

Influence of Sodium Bicarbonate Upon the  
Performance of Short-Duration  
Maximal Exercise of Trained Females

---

A Thesis Presented  
to  
The Graduate Faculty  
University of Wisconsin-LaCrosse

---

In Partial Fulfillment  
of the Requirements for the  
Master of Science Degree

---

by  
Douglas L. Crowell

August 1984

## ABSTRACT

CROWELL, Douglas L. Influence of sodium bicarbonate upon the performance of short-duration maximal exercise of trained females. M.S. in Adult Fitness-Cardiac Rehabilitation, 1984. 86 p. (N.K. Butts)

Fifteen trained college-aged females were studied under alkalotic ( $\text{NaHCO}_3$  ingestion) and placebo ( $\text{NaCl}$  ingestion) conditions to determine the effect of  $\text{NaHCO}_3$  on power output for 30 and 60 sec of all-out cycling. Time to exhaustion was also measured.  $\text{NaHCO}_3$  ingestion had no sig ( $p < .05$ ) effect on power output for 30 (1245.6 vs 1225.5  $\text{kgm} \cdot 30 \text{ sec}^{-1}$ ) and 60 sec (1972.4 vs 1925.9  $\text{kgm} \cdot 60 \text{ sec}^{-1}$ ) of max exercise and time to exhaustion (107.8 vs 82.7 sec). These results suggested that the alteration in blood acid-base balance (due to  $\text{NaHCO}_3$  ingestion) had little influence on muscle pH. Thus, it may be that the pH of the muscle was not the decisive limiting factor in max exercise of 30 or 60 sec duration. It was concluded that the ingestion of  $\text{NaHCO}_3$  prior to max exercise of 30 or 60 sec duration had no ergogenic benefit in trained females.

UNIVERSITY OF WISCONSIN-LACROSSE  
College of Health, Physical Education and Recreation  
LaCrosse, Wisconsin 54601

Candidate: Douglas L. Crowell

We recommend acceptance of this thesis in partial fulfillment of this candidate's requirements for the degree:

Master of Science in Adult Fitness-Cardiac Rehabilitation

The candidate has completed his oral report.

Nancy Katy Brutt  
Thesis Committee Chairperson

Aug 21, 1984  
Date

Kurt A. Kemper  
Thesis Committee Member

August 21, 1984  
Date

Kathy Wood  
Thesis Committee Member

August 21, 1984  
Date

This thesis is approved for the College of Health, Physical Education and Recreation.

John C. Mitchem  
Dean, College of Health, Physical Education and Recreation

August 21, 1984  
Date

Harvey C. Rose  
Dean of Graduate Studies

August 22, 1984  
Date

## ACKNOWLEDGEMENTS

We may be unique in our separate talents, but we can unite in our common goals.

-Anonymous

I would like to thank Dr. Nancy K. Butts, Dr. Keith A. Kensinger, and Dr. Kimberly L. Wood for their time and patience during the preparation of this manuscript.

I would like to thank Ellen Brewster for her help throughout the study.

I would like to thank Rhondda and Sonny for their love and constant support in everything that I do.

I would like to thank the friends who have allowed me to be a part of their lives. I have learned so much from all of you.

## TABLE OF CONTENTS

CHAPTER	PAGE
I. INTRODUCTION.....	1
Purpose.....	3
Hypothesis.....	3
Assumptions.....	3
Delimitations.....	4
Limitations.....	4
Definition of Terms.....	4
II. REVIEW OF THE LITERATURE.....	7
Introduction.....	7
Anaerobic Metabolism.....	7
Lactate Accumulation during Exercise...	10
Intramuscular Lactate.....	10
Blood Lactate.....	13
Summary.....	16
pH Changes during Exercise.....	17
Buffering Systems of the Muscle.....	21
Lactate and H <sup>+</sup> ion Efflux from Muscle..	23
Studies Investigating Induced Alkalosis Prior to Exercise.....	25
Improved Performance.....	26
No Influence on Performance.....	30
Summary.....	33

III.	METHODOLOGY.....	37
	Introduction.....	37
	Subject Selection.....	37
	Ingestion Procedures.....	38
	Exercise Test.....	39
	Experimental Treatment of Procedures...	41
	Statistical Treatment of Data.....	43
IV.	RESULTS AND DISCUSSION.....	45
	Introduction.....	45
	Results.....	45
	Subjects.....	45
	Power Output for 30 Second Tests....	46
	Power Output for 60 Seconds of the Tests to Exhaustion.....	49
	Time to Exhaustion.....	49
	Discussion.....	52
	Subjects.....	52
	Power Output for 30 Second Tests....	54
	Power Output for 60 Seconds of the Tests to Exhaustion.....	56
	Time to Exhaustion.....	58
	Summary.....	59
V.	SUMMARY, CONCLUSIONS AND RECOMMENDATIONS.	60
	Summary.....	60
	Conclusions.....	61
	Recommendations for Further Study...	62

REFERENCES CITED..... 64

APPENDICES..... 70

    A. Activity Questionnaire..... 71

    B. Informed Consent Form..... 74

    C. Data Collection Form..... 77

    D. Physical Characteristics of Subjects..... 79

    E. Dosage and Pedal Resistance for Subjects. 81

    F. The Use of the Wingate Test for Short-  
        Duration Maximal Exercise..... 83

## LIST OF FIGURES

FIGURE	PAGE
1. Five-second-by-five-second mean power output values for the 30 second tests.....	48
2. Five-second-by-five-second mean power output values up to 60 seconds of the exhaustion tests.....	51

## LIST OF TABLES

TABLE	PAGE
1. Summary of studies supporting that NaHCO <sub>3</sub> improves performance.....	33
2. Summary of studies showing that NaHCO <sub>3</sub> had no influence on performance.....	34
3. Means and standard deviations for physical characteristics of subjects.....	46
4. Power output values (kgm·30 seconds <sup>-1</sup> ) for the 30 second tests.....	47
5. Power output values (kgm·60 seconds <sup>-1</sup> ) for 60 seconds of the exhaustion tests...	50
6. Time to exhaustion (seconds) for the tests to exhaustion.....	53

## CHAPTER I

### INTRODUCTION

Fox and Mathews (1981) define an ergogenic aid as "something which improves or is thought to improve performance..." (p. 582). An ergogenic aid may be classified as a drug, music, warm-up, nutritional substance or even a psychological aid such as hypnosis.

As a result of the intense competition that exists between athletes today, many have found it necessary to employ an ergogenic aid in belief that it will give them an edge over their competitors. A majority of ergogenic aids have been shown to cause harmful effects on the body and many have been banned from athletic competition. However, athletes have continued to use them and many remain under investigation as to their effects on performance and their possible side effects.

Most studies involving the use of ergogenic aids have produced inconsistent results due to individual physiological and psychological variations. Some ergogenic aids may help one person and not another. Also, according to Fox and Mathews (1981), "Certain ergogenic aids may influence a person's endurance performance but may have little or no effect upon activities requiring short bursts of strength

and power." (p. 582)

In recent years several investigations have been undertaken to ascertain whether or not the ingestion of sodium bicarbonate or baking soda will enhance an individual's performance of high intensity, short-duration exercise (Balberman & Roby, 1983; Costill, Verstappen, Kuipers, Jansson, & Fink, 1983; Jones, Sutton, Taylor, & Toews, 1977; Kindermann, Keul, & Huber, 1977; McCartney, Heigenhauser, & Jones, 1983; Rupp, Bartels, Zuelzer, & Fox, 1983; Sutton, Jones, & Toews, 1981; Wilkes, Gledhill, & Smyth, 1983). These studies proposed that the maintenance of the intramuscular acid-base (pH) system during exercise would enhance performance. A drop in intramuscular pH occurs with high intensity exercise and this drop is associated with a number of biochemical alterations resulting in the inability to continue exercise (Hultman & Sahlin, 1980). Thus, these authors have suggested that the ingestion of sodium bicarbonate could maintain the intramuscular acid-base system within acceptable levels.

