
14. Oxygen Uptake 4th and 5th Minutes of Recovery
15. Oxygen Uptake 6th and 7th Minutes of Recovery
16. Oxygen Uptake 8th and 9th Minutes of Recovery
17. Oxygen Uptake 10th, 11th and 12th Minutes of Recovery
18. Oxygen Uptake 13th, 14th and 15th Minutes of Recovery
19. Gross O_2 Debt (Total O_2 Uptake During Recovery)
20. Heart Rate at the End of the 1st 30 Seconds of Exercise
21. Heart Rate at the End of the 2nd 30 Seconds of Exercise

22. Heart Rate at the End of the 3rd 30 Seconds of Exercise
23. Heart Rate at the End of the 4th 30 Seconds of Exercise
24. Maximum Heart Rate During Exercise
25. Heart Rate at the End of the 1st Minute of Recovery
26. Heart Rate at the End of the 2nd Minute of Recovery
27. Heart Rate at the End of the 3rd Minute of Recovery
28. Heart Rate at the End of the 4th Minute of Recovery
29. Heart Rate at the End of the 5th Minute of Recovery
30. Heart Rate at the End of the 6th Minute of Recovery
31. Heart Rate at the End of the 9th Minute of Recovery
32. Heart Rate at the End of the 12th Minute of Recovery
33. Heart Rate at the End of the 15th Minute of Recovery
34. RQ During the 1st 30 Seconds of Exercise
35. RQ During the 2nd 30 Seconds of Exercise
36. RQ During the 3rd 30 Seconds of Exercise
37. RQ During the 4th 30 Seconds of Exercise
38. RQ During the 1st Minute of Recovery
39. RQ During the 2nd Minute of Recovery
40. RQ During the 3rd Minute of Recovery
41. RQ During the 4th and 5th Minutes of Recovery
42. RQ During the 6th and 7th Minutes of Recovery
43. RQ During the 8th and 9th Minutes of Recovery
44. RQ During the 10th, 11th and 12th Minutes of Recovery
45. RQ During the 13th, 14th and 15th Minutes of Recovery
46. pH of Arterialized Capillary Blood Before Exercise
47. pH of Arterialized Capillary Blood 5 Minutes After Exercise
48. pH of Arterialized Capillary Blood 10 Minutes After Exercise
49. pH of Arterialized Capillary Blood 15 Minutes After Exercise

50. BE of Arterialized Capillary Blood Before Exercise

51. BE of Arterialized Capillary Blood 5 Minutes After Exercise

52. BE of Arterialized Capillary Blood 10 Minutes After Exercise

53. BE of Arterialized Capillary Blood 15 Minutes After Exercise

54. PCO_2 of Arterialized Capillary Blood Before Exercise

55. PCO_2 of Arterialized Capillary Blood 5 Minutes After Exercise

56. PCO_2 of Arterialized Capillary Blood 10 Minutes After Exercise

57. PCO_2 of Arterialized Capillary Blood 15 Minutes After Exercise

58. Lactate Concentration of Arterialized Capillary Blood Before Exercise

59. Lactate Concentration of Arterialized Capillary Blood 5 Minutes After Exercise

60. Lactate Concentration of Arterialized Capillary Blood 10 Minutes After Exercise

61. Lactate Concentration of Arterialized Capillary Blood 15 Minutes After Exercise

62. Maximum Change in pH (pH Before Exercise - Lowest pH After Exercise)

63. Maximum Change in BE (BE Before Exercise - Lowest BE After Exercise)

64. Maximum Change in Lactate (Lactate Before Exercise - Highest Lactate After Exercise)

APPENDIX H

ACID-BASE BALANCE AND DIET

In a preliminary pilot study, the effects on arterialized capillary blood pH of five consecutive days of either a high-carbohydrate (80% carbohydrate) or a high-fat (80% fat) diet were determined. Only two subjects were used, but they went on controlled diets for five consecutive weeks (three high-carbohydrate and two high-fat). All ten measures were consistent, with the high-fat diet producing a negative .02 to .05 pH effect.