The above studies involving the use of sodium bicarbonate to maintain the intramuscular pH within acceptable levels have produced conflicting results. It appears that the beneficial effects of sodium bicarbonate ingestion is dependent on factors such as the type of exercise performed, the dosage of sodium bicarbonate given, and possibly the metabolic profile of the working muscles determined by an

individual's fitness state. Also, studies on sodium bicarbonate ingestion have involved only males. It would be of interest to investigate the effects of sodium bicarbonate ingestion on exercise for females.

#### Purpose

The purpose of this investigation was to ascertain whether the ingestion of sodium bicarbonate enhanced performance during short-duration maximal exercise of trained females.

#### Hypothesis

The major hypothesis that was tested at the .05 level of confidence was: the ingestion of sodium bicarbonate will have no effect upon the performance of short-duration maximal exercise of trained females.

#### Assumptions

The following assumptions were made for this study: (1) the subjects performed each work test to the best of their ability; (2) the subjects did not vary their diet or daily living habits in any way between the tests to significantly influence them; (3) the subjects were unable to detect whether they were given sodium bicarbonate or sodium chloride (in the drink used in the study); (4) the minimum amount of time (72 hours between tests) was sufficient

enough to avoid undue fatigue and any residual effects from the sodium bicarbonate ingestion; and, (4) the Monark Bicycle Ergometer would function accurately and consistently during each test.

#### Delimitations

The delimitations to this study were: (1) the subjects were healthy trained females attending the University of Wisconsin-LaCrosse; (2) the study group involved 15 subjects; and, (3) the subjects participated in two 30 second tests and two tests to exhaustion.

#### Limitations

The limitations to this study were: (1) a possible learning factor could have influenced the results because the subjects had to exercise on the bicycle four times; (2) the subjects were not randomly selected; (3) the motivation of the subjects to complete the four exercise tests could have influenced the results; and, (4) human error may have existed in the measurement of power output.

#### Definition of Terms

Acid - a chemical compound that in solution gives up hydrogen ions ( $H^+$ ).

Base - a chemical compound that in solution gives up hydroxyl ions ( $OH^-$ ).

Buffers - substances which react with the acids and bases to maintain a proper acid-base balance.

Kilopond meter (kpm) - the work performed on a Monark bicycle ergometer when a mass of one kilogram is moved a distance of one meter against the force of gravity.

Lactic acid - the end-product of anaerobic glycolysis. This term may be used interchangeably with lactate, which is the dissociated form of lactic acid.

Maximal Oxygen Uptake ( $\dot{V}O_2$  max) - the maximal amount of oxygen that can be taken in, transported and used by the body during strenuous activity per unit time.

Monark Bicycle Ergometer - a stationary bicycle that gives varying resistances through adjustment of a belt which applies friction to the wheel, acting like a brake. The resulting work is expressed in kpm.

Nicotinamide Adenine Dinucleotide (NAD) - a coenzyme, which acts as an electron acceptor in many oxidation reactions of energy metabolism and an electron donor in reduction reactions.

pH - a measure of the acidity of a solution. The symbol "pH" refers to the power of the hydrogen ion ( $H^+$ ) and is equal to the negative log of the hydrogen ion concentration.

Power - work divided by time and expressed as  $kgm \cdot sec^{-1}$ .

Sodium Bicarbonate ( $NaHCO_3$ ) - this substance acts as a buffer in order to maintain a proper acid-base balance.

Sodium bicarbonate buffers an acid with formation of a strong salt and a weak acid. It is expressed in chemical symbols as  $\text{NaHCO}_3$  and is also known as "baking soda".

Trained - a subject is considered trained if they engage in a continuous, aerobic activity involving large muscle groups at a heart rate exceeding 60 percent of their maximal heart rate reserve for more than 20 minutes per exercise session, three or more times per week. This is based on guidelines provided by the American College of Sports Medicine (1978).

Wingate Anaerobic Test - a short-duration maximal exercise test performed on a bicycle ergometer (Ayalon, Inbar, & Bar-Or, 1974).

Work - force times distance and expressed in kgm.

## CHAPTER II

### REVIEW OF THE LITERATURE

#### Introduction

A review of the literature is necessary in order to understand the use of sodium bicarbonate ( $\text{NaHCO}_3$ ) as an ergogenic aid. This review has been divided into:

- 1) anaerobic metabolism; 2) lactate accumulation; 3) pH changes during exercise; 4) buffering systems of the muscle; 5) lactate and  $\text{H}^+$  ion efflux from muscle; and,
- 6) studies investigating induced alkalosis prior to exercise.

#### Anaerobic Metabolism

"The physiology of muscular work and exercise is basically a matter of transforming bound energy into mechanical energy" (Astrand & Rodahl, 1977, p. 11). This energy is stored in a compound called adenosine triphosphate (ATP). There are three energy systems that are used in the resynthesis of ATP: 1) the adenosine triphosphate-phosphocreatine system (ATP-PC); 2) the anaerobic glycolysis system; and, 3) the oxidative phosphorylation system.

The energy used in short-duration exhaustive exercise

is derived in various proportions from aerobic and anaerobic metabolic pathways (Cunningham & Faulkner, 1969). Adenosine triphosphate (ATP) is the immediate energy source for muscular contraction. Approximately 4 mmoles per kilogram muscle of ATP is ready for the immediate demands of exercise (Gollnick & Hermansen, 1973). The ATP breaks down to adenosine diphosphate (ADP) plus inorganic phosphate ( $P_i$ ) and energy. The muscle also stores approximately 16 mmoles per kilogram muscle of phosphocreatine (PC) (Gollnick & Hermansen, 1973). This reserve is called upon when the immediate source of ATP is being used up. The PC is used to rebuild the ATP molecule from ADP and P.

The maximum ATP depletion in muscle following exercise is 40 percent of resting values (Gollnick & Hermansen, 1973). In contrast, the PC stores are nearly depleted by exercise.

Margaria, Cerretelli, and Mangili (1964) have shown that the PC system is depleted in less than 20 seconds and must then be replenished. This is done through the aerobic process or oxidative phosphorylation for which oxygen is required. In contrast, the breakdown of PC does not require the presence of oxygen and, therefore, is considered anaerobic. The adenosine triphosphate-phosphocreatine (ATP/PC) system is one of only two anaerobic means of replenishing ATP. The other involves the breakdown of glycogen or glucose to lactic acid.

The series of chemical reactions that cause glucose

to be broken down to lactic acid is called anaerobic glycolysis. During this breakdown, energy is released and, through coupled reactions, is used to resynthesize ATP.

Some research has reported that the depletion of the ATP-PC system precedes anaerobic glycolysis (Margaria et al., 1964). However, Jacobs, Tesch, Bar-Or, Karlsson, and Dotan (1983) have suggested, based on their research, that anaerobic glycolysis commences within a very short time delay after the onset of muscular contraction. In any case, anaerobic glycolysis, like the ATP-PC system, provides a relatively rapid supply of ATP and exercises that can be performed at a maximum rate for between one and three minutes depend on both systems for ATP formation (Fox & Mathews, 1981).

Anaerobic glycolysis allows exercise to continue in the absence of oxygen. When oxygen is available the end-product of glycolysis, pyruvic acid, is further metabolized via the tricarboxylic acid cycle. However, in short-duration maximal exercise, sufficient oxygen is not available and pyruvic acid cannot be further metabolized. Pyruvic acid will quickly dissociate into pyruvate and  $H^+$  ions. The  $H^+$  ions combine with nicotinamide adenine dinucleotide ions ( $NAD^+$ ) to form NADH and  $H^+$  ions. The cell can only tolerate a small change in the  $NAD^+/NADH$  ratio. Thus, excessive pyruvic acid accumulation is

impossible (Hultman & Sahlin, 1980).