Subject BH			Subject CB		
Week	Diet	pH	Week	Diet	pH
1	carbo	7.40	1	carbo	7.43
2	fat	7.37	2	fat	7.41
3	carbo	7.42	3	carbo	7.45
4	fat	7.37	4	fat	7.41
5	carbo	7.40	5	carbo	7.43
$\bar{X}$ for BH high carbo 7.407			$\bar{X}$ for CB high carbo 7.437		
$\bar{X}$ for BH high fat 7.37			$\bar{X}$ for CB high fat 7.41		

$\bar{\bar{X}}$ for high carbo 7.422

$\bar{\bar{X}}$ for high fat 7.39

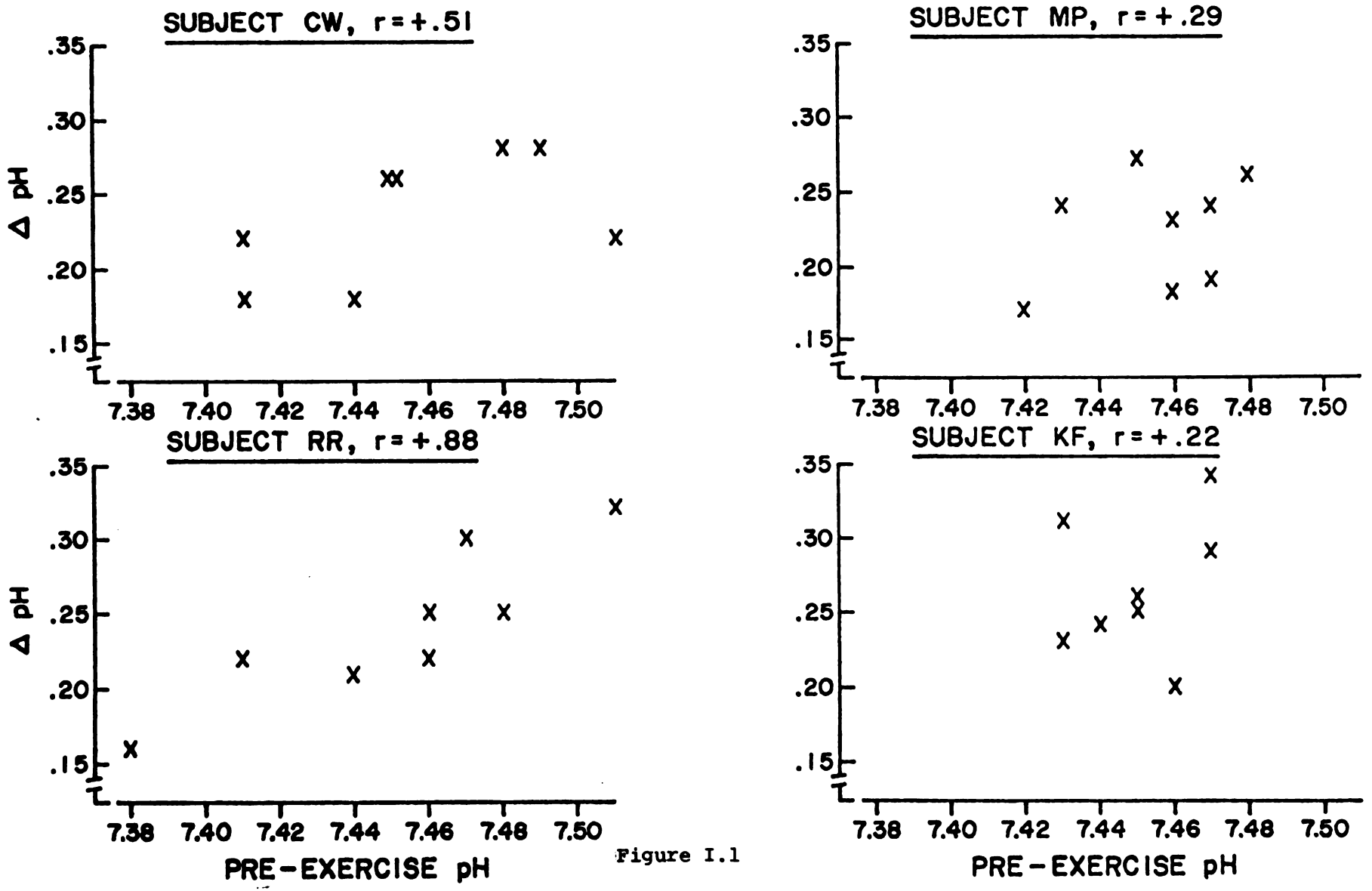

INTRASUBJECT CORRELATIONS BETWEEN
PRE-EXERCISE pH AND CHANGE IN pH
SUBJECT CW, r = +.51
SUBJECT MP, r = +.29
SUBJECT RR, r = +.88
SUBJECT KF, r = +.22
Δ pH
.35
.30
.25
.20
.15
7.38
7.40
7.42
7.44
7.46
7.48
7.50
PRE-EXERCISE pH