Fortunately, excessive accumulation of pyruvate and  $H^+$  ions react with each other to form lactic acid and  $NAD^+$ . Lactic acid will quickly dissociate into lactate and  $H^+$  ions. Lactate and  $H^+$  ions can then be transported to the blood or can accumulate within the tissue.

### Lactate Accumulation during Exercise

It has been known for many years that lactate is produced during vigorous muscle contractions. This fact has been based on direct evidence (i.e., measurement of lactate in the muscle itself) and on indirect evidence from measurements of lactate in the blood.

### Intramuscular Lactate

Hultman and Sahlin (1980) have proposed that the accumulation of lactate in working muscles is related to the intensity of exercise. They suggested that the lactate content will be low with workloads corresponding to 60% of a person's maximal oxygen uptake ( $VO_2$  max) and increase to maximal levels with workloads corresponding to a person's  $VO_2$  max and beyond that. They also reported a study by Hultman and Bergstrom (1973) which showed that at workloads corresponding to 75-85% of  $VO_2$  max intramuscular lactate values increased during the first five to

fifteen minutes of continuous exercise (20-35 mmol·kg<sup>-1</sup> wet muscle) then decreased toward the end of the exercise period (13-20 mmol·kg<sup>-1</sup> wet muscle).

Karlsson (1971) suggested that the highest muscle lactate concentrations are found after exhaustive exercise of one to seven minutes duration. He found that the concentration of lactate in muscles at the end of maximal work was approximately the same whether the maximal work lasted two to three or seven minutes. Karlsson reported muscle lactate concentrations as high as 22.0 and 24.8 mmol·kg<sup>-1</sup> wet muscle in two male subjects after maximal exercise. This was compared with .92-1.84 mmol·kg<sup>-1</sup> wet muscle for the resting skeletal muscle. He also pointed out that repeated maximal work periods do not increase muscle lactate concentrations further.

Tesch, Sjodin, and Karlsson (1978) measured intramuscular lactate in ten males following 25 repeated isokinetic contractions of the quadriceps. This work bout lasted for approximately 30 seconds. The mean lactate concentration was 18.5 mmol·kg<sup>-1</sup> wet muscle.

Tesch (1978) measured intramuscular lactate in seven males following 60-120 seconds of intense bicycle exercise. He reported a mean intramuscular lactate concentration of 20.8 mmol·kg<sup>-1</sup> wet muscle.

Jacobs (1981) measured intramuscular lactate in four

males following 50 repeated isokinetic contractions of the quadriceps. This work bout lasted for approximately 60 seconds. The mean lactate concentration was  $22.3 \text{ mmol}\cdot\text{kg}^{-1}$  wet muscle.

Jacobs et al. (1983) measured intramuscular lactate following supramaximal bicycling tests of 10 and 30 seconds. The mean lactate for 15 males after 10 and 30 seconds of supramaximal work were  $10.6$  and  $16.9 \text{ mmol}\cdot\text{kg}^{-1}$  wet muscle, respectively.

All of the above studies suggested that high levels of lactate can accumulate in the muscles of males very quickly after the onset of muscular contractions in high-intensity exercise. There has been limited data reported regarding maximal muscle lactate values in females. Their values for short-term high intensity exercise have appeared to be lower than males.

Jacobs, Bar-Or, Karlsson, Dotan, Tesch, Kaiser, and Inbar (1982) cited a study by Jacobs and Tesch (1981) who measured intramuscular lactate in females following 30 seconds of bicycle exercise. The number of subjects was not mentioned. The mean lactate was  $12.3 \text{ mmol}\cdot\text{kg}^{-1}$  wet muscle.

Jacobs et al. (1982) measured selected intramuscular metabolites in nine females following a supramaximal bicycle test of 30 seconds duration. They reported a mean intramuscular lactate of  $13.9 \text{ mmol}\cdot\text{kg}^{-1}$  wet muscle.

In the previously cited study by Jacobs et al. (1983), intramuscular lactate was also measured in seven females following supramaximal bicycling tests of 10 and 30 seconds. The mean lactates for women after 10 and 30 seconds of supramaximal work were 5.7 and 10.8  $\text{mmol}\cdot\text{kg}^{-1}$  wet muscle, respectively.

Although females' intramuscular lactate values after exhaustive exercise appear to be lower than males, lactate will also accumulate in their muscles very quickly after the onset of muscular contraction. Lactate is known to be a small and easily diffusible molecule. Thus, lactate will also accumulate in the blood.

### Blood Lactate

Astrand, Hallback, Hedman, and Saltin (1963) measured blood lactate in 18 males after a 10 kilometer race (work time of 35 to 36 minutes), a 30 kilometer race (work time of 1 hour 50 minutes to 1 hour 56 minutes), and a 50 kilometer race (work time of 3 hours 6 minutes to 3 hours 18 minutes). The mean blood lactates were 15.4, 7.5, and 4.3  $\text{mmol}\cdot\text{L}^{-1}$ , respectively. Thus, it appeared that blood lactate was higher in maximal exercise of a shorter work period.

Osnes and Hermanssen (1972) measured blood lactate in fourteen male subjects after intermittent and continuous bicycling or running. The intermittent protocol involved

one minute bouts of maximal exercise five times. The duration of the maximal continuous test was approximately two minutes. These investigators showed that maximal exercise of short duration could increase the blood lactate concentration up to values as high as  $32 \text{ mmol}\cdot\text{L}^{-1}$ , however, no mean value was given. This can be compared to a resting blood lactate value of  $1.1 \text{ mmol}\cdot\text{L}^{-1}$  as reported by Gollnick and Hermansen (1973). The authors also mentioned that blood lactate will be higher during maximal intermittent exercise than during maximal continuous exercise.

Sahlin, Alvestrand, Brandt, and Hultman (1978) measured blood lactate in three males at the end of maximal bicycling exercise. The work load for exercise was calculated to lead to exhaustion after six minutes. The mean total work time for the subjects was ten minutes with a mean blood lactate of  $18.3 \text{ mmol}\cdot\text{L}^{-1}$ .

Fujitsuka, Yamamoto, Ohkuwa, Saito, and Miyamara (1982) measured blood lactate in 19 males after maximal treadmill exercise lasting for about one minute. The mean peak blood lactate concentration was  $12.9 \text{ mmol}\cdot\text{L}^{-1}$ . The authors also found that blood lactate reaches a maximum level six to nine minutes after the cessation of exercise, suggesting a delay in achieving peak lactate values in the blood. The reason for this delay will be discussed later in this review.

Recently, Costill, Barnett, Sharp, Fink, and Katz (1983)

measured blood lactate in six males following a treadmill sprint run and 400 meter. The mean time for the treadmill sprint run to exhaustion was 82 seconds. The mean time for the 400 meter run was 60.4 seconds. The mean blood lactates for the treadmill sprint run and the 400 meter run were 11.3 and 12.3  $\text{mmol}\cdot\text{L}^{-1}$ , respectively.

In the above study the authors noted that the subjects appeared fatigued after each trial, but they were not totally exhausted. The authors reasoned that in sprint running the participant seems to terminate the exercise before total exhaustion. They felt that this was in contrast to exhaustive anaerobic work on a bicycle, because unlike running, the subject's weight is supported, and exercise can be continued to exhaustion without risk of bodily injury. This reasoning could explain lower blood and muscle lactate values reported after sprint running as compared to bicycling.

There has been little data regarding blood lactate in women following short-term exhaustive exercise. However, blood lactates following maximal work have been documented.

Astrand (1960) measured blood lactate in women whose ages ranged from 20 to 65. The women were divided into the age groups of 20 to 29, 30 to 39, 40 to 49, and 50 to 65 years of age. Each woman performed an incremental bicycle test until exhaustion. Mean blood lactates determined after exercise for these age groups were 13.4, 10.8, 9.5, and 8.7  $\text{mmol}\cdot\text{L}^{-1}$ , respectively. The author mentioned that

the decrease in blood lactate with age was due to the younger subject being able to do more work during the bicycle test.

Hagerman, Fox, Connors, and Pompei (1974) measured blood lactate in 12 women rowers after ergometric rowing. The work consisted of four minutes of maximal rowing. They found a mean blood lactate of  $14.5 \text{ mmol}\cdot\text{L}^{-1}$ . The range for blood lactate in their study was 12.7 to  $17.0 \text{ mmol}\cdot\text{L}^{-1}$ .

### Summary

It appears that muscle lactate concentrations can increase very quickly after the onset of dynamic exercise, and reach high values in only 30 seconds. Also, males have higher values than females for short-term high intensity exercise. According to Jacobs et al. (1983), the difference in work performed for a specific time period may account for the lower lactate values for females. The reason for this could be due to a larger muscle mass in males. However, some recent studies suggest that female skeletal muscle may not possess as high a glycogenolytic potential as male muscle (Komi & Karlsson, 1979; Nygaard, 1981).

Lactate will also accumulate in the blood, But like muscle lactate, the amount will also be dependent upon the intensity, duration, and type of exercise. The work of Jorfeldt, Juhlin-Dannfelt, and Karlsson (1978) shows that the lactate formed in the muscle during exercise is released

at low and moderate workloads, but is partly accumulated in the tissue at heavy workloads when rate of lactate formation is high. Thus, the release of lactate into the blood may be delayed with high intensity exercise. Also, it appears that peak blood lactate levels occur some time after exercise. It is noted that females tend to have lower levels of lactate in their blood following maximal exercise than do males (Fox & Mathews, 1981). This may be due to the same reasons for differences in muscle lactate concentrations in males and females previously discussed.

The formation of lactate during exercise is associated with release of  $H^+$  ions. These  $H^+$  ions influence the acid-base (pH) balance of the muscle during exercise.

#### pH Changes during Exercise

Many metabolic processes will affect acid-base (pH) balance during exercise, but the major factor determining the change in muscle pH is the accumulation of lactic acid (Hultman & Sahlin, 1980). As previously mentioned, lactic acid will dissociate into lactate and  $H^+$  ions and the accumulation of  $H^+$  ions produces a metabolic acidosis (low pH). Only a few attempts have been made to investigate the changes in muscle pH which occur during muscular activity.

Hermansen and Osnes (1972) investigated blood and muscle pH after continuous exercise to exhaustion and

intermittent exercise. The exercise was performed on a treadmill or bicycle. The maximal continuous exercise was designed to last for approximately two minutes. For the intermittent exercise, the subjects (2 females and 11 males) performed maximal work which exhausted them in 40 to 60 seconds. They repeated this exercise five times with a four minute rest between tests.

The mean pH of resting muscle was 6.92 and after one maximal continuous exercise bout to exhaustion the mean muscle pH dropped to 6.41. The blood pH decreased from a mean of 7.42 at rest to a mean of 7.17 immediately after cessation of one maximal continuous exercise bout. The blood pH continued to fall during recovery from the maximal bout and reached its lowest mean value of 7.11 approximately four minutes after the exercise stopped. In contrast, the pH of muscle increased rapidly during the first few minutes of recovery (Hermansen & Osnes, 1972).

For the maximal intermittent exercise, the blood pH decreased from a mean of 7.42 at rest to a mean of 7.25 after the first exercise bout. The blood pH continued to fall after each bout to its lowest mean of 6.94. No mean value was given for muscle pH, but it was shown to decrease to about the same level after each exercise period, whereas the blood pH showed a continuous fall. Also, during the recovery periods for the intermittent exercise, the pH of the muscle increased rapidly, whereas blood pH continued

to fall (Hermansen & Osnes, 1972).

The observation that after maximal intermittent work the blood pH decreased to lower values than those observed after one maximal continuous exercise bout led the authors to suggest that the blood pH did not limit the work performance of the continuous bout. Furthermore, with intermittent exercise, the blood pH at the start of the fifth exercise bout was much lower than at the start of the first or second work period. The subjects, however, performed at the same intensity during each of the five exercise bouts. The authors concluded that the blood pH was not the limiting factor for maximal work of this type (Hermansen & Osnes, 1972).

The observation that after each intermittent bout the muscle pH decreased to about the same level led the authors to conclude that the muscle pH might be a limiting factor during maximal exercise of short duration. The authors felt that the lowered muscle pH during exercise might possibly affect the rate of anaerobic glycolysis and this was the reason why the muscle pH did not decrease further after each intermittent bout (Hermansen & Osnes, 1972).

In the above study the authors suggested that the muscle pH might be a limiting factor during maximal exercise of short duration. A relationship between muscle fatigue and a low muscle pH has been suggested.

Hermansen and Osnes (1972) reported a study by Fuchs,

Reddy, and Briggs (1970) which suggested that an increased  $H^+$  ion concentration in the muscle will reduce the binding capacity for calcium through an inactivation of the fibrillar protein, troponin. This would lead to an inability of the muscle to contract.

Based on a review of various studies, Hultman and Sahlin (1980) suggested that a low muscle pH may affect glycolysis by inhibiting two key enzymes in the glycolytic pathway. The two enzymes were phosphorylase and phosphofructokinase. If these two enzymes were inhibited, then glycolysis would not continue. The authors also suggested that a low pH can have an effect on muscle contraction by requiring more calcium to maintain muscular contraction.

Sutton et al. (1981) showed a reduced exercise performance in subjects with a low muscle pH. The authors measured muscle glycolytic intermediates in five males after exercise and suggested that a low pH in the muscle resulted in the inhibition of phosphofructokinase. This would lead to the inhibition of glycolysis and the inability to maintain and regulate a regular supply of ATP for muscular contraction. The authors suggested that in heavy exercise, the production of lactate at a rate higher than lactate removal may cause a series of events consisting of high muscle lactate and  $H^+$  ion concentrations which could lead to the inhibition of glycolysis.

As previously mentioned, the major factor determining

the change in muscle pH during exercise is the accumulation of lactic acid. Sahlin, Harris, Nyland, and Hultman (1976) have shown a linear relationship between the muscle content of lactate and the decrease in muscle pH of muscle samples after short-term bicycle exercise. Thus, changes in muscle lactate and muscle pH parallel each other.

During exercise, lactate accumulates in the muscle and the muscle pH will fall. As previously mentioned, a fall in muscle pH can affect the homeostasis and function of certain components and systems in the exercising muscle. Thus, maintenance of pH is of importance if exercise is to continue. This is determined by the buffering systems of the muscle.

#### Buffering Systems of the Muscle

Hydrogen ions ( $H^+$ ) are released in the muscle during strenuous exercise. These  $H^+$  ions are the result of the accumulation of lactic acid (94%), pyruvic acid (.3%), malate (3%), glucose 6-P (2%), and glycerol 1-P (1%) (Hultman & Sahlin, 1980). The pH would decrease to about 1.5 if the above  $H^+$  ions were added to an unbuffered solution. However, the muscle pH can reach as low as 6.4 (Hermansen & Osnes, 1972) and the released  $H^+$  ions are taken up by different buffering processes.

Hultman and Sahlin (1980) have classified these processes as physico-chemical buffering and metabolic

buffering. About 61% of the  $H^+$  ion uptake in muscle during exercise is due to physico-chemical buffering. The remaining 39% of the  $H^+$  ion uptake is provided by metabolic buffering processes.

The contribution of physico-chemical buffering depends on the uptake of  $H^+$  ions by weak bases. This buffering is done by phosphate compounds, bicarbonate ( $HCO_3^-$ ), and amino acids. The amino acids account for approximately half of the buffering done by the physico-chemical processes (Hultman & Sahlin, 1980).

The metabolic buffering processes involve the uptake of  $H^+$  ions through certain metabolic reactions. Such reactions include the utilization of creatine phosphate (PC), formation of inosine monophosphate (IMP) formed from AMP through deamination, and the oxidation of amino acids. Other metabolic changes such as decreased tissue contents of lactic acid and pyruvic acid absorb  $H^+$  ions. Thus, the metabolic processes involved in the  $H^+$  ion balance are dependent upon the overall metabolism (Hultman & Sahlin, 1980).