Figure I.1

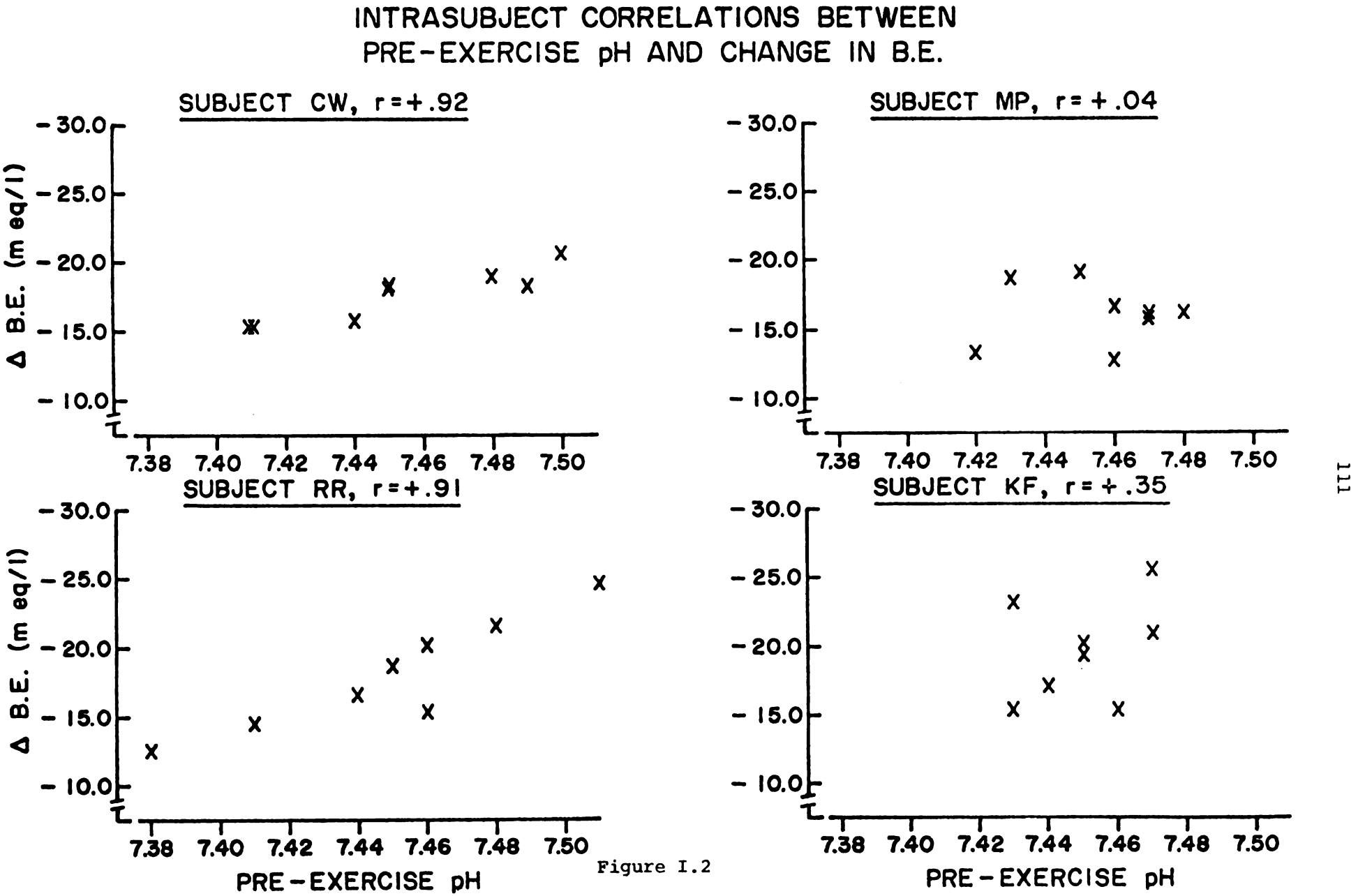

INTRASUBJECT CORRELATIONS BETWEEN
PRE-EXERCISE pH AND CHANGE IN B.E.
SUBJECT CW, r = +.92
SUBJECT MP, r = +.04
SUBJECT RR, r = +.91
SUBJECT KF, r = +.35
Δ B.E. (m eq/l)
-30.0
-25.0
-20.0
-15.0
-10.0
7.38
7.40
7.42
7.44
7.46
7.48
7.50
PRE-EXERCISE pH

Figure I.2

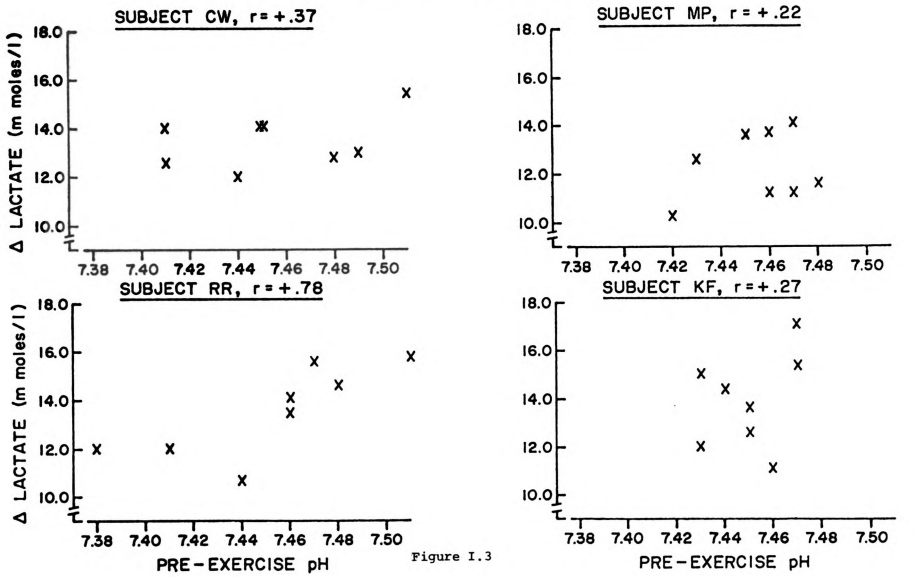

INTRASUBJECT CORRELATIONS BETWEEN
PRE-EXERCISE pH AND CHANGE IN LACTATE
SUBJECT CW, r = +.37
SUBJECT MP, r = +.22
SUBJECT RR, r = +.78
SUBJECT KF, r = +.27
Δ LACTATE (m moles/l)
PRE-EXERCISE pH
18.0
16.0
14.0
12.0
10.0
7.38
7.40
7.42
7.44
7.46
7.48
7.50