The measurement of chemical buffers such as  $HCO_3^-$  extracellularly (i.e., the plasma) has provided information concerning the efflux of  $H^+$  ions from the exercising muscle. Investigations have revealed a fall of plasma  $HCO_3^-$  concentrations during exercise which were equivalent to the rise of plasma lactate concentrations (Osnes &

Hermansen, 1972; Sahlin et al., 1978). This suggests that lactate and  $H^+$  ions enter the plasma or extracellular fluid together.

#### Lactate and $H^+$ ion Efflux from Muscle

With the exception of the early phase of recovery after exhaustive exercise, lactate and hydrogen ions seem to move through the muscle cell membrane at the same rate (Sahlin et al., 1978). It is possible, therefore, to use the measurement of lactate within muscle and blood to gain information on the  $H^+$  ion activity.

Hultman and Sahlin (1980) reported a study by Sacks and Sacks (1937) that showed the concentration of lactate within the muscle, even at steady state, was higher than that in the blood. This slow translocation of lactate was proposed to serve a physiological function by protecting the blood from a low pH or severe acidosis.

Sahlin et al. (1976) found that after dynamic exercise the lactate content was highly elevated in muscle and the concentration was two to three times higher than in the blood. This led the authors to suggest that the translocation of lactate was somewhat restricted.

Jorfelat et al. (1978) found that the release of lactate rose approximately linearly with the muscle lactate concentration up to about 4-5 mmol/min, but then leveled off. A further increase in muscle lactate did not increase

the efflux, suggesting a saturation of the lactate translocation process in the muscle.

The mechanisms behind lactate release are not known in detail. Lactate is an anion, which means that a cation must be released simultaneously to maintain stable electrophysiological properties in the cell. Karlsson and Jacobs (1982) have proposed that lactate release is neither an active transport nor a simple diffusion process. These authors have suggested that lactate release may be a "facilitated diffusion" (p. 191). It may also be possible that a membrane bound fraction of the enzyme lactate dehydrogenase (LDH) is involved in the transport/release of lactate, suggesting a shuttle mechanism (Karlsson & Jacobs, 1982). However, the rate of lactate efflux from muscle has been shown to be influenced by the pH of the extracellular fluid.

Mainwood, Worsley-Brown, and Paterson (1972) found that lactate efflux from frog sartorius muscles stimulated to fatigue was impaired at a low external bicarbonate ( $\text{HCO}_3^-$ ) concentration or a low pH and facilitated at a high external  $\text{HCO}_3^-$  concentration or high pH. Hirche, Hombach, Langohr, Wacker, and Busse (1975) showed that lactate efflux from dogs' gastrocnemii was three times higher during an extracellular acidosis, low pH. Thus, a high extracellular  $\text{HCO}_3^-$  concentration or low  $\text{H}^+$  ion concentration appeared to increase the efflux of lactate and

and a low extracellular  $\text{HCO}_3^-$  concentration or high  $\text{H}^+$  ion concentration decreased lactate efflux.

Although lactate and  $\text{H}^+$  ion efflux from the muscle to plasma has been considered to occur at similar rates, the entry may not be strictly equimolar (Jones & Ehram, 1982). It has been shown that transmembrane fluxes of  $\text{H}^+$  ions are linked to the extra- and intracellular concentration of other electrolytes (Hultman & Sahlin, 1980). In any case, lactate and  $\text{H}^+$  ions can leave the intracellular compartment of muscle and enter the plasma, however, when the rate of lactate formation is high (i.e., during maximal exercise), lactate will partly accumulate in the muscle (Jorfeldt et al., 1978).

Because bicarbonate ( $\text{HCO}_3^-$ ) is an effective intracellular buffer and the efflux of  $\text{H}^+$  ions from muscle is increased by adding additional extracellular buffer, it may be possible to delay the fall in intracellular pH that occurs with heavy exercise. Many investigators have attempted to enhance exercise performance by increasing the  $\text{HCO}_3^-$  reserve prior to exercise.

#### Studies Investigating Induced Alkalosis Prior to Exercise

In 1931, Dennig, Talbot, Edwards, and Dill reported that inducing metabolic alkalosis in a normal male with sodium bicarbonate prior to exercise resulted in an improvement in performance. Their early findings have

been supported (Costill et al., 1983; Jones et al., 1975, 1977; Rupp et al., 1983; Sutton et al., 1981; Wildes et al., 1983) and contradicted (Balberman & Roby, 1983; Johnson & Black, 1953; Kindermann et al., 1977; McCartney et al., 1983; Poulus, Docter, & Westra, 1974).

### Improved Performance

In 1975, Jones and associates investigated the effects of alkalosis and acidosis on exercise in five subjects produced by oral administration of sodium bicarbonate ( $\text{NaHCO}_3$ ) and ammonium chloride ( $\text{NH}_4\text{Cl}$ ), respectively. (This abstract did not include the subjects's sex.) The oral administration was done with capsules and there was no mention of the amount. Calcium carbonate ( $\text{CaCO}_3$ ) was also given as a control procedure. Exercise was performed on a bicycle ergometer and was continuous at 30%  $\dot{V}\text{O}_2$  max for 20 minutes, 70%  $\dot{V}\text{O}_2$  max for 20 minutes, and ending with 90%  $\dot{V}\text{O}_2$  max to exhaustion. It was shown that endurance time to exhaustion was increased in alkalosis and decreased during acidosis. Mean endurance times at 90%  $\dot{V}\text{O}_2$  max for alkalosis, acidosis, and control trials were 7.30, 1.67, and 4.50 minutes, respectively. No significant p value was reported for these differences.

Jones et al. (1977) again investigated the effects of  $\text{NaHCO}_3$ ,  $\text{NH}_4\text{Cl}$ , and  $\text{CaCO}_3$  on exercise performance for five

healthy male subjects. The investigators used a dose of 0.3 grams per kilogram body weight ( $.3\text{g}\cdot\text{kg}^{-1}$  body weight) given in capsule form over a period of three hours. The capsules appeared identical and neither the subjects nor the investigators knew which agent was being taken in the study. With this dosage, the investigators noted a significant change in resting blood pH between the three ingestion procedures. The pre-exercise blood pHs for  $\text{NaHCO}_3$ ,  $\text{NH}_4\text{Cl}$ , and  $\text{CaCO}_3$  were 7.43, 7.21, and 7.38, respectively. This suggested that an extracellular alkalosis or acidosis had occurred. Exercise was continuous with the subjects bicycling at 33%  $\dot{V}\text{O}_2$  max for 20 minutes, 66%  $\dot{V}\text{O}_2$  max for 20 minutes, and at 95%  $\dot{V}\text{O}_2$  max until exhaustion. These investigators showed that endurance time to exhaustion was increased in the alkalotic condition and decreased in the acidotic condition. Mean endurance times at 95%  $\dot{V}\text{O}_2$  max for  $\text{NaHCO}_3$ ,  $\text{NH}_4\text{Cl}$ , and  $\text{CaCO}_3$  were 438, 160, and 270 seconds, respectively. The authors mentioned that these differences were significant, however, they did not supply any p values. With respect to the dosages of  $\text{NaHCO}_3$  and  $\text{NH}_4\text{Cl}$ , the authors mentioned that although the dosages were not equimolar, preliminary studies showed that they were the highest that could be given without leading to symptoms. Ammonium chloride in higher dosages led to gastric discomfort and  $\text{NaHCO}_3$  led to diarrhea and vomiting.

In the same laboratory, Sutton et al. (1981) repeated the same experiment on five other males with similar results. Mean endurance times at 95%  $\dot{V}O_2$  max for  $\text{NaHCO}_3$ ,  $\text{NH}_4\text{Cl}$ , and  $\text{CaCO}_3$  were 5.44, 3.13, and 4.56 minutes, respectively. These differences were significant ( $p < .05$ ) when compared to the control ( $\text{CaCO}_3$ ).

The previous studies were concerned with the effects of pH on exercise performance and muscle metabolism. These studies clearly showed that although low  $\text{HCO}_3^-$  levels or a low pH inhibit performance, high  $\text{HCO}_3^-$  levels or high pH may improve it. Three recently published investigations also showed that increasing  $\text{HCO}_3^-$  levels prior to exercise improved performance.

Rupp et al. (1983) used the same ingestion procedure for  $\text{NaHCO}_3$  as in the previous two studies, however, lactose was used as a control. These investigators had four male subjects ride a bicycle ergometer for 20 minutes at 66%  $\dot{V}O_2$  max followed by 95%  $\dot{V}O_2$  max until exhaustion. Their results showed  $\text{NaHCO}_3$  significantly increased ( $p < .05$ ) times to exhaustion when compared with the control. Mean times to exhaustion for  $\text{NaHCO}_3$  and lactose were 287 and 214 seconds, respectively.

Costill et al. (1983) had ten males and one woman ride a bicycle ergometer one hour after consuming either  $.2\text{g}\cdot\text{kg}^{-1}$  body weight of a  $\text{NaHCO}_3$  or a placebo drink, table salt ( $\text{NaCl}$ ). The  $\text{NaHCO}_3$  ingestion increased the resting

blood pH to 7.42 which was significantly different ( $p < .05$ ) from the placebo blood pH. The subjects performed four one minute exercise bouts at 125%  $\dot{V}O_2$  max and a fifth exercise bout was performed to exhaustion. Mean endurance times during the fifth exercise bout for  $\text{NaHCO}_3$  and  $\text{NaCl}$  were 169.8 and 113.5 seconds, respectively. This 42% difference was significant at the .01 level.

Wilkes et al. (1983) investigated the effects of  $\text{NaHCO}_3$  on 800 meter racing time. These investigators had six male track athletes ingest  $\text{NaHCO}_3$  and  $\text{CaCO}_3$  (placebo) in a dose of  $.3\text{g}\cdot\text{kg}^{-1}$  body weight over a period of two hours in capsule form. Water was given ad libitum. Three 800 meter runs for time were performed after ingesting either  $\text{NaHCO}_3$ ,  $\text{CaCO}_3$ , or no drug (control). The mean times for the 800 meter run were 2:02.9, 2:05.1, 2:05.8 minutes for  $\text{NaHCO}_3$ ,  $\text{CaCO}_3$ , and control, respectively. The alkalosis time was significantly ( $p < .05$ ) faster than the placebo and control times. Thus, following  $\text{NaHCO}_3$  ingestion, the average racing time was significantly improved by 2.9 seconds. The authors felt that this improvement in an 800 meter race could be the difference between first and last place.

In conclusion, all of the above studies have shown that  $\text{NaHCO}_3$  improved the performance of high intensity, short-duration exercise. The reason for this has not been fully confirmed.

In those previous studies which measured plasma lactate following exercise, it was shown that plasma lactate was always higher with  $\text{NaHCO}_3$  ingestion (Jones et al., 1975, 1977; Rupp et al., 1983; Sutton et al., 1981; Wilkes et al., 1983). Also, two studies showed that there was a greater reduction in plasma  $\text{HCO}_3^-$  following exercise with  $\text{NaHCO}_3$  ingestion (Rupp et al., 1983; Wilkes et al., 1983). This evidence of an increase in extracellular  $\text{H}^+$  ions following exercise after  $\text{NaHCO}_3$  ingestion, coupled with the observed increase of extracellular lactate, implies an augmented efflux of  $\text{H}^+$  ions and lactate from the exercising muscle. This would result in limiting the decrease in intracellular pH and possibly postponing muscle fatigue. However, some studies have shown that sodium bicarbonate has no influence on performance.

#### No Influence on Performance

Johnson and Black (1953) investigated the effects of certain ergogenic aids on a 1.5 mile cross country race in 11 male high school cross country runners. For two races, the subjects ingested 3.5 grams of  $\text{NaHCO}_3$  four hours prior to the race. The investigators reported that the runners did not improve their performance after  $\text{NaHCO}_3$  ingestion. No mention was made of racing times in their study.

Margaria et al. (1971) investigated the effects of

induced alkalosis on supramaximal exercise. The exercise was performed by 12 male subjects who varied in fitness levels. These subjects ingested 3.24 grams of an alkali solution ( $\text{NaHCO}_3$ , sodium citrate, and potassium citrate) one-half hour before a run on a treadmill. The subjects ran at 16 kilometers per hour at an incline of 10% involving a net energy requirement of  $80 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ . A few additional tests also were done after the administration of 12 grams of  $\text{NaHCO}_3$  one hour before the run. The investigators reported that the maximal time of performance without the alkali solution ranged from a minimum of 27 seconds to a maximum of 140 seconds and was not influenced significantly by the administration of the alkali mixture. The investigators did find, however, only after massive doses of  $\text{NaHCO}_3$  (12 grams) did the time of performance increase up to 5.8%. This improvement, however, was not considered significant.

Poulus et al. (1974) investigated the influence of  $\text{NaHCO}_3$  infusion on acid-base balance and subjective feelings of fatigue in six trained male subjects during progressive exercise on a bicycle ergometer. The average amount of  $\text{NaHCO}_3$  (8%) infused was 270 ml. The infusion was done through a superficial vein in the arm. The subjects were also infused with  $\text{NaCl}$  (.9%) to serve as a placebo. Exercise was performed on a bicycle ergometer with the external load increasing every minute by 10 watts until

exhaustion. Maximum performance ranged from 335.0 to 340.2 watts. There was no significant difference in maximum performance between the conditions.

Kindermann et al. (1977) investigated the influence of bicarbonate and Tris buffer infusion on the performance of a 400 meter run. Ten males ran 400 meters twice in two weeks. Before the second 400 meter run, six subjects were infused with 190 mmol of 8.4%  $\text{NaHCO}_3$  and four subjects were infused with 130 mmol of Tris buffer. Infusions were stopped when blood pH values of greater than 7.5 were reached. The subjects then had a 15 minute warm-up after which they ran 400 meters. Mean running times were 62.4 seconds without buffer infusions and 62.6 seconds for buffered infusions. The authors concluded that running times were not improved by the buffer infusions.

In a more recent study, McCartney et al. (1983) investigated the effects of metabolic alkalosis induced by  $\text{NaHCO}_3$ , metabolic acidosis induced by  $\text{NH}_4\text{Cl}$ , and respiratory acidosis induced by 5%  $\text{CO}_2$  inhalation on short-term dynamic exercise. Six healthy male subjects performed a work test that required a maximal effort for 30 seconds on a constant velocity ergometer at a crank velocity of 100 revolutions per minute (rpm). Prior to the work test, the subjects ingested gelatin capsules containing a dose equivalent to  $.3\text{g}\cdot\text{kg}^{-1}$  body weight of  $\text{NaHCO}_3$ ,  $\text{NH}_4\text{Cl}$ , and  $\text{CaCO}_3$  (control) over a three hour period. The results

showed small differences in total work. Mean total work, expressed in joules (J), was 21,529, 20,482, 21,714, 19,595 joules for  $\text{CaCO}_3$ ,  $\text{NH}_4\text{Cl}$ ,  $\text{NaHCO}_3$ , and 5%  $\text{CO}_2$  inhalation, respectively. None of these small differences were significant.

In a recently published abstract, Balberman and Roby (1983) investigated the effects of induced alkalosis and acidosis on ten male subjects exercising maximally for one minute on a Cybex II dynamometer. The dosage employed was  $.3\text{g}\cdot\text{kg}^{-1}$  body weight of  $\text{NaHCO}_3$ ,  $\text{NH}_4\text{Cl}$ , and  $\text{CaCO}_3$ . Their results showed no significant differences in total work between trials. Total work, expressed in kilojoules (KJ), was 728, 727, 753 kilojoules for  $\text{CaCO}_3$ ,  $\text{NH}_4\text{Cl}$ , and  $\text{NaHCO}_3$ , respectively. This led the authors to state "that any possible ergogenic effects of sodium bicarbonate are not apparent during short intense exercise" (p. 143).