Figure I.3

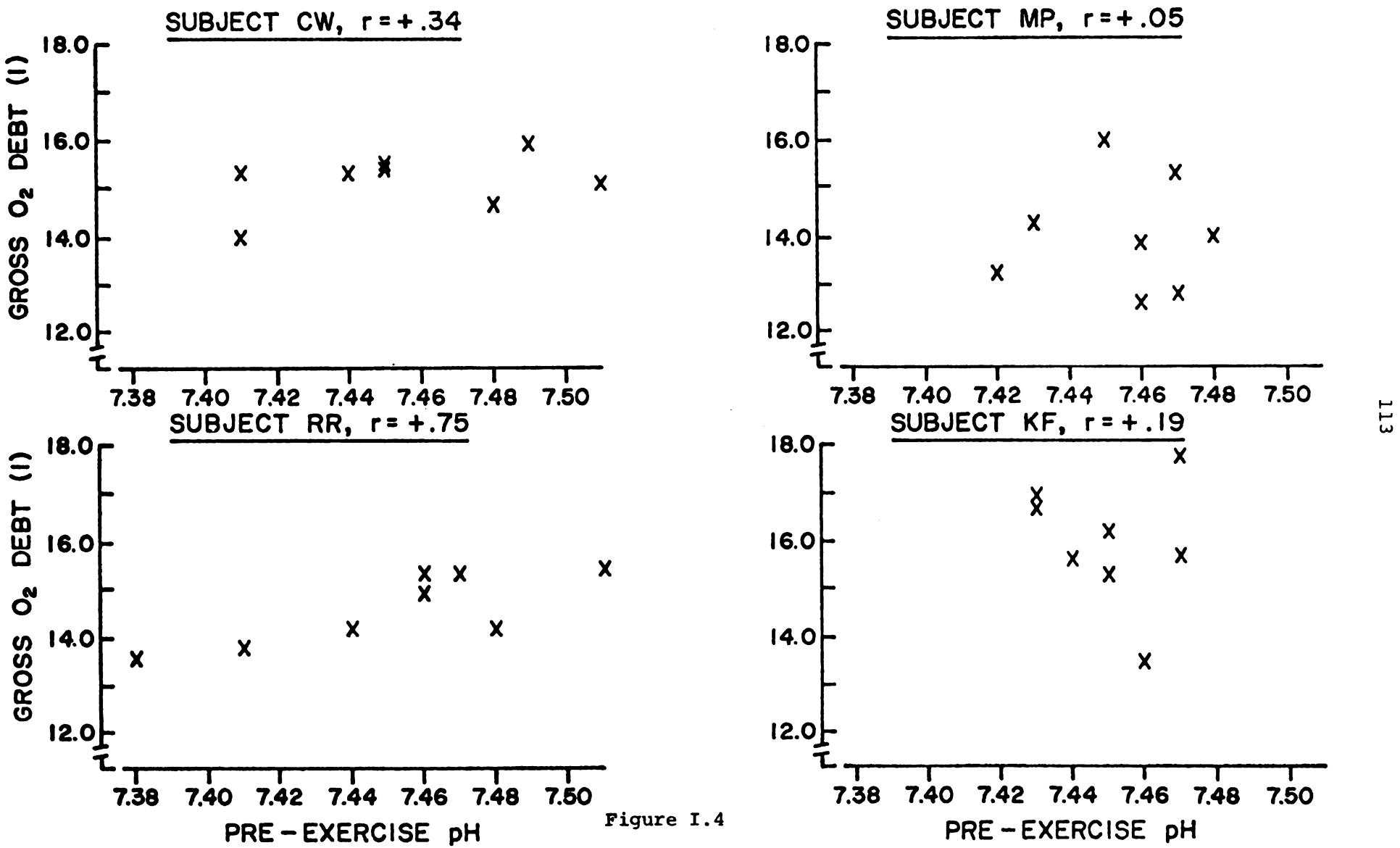

INTRASUBJECT CORRELATIONS BETWEEN
PRE-EXERCISE pH AND GROSS O_2 DEBT
SUBJECT CW, r = +.34
SUBJECT MP, r = +.05
SUBJECT RR, r = +.75
SUBJECT KF, r = +.19
GROSS O_2 DEBT (l)
18.0
16.0
14.0
12.0
7.38
7.40
7.42
7.44
7.46
7.48
7.50
PRE-EXERCISE pH

Figure I.4

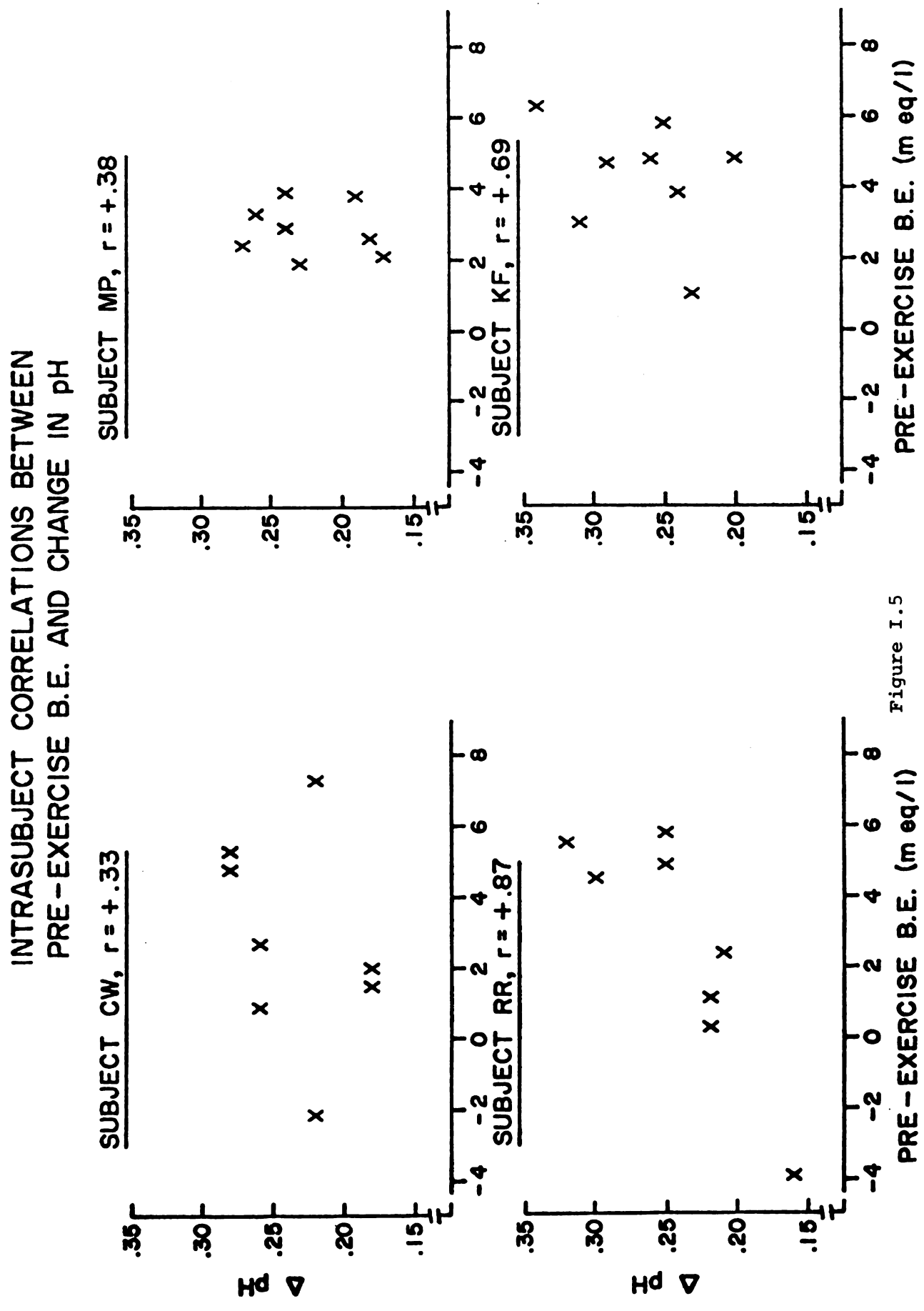

INTRASUBJECT CORRELATIONS BETWEEN
PRE-EXERCISE B.E. AND CHANGE IN pH
SUBJECT CW, r = +.33
SUBJECT MP, r = +.38
SUBJECT RR, r = +.87
SUBJECT KF, r = +.69
Δ pH
PRE-EXERCISE B.E. (m eq/l)
.35
.30
.25
.20
.15
-4
-2
0
2
4
6
8

Figure I.5

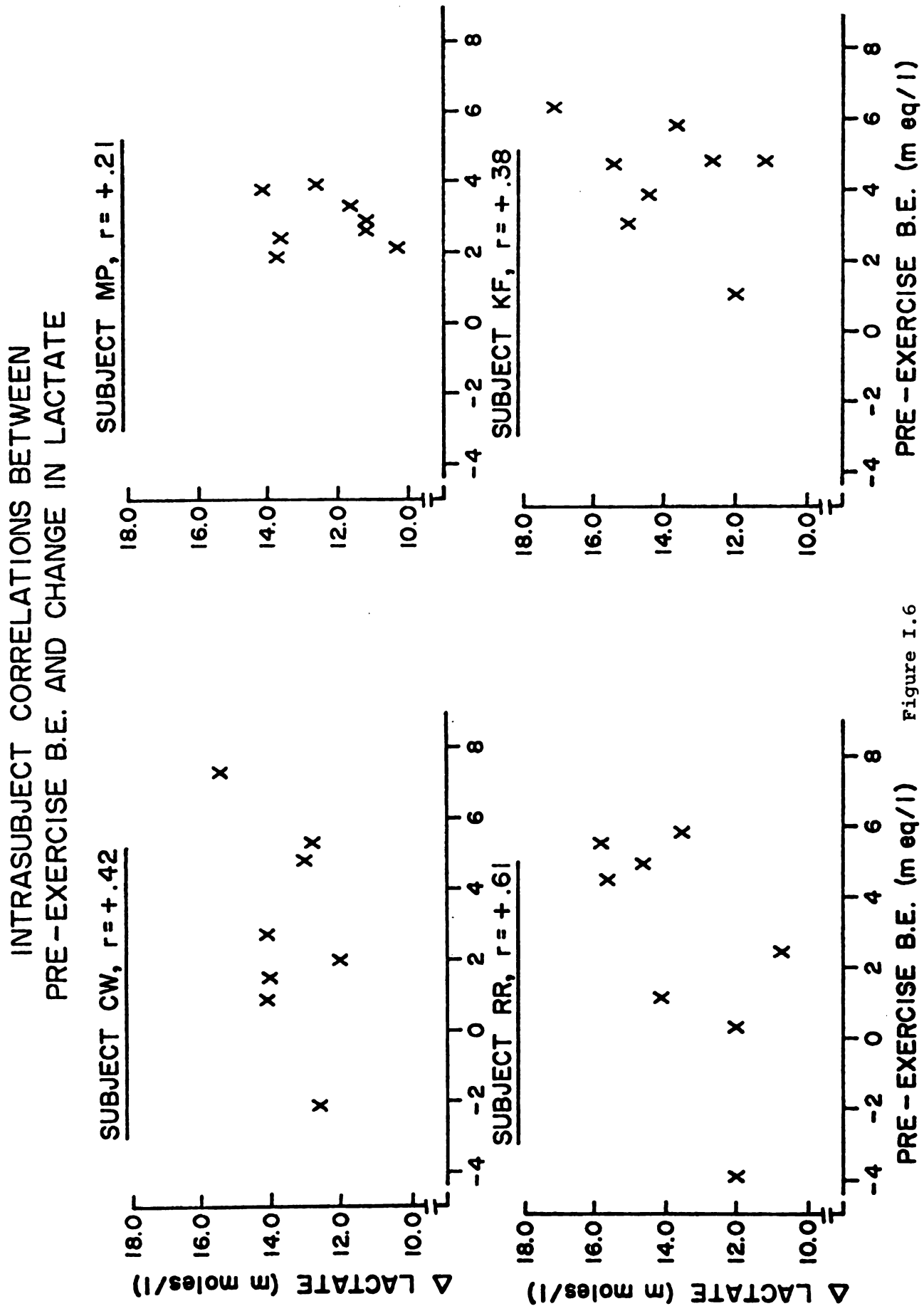

INTRASUBJECT CORRELATIONS BETWEEN
PRE-EXERCISE B.E. AND CHANGE IN LACTATE
SUBJECT CW, r = +.42
SUBJECT MP, r = +.21
SUBJECT RR, r = +.61
SUBJECT KF, r = +.38
Δ LACTATE (m moles/l)
PRE-EXERCISE B.E. (m eq/l)
18.0
16.0
14.0
12.0
10.0
-4
-2
0
2
4
6
8