### Summary

On the basis of all the studies discussed (see Tables 1 and 2), the use of  $\text{NaHCO}_3$  as an ergogenic aid seemed to depend on three factors: 1) the dosage given prior to exercise; 2) the type of exercise performed; and, possibly 3) the fitness levels of the subjects. It may have been possible that in two of the studies showing no improvement in performance, the dosage of  $\text{NaHCO}_3$  was not sufficient enough to produce a substantial increase in the buffer

Table 1. Summary of studies supporting that NaHCO<sub>3</sub> improves performance.

Study	Subjects	Treatment	Dosage	Work Protocol	Results
Jones et al. (1975)	5 (sex ?)	NaHCO <sub>3</sub> CaCO <sub>3</sub> NH <sub>4</sub> Cl	?	30% $\dot{V}O_2$ max for 20 min., 70% $\dot{V}O_2$ max for 20 min., 90% $\dot{V}O_2$ max to exhaustion.	Time to exhaustion increased with NaHCO <sub>3</sub> . (No p value)
Jones et al. (1977)	5 males	NaHCO <sub>3</sub> CaCO <sub>3</sub> NH <sub>4</sub> Cl	.3g·kg <sup>-1</sup> body wt.	33% $\dot{V}O_2$ max for 20 min., 66% $\dot{V}O_2$ max for 20 min., 95% $\dot{V}O_2$ max to exhaustion.	Time to exhaustion increased with NaHCO <sub>3</sub> . (No p value)
Sutton et al. (1981)	5 males	NaHCO <sub>3</sub> CaCO <sub>3</sub> NH <sub>4</sub> Cl	.3g·kg <sup>-1</sup> body wt.	33% $\dot{V}O_2$ max for 20 min., 66% $\dot{V}O_2$ max for 20 min., 95% $\dot{V}O_2$ max to exhaustion.	Time to exhaustion increased (p<.05) with NaHCO <sub>3</sub> .
Rupp et al. (1983)	4 males	NaHCO <sub>3</sub> Lactose	.3g·kg <sup>-1</sup> body wt.	66% $\dot{V}O_2$ max for 20 min., 95% $\dot{V}O_2$ max to exhaustion.	Time to exhaustion increased (p<.05) with NaHCO <sub>3</sub> .
Costill et al. (1983)	10 males 1 female	NaHCO <sub>3</sub> NaCl	.2g·kg <sup>-1</sup> body wt.	4, 1 min. bouts at 125% $\dot{V}O_2$ max, 5th bout at 125% $\dot{V}O_2$ max to exhaustion.	Time to exhaustion increased (p<.01) with NaHCO <sub>3</sub> .
Wilkes et al. (1983)	6 males	NaHCO <sub>3</sub> CaCO <sub>3</sub>	.3g·kg <sup>-1</sup> body wt.	800 meter run.	Run time was faster (p<.05) with NaHCO <sub>3</sub> .

Table 2. Summary of studies showing that  $\text{NaHCO}_3$  had no influence on performance.

Study	Subjects	Treatment	Dosage	Work Protocol	Results
Johnson & Black (1953)	11 males	$\text{NaHCO}_3$	3.5 grams	1.5 mile cross country race.	Times did not improve with $\text{NaHCO}_3$ .
Margarita et al. (1971)	12 males	An alkali solution.	3.24 grams	Treadmill run at 16 kph and 10% grade.	Time of performance did not improve with solution.
Poulus et al. (1974)	6 males	$\text{NaHCO}_3$ $\text{NaCl}$	Infusion of 270 ml.	10 watts every 1 min. until exhaustion.	Maximal performance did not improve with $\text{NaHCO}_3$ .
Kindermann et al. (1977)	10 males	$\text{NaHCO}_3$ Tris buffer	Infusion of 190 ml of $\text{NaHCO}_3$ , 130 ml of Tris buffer.	400 meter run.	Run time did not improve with $\text{NaHCO}_3$ .
McCartney et al. (1983)	6 males	$\text{NaHCO}_3$ $\text{NH}_4\text{Cl}$ $\text{CaCO}_3$	.3g·kg <sup>-1</sup> body wt.	30 second bike test.	Total work did not improve with $\text{NaHCO}_3$ .
Balberman & Roby (1983)	10 males	$\text{NaHCO}_3$ $\text{NH}_4\text{Cl}$ $\text{CaCO}_3$	.3g·kg <sup>-1</sup> body wt.	1 min. Cybex test.	Total work did not improve with $\text{NaHCO}_3$ .

reserve (Johnson & Black, 1953; Margaria et al., 1971). Is there an optimal or minimal dosage of  $\text{NaHCO}_3$  that can be taken to enhance performance? Also, the type of exercise performed in the studies varied from performing to exhaustion, performing during a specified time period, and performing for a specified distance. Is  $\text{NaHCO}_3$  useful in exercise lasting less than two minutes? And last, the physical fitness of the subjects varied between studies. It has been shown that the metabolic profile of the working muscles can be modified within an individual by training. Will a change of blood pH therefore be expected to produce varying effects on performance capacity?

It may be of interest to notice the lack of use of female subjects in all the previous studies. Will females improve their performance with the use of  $\text{NaHCO}_3$  prior to exercise? As cited earlier in this review, female skeletal muscle may not produce as high lactate levels as males. This may be due to a lower glycogenolytic potential in their muscle or it may also be related to the smaller muscle mass in females as compared to males. The consequences of these factors relative to the use of  $\text{NaHCO}_3$  as an ergogenic aid to improve exercise performance have not been investigated.

## CHAPTER III

### METHODOLOGY

#### Introduction

The purpose of this investigation was to ascertain whether the ingestion of sodium bicarbonate enhanced performance during short-duration maximal exercise of trained females. All testing took place in the Human Performance Laboratory at the University of Wisconsin-LaCrosse. The procedures and instrumentation used to obtain data for this investigation have been described in this chapter.

#### Subject Selection

Fifteen female graduate and undergraduate students at the University of Wisconsin-LaCrosse volunteered to participate in this study. The subjects were given a self-administered activity questionnaire to determine if they were trained or untrained (see Appendix A). The activity questionnaire was based on exercise guidelines provided by the American College of Sports Medicine (1978). A subject was considered trained if they engaged in a continuous, aerobic activity involving large muscle groups at a heart rate exceeding 60 percent of their maximal heart rate reserve for more than 20 minutes per exercise session, three or more

times per week.

Prior to participation in any part of the experiment, the purpose and design of the experiment was explained. Also, the investigators explained the equipment and testing procedures. Each subject was then required to read and sign an informed consent form (see Appendix B). The subjects were also required to participate in two practice sessions to become familiar with the testing equipment and protocol.

The subjects were told the purpose of the study was to determine whether sodium bicarbonate ( $\text{NaHCO}_3$ ) enhanced performance during short-duration maximal exercise on a bicycle ergometer. Also, in conjunction with another study, blood lactate levels were also investigated. The subjects were encouraged to give a "true" maximal effort.