Figure I.6

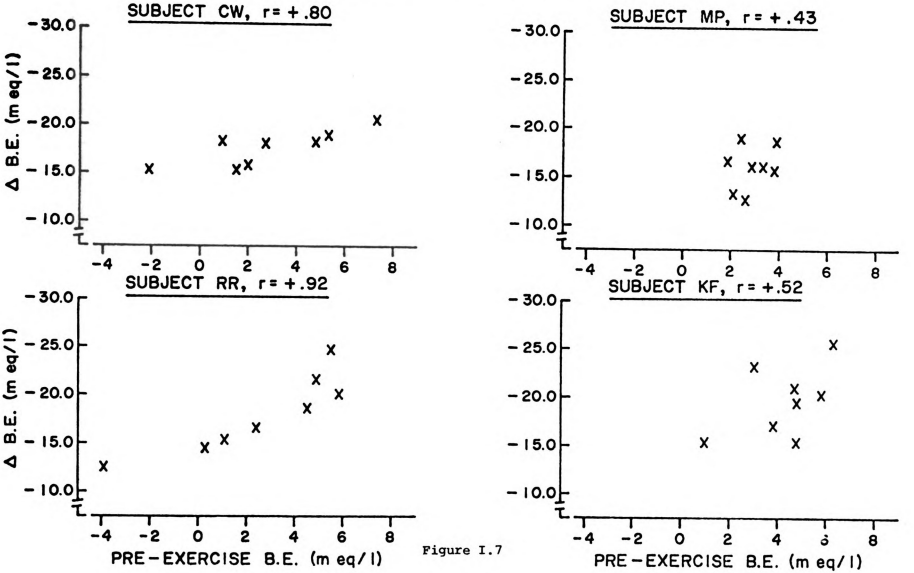

INTRASUBJECT CORRELATIONS BETWEEN
PRE-EXERCISE B.E. AND CHANGE IN B.E.
SUBJECT CW, r = +.80
SUBJECT MP, r = +.43
SUBJECT RR, r = +.92
SUBJECT KF, r = +.52
Δ B.E. (m eq/l)
PRE-EXERCISE B.E. (m eq/l)
-30.0
-25.0
-20.0
-15.0
-10.0
-4
-2
0
2
4
6
8

Figure I.7

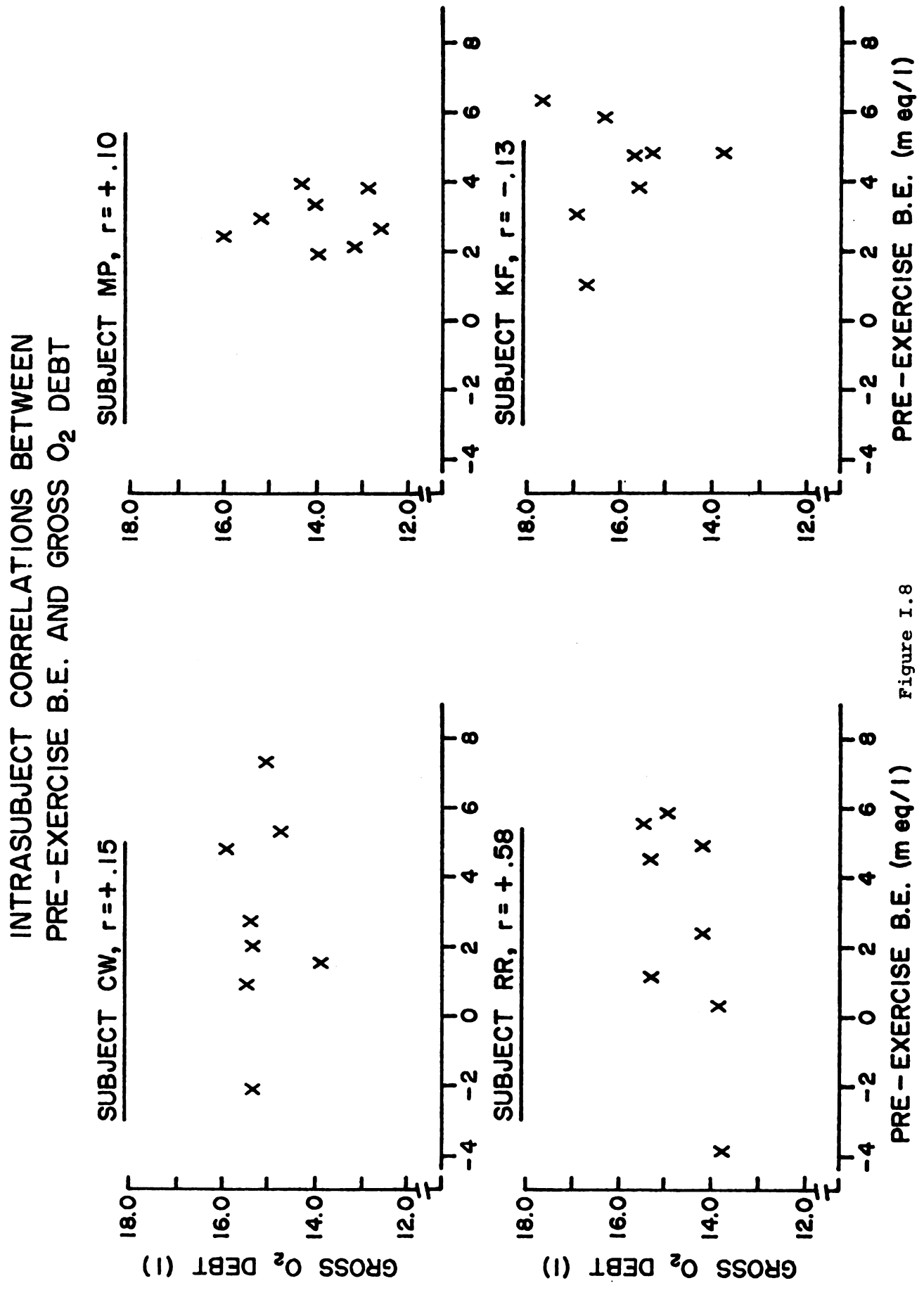

INTRASUBJECT CORRELATIONS BETWEEN
PRE-EXERCISE B.E. AND GROSS O_2 DEBT
SUBJECT CW, r=+.15
SUBJECT MP, r=+.10
SUBJECT RR, r=+.58
SUBJECT KF, r=-.13
GROSS O_2 DEBT (l)
PRE-EXERCISE B.E. (m eq/l)
18.0
16.0
14.0
12.0
-4
-2
0
2
4
6
8

Figure I.8

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BIBLIOGRAPHY

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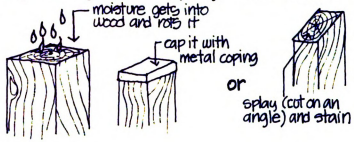
restain when it starts to wear off (about every 3 to 5 years.) To help prevent rot on your fence posts seal the tops well, with stain or a metal cap or you can splay and stain them.



☐ Legal & Social Considerations

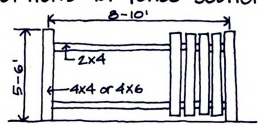
Usually, there is a legal limit on the height of a fence you can put up around your property. For Lansing, a fence on the back and sides of your house can be any height you want - there are no restrictions on these. The only restriction for Lansing residents, is on the front yard. The maximim height allowed is 4 feet.

6 feet is high enough for the back and sides; very few people can see over a 6 foot fence. A higher fence blocks out sunlight from your plants and is more costly. For any questions call the Building Department at City Hall (487-1250).

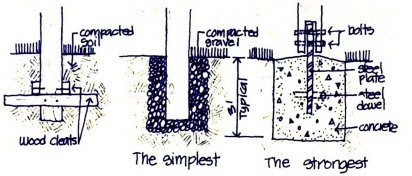
Social considerations concern you and your neighbors. Make sure the fence you build looks nice from their side, as well as from your side. Ask your neighbor about the height and style before you build. Try to work out who will repair and paint his side, before it is put up.

☐ Construction Hints

Here are some typical fence proportions for fence sections:

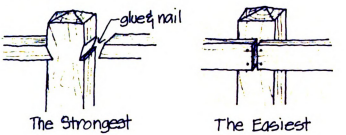


Ways to set wooden posts into the ground:



The simplest — The strongest

Joints:



The Strongest — The Easiest

note: always use galvanized nails, regular nails rust & will stain your wood.

For more information:
Fences and Gates, Sunset Book ($2.20)

The Outdoor How-to-Build-it-Book, by Robert Lee Behme, Hawthorn Books, Inc., N.Y. 1971. Look for it in your local library.

☐ Fence Styles - Here are some good fence styles you may want to copy and use around your yard.