#### Ingestion Procedures

The subjects were tested in a post-absorptive state (i.e., fasting at least eight hours). They were asked to ingest a drink containing 18 ounces of cold tap water with either  $.2\text{g}\cdot\text{kg}^{-1}$  body weight of  $\text{NaHCO}_3$  or 5g of NaCl. This dosage of  $\text{NaHCO}_3$  has been shown to change blood parameters enough to place the subject in an alkalotic condition (Costill et al., 1983). In a personal communication with Fink (1983), who works with Costill at the Ball State Laboratory, a dosage of  $.2\text{g}\cdot\text{kg}^{-1}$  body weight was given instead of  $.3\text{g}\cdot\text{kg}^{-1}$  body weight because it was felt that

the subject could not tolerate the latter dosage in a drink. Also, preliminary studies at Ball State showed that  $.2\text{g}\cdot\text{kg}^{-1}$  body weight changed the blood pH significantly toward the alkalotic condition after 45 minutes post ingestion and plateaued at one hour. On this basis, a period of 60 minutes elapsed prior to the exercise test. In addition; sodium chloride (NaCl) was used as a placebo in the Ball State studies simply because it dissolved in water and was not much different in taste from  $\text{NaHCO}_3$ . The five grams of NaCl used in this study was determined by the investigators to sufficiently mimic the taste of varying amounts of  $\text{NaHCO}_3$ . The subjects were informed that a double blind situation existed in that neither the subject nor the investigators knew which treatment,  $\text{NaHCO}_3$  or NaCl, the subject received.

#### Exercise Test

The subjects participated in four trials on a Monark bicycle ergometer. Two trials involved a work test of 30 seconds duration 60 minutes after ingesting either  $\text{NaHCO}_3$  or NaCl. The remaining two trials involved a work test to exhaustion 60 minutes after ingesting either  $\text{NaHCO}_3$  or NaCl. The trials were randomly assigned and the subjects did not know which trial they were participating in prior to each testing session.

The work task employed was the Wingate Anaerobic

Test (Ayalon et al., 1974) for two trials and a modification for the remaining two trials. The Wingate test has involved all-out pedalling for 30 seconds against a specified resistance. In this study, two trials involved a 30 second time period and the remaining two were continued to exhaustion. The Wingate test has been used for the evaluation of the capacity for short-duration, maximal exercise. Its reliability and usage has been described in many studies (Ayalon et al., 1974; Inbar, Dotan, & Bar-Or, 1976; Jacobs, 1980; Inbar, Kaiser, & Tesch, 1981; Jacobs et al., 1982; Jacobs et al., 1983; Kaiser, Rossner, & Karlsson, 1981; Rotstein, Bar-Or, & Dlin, 1982). However, only one study was found in which the Wingate test was extended to 60 seconds (Bosco, Lutanen, & Komi, 1983).

A mechanically braked bicycle ergometer was used and the resistance applied was standardized for all subjects. All subjects pedalled maximally against a resistance of .075kg x kg body weight. The work test involved all-out pedalling at this resistance. The number of pedal revolutions was electronically recorded on a chart recorder and the number of pedal revolutions were counted for every five-second interval during each test (see Appendix C). From this, the following indices were derived: power output ( $\text{kgm} \cdot 30 \text{ seconds}^{-1}$ ) for the 30 second tests; power output for 60 seconds ( $\text{kgm} \cdot 60 \text{ seconds}^{-1}$ ) of the work tests to exhaustion if the subject reached this point; power

output for each five-second interval ( $\text{kgm} \cdot 5 \text{ seconds}^{-1}$ ) of the 30 second tests; and power output for each five-second interval ( $\text{kgm} \cdot 5 \text{ seconds}^{-1}$ ) up to 60 seconds of the work tests to exhaustion. The formula used to calculate power ( $\text{kgm} \cdot \text{seconds}^{-1}$ ) was: kilograms of resistance x 6 meters x revolutions. Time to exhaustion (in seconds) was also recorded.

### Experimental Treatment of Procedures

The subjects were required to participate in two practice sessions prior to the actual testing. At the first practice session, the purpose and design of the experiment was explained. The subject was asked to read and sign the informed consent form and fill out the activity questionnaire. The subject was also weighed with clothes and shoes on and the dosage of  $\text{NaHCO}_3$  and exercise test workload were calculated. Following these procedures, the subject was seated on the bicycle and the proper seat height was determined. The seat height allowed for a slight bend in the subject's knee when their leg was fully extended on the pedal. This was considered to be the most efficient position for bicycling. However, subject comfort was emphasized. The feet were strapped into the pedals with velcro straps. Both practice sessions involved bicycling for approximately five minutes at a workload of .5kp and a speed of 15 kilometers per hour. Then the subject's

actual test workload was applied to the bicycle wheel and the subject was asked to pedal as quickly as they could for approximately 15 seconds. The workload was then reduced to .5kp and the subject was to pedal lightly for a minute. Appointments for the actual testing were made at the second practice session.

The tests were conducted with at least 72 hours between tests. As previously stated, the exercise tests and ingestion treatments were randomized.

On the day of each test, the subject arrived one hour prior to the exercise test. The subject was given a drink containing 18 ounces of cold tap water with a predetermined dosage of  $\text{NaHCO}_3$  ( $.2\text{g}\cdot\text{kg}^{-1}$  body weight) or 5g of  $\text{NaCl}$ . The subject was given 5 minutes to consume the drink and was asked to remain in the laboratory for the next 55 minutes. The subject was allowed to void if necessary.

Fifty-five minutes after ingesting the dosage, the subject was prepared for the test. The seat was adjusted to the proper height and the subject's feet were strapped onto the pedals. Sixty minutes after ingesting the dosage, the subject was asked to warm-up for three minutes at .5kp resistance and a speed of 15 kilometers per hour. After three minutes of warm-up, the subject stopped pedalling. Before the test began, the subject was reminded to pedal as fast and as hard as possible until instructed to stop or until exhaustion. The subject was instructed not to

pace herself. The subject was then instructed to slowly increase their pedal revolutions against .5kp resistance for five seconds at which point the predetermined workload was applied to the bicycle wheel and the test began. The subjects were verbally encouraged throughout the bicycle test. The test was terminated at either 30 seconds or exhaustion. Exhaustion was defined as the inability to complete one pedal revolution while sitting on the bicycle. The investigators carefully observed the subject to prevent recruitment of other muscles, such as standing or pulling on the handle bars.

Upon termination of the test, the workload was removed and the subject warmed-down for three minutes at .5kp and a comfortable speed. The subject was encouraged to walk around after getting off the bicycle.

In conjunction with another study, blood samples were drawn from each subject. A blood sample was drawn one-half hour before each work test and six minutes after each work test. The blood sample was analyzed for lactate concentration.

#### Statistical Treatment of Data

The means and standard deviations were calculated for all physical characteristics and all other indices derived. The results were analyzed to determine whether the ingestion of sodium bicarbonate enhanced performance during short-duration maximal exercise of trained females. A dependent

"t" test was used to examine the effect of  $\text{NaHCO}_3$  and  $\text{NaCl}$  ingestion on: 1) power output means ( $\text{kgm}\cdot 30 \text{ seconds}^{-1}$ ) for the 30 second tests; 2) power output means for 60 seconds ( $\text{kgm}\cdot 60 \text{ seconds}^{-1}$ ) of the tests to exhaustion; and, 3) mean times to exhaustion (seconds). A two-way analysis of variance with repeated measures (BMD program) was used to examine the effect of  $\text{NaHCO}_3$  and  $\text{NaCl}$  ingestion on: 1) power output means ( $\text{kgm}\cdot 5 \text{ seconds}^{-1}$ ) for each five-second interval of the 30 second tests; and, 2) power output means ( $\text{kgm}\cdot 5 \text{ seconds}^{-1}$ ) for each five-second interval up to 60 seconds of the tests to exhaustion. Significance was accepted at the .05 level of confidence.

## CHAPTER IV

### RESULTS AND DISCUSSION

#### Introduction

The basic intent of this study was to ascertain whether the ingestion of sodium bicarbonate enhanced performance during short-duration maximal exercise in trained females. The statistical analyses of data and the findings have been discussed in this chapter.

#### Results

##### Subjects

Data were collected on 15 female college students who were attending the University of Wisconsin-LaCrosse. All were screened before their acceptance as subjects. Each subject fulfilled the requirements to be considered aerobically trained, as outlined by the American College of Sports Medicine (1978). Physical characteristics for this group can be found in Table 3 with individual data in Appendix D.

The weight of each subject was used to calculate their  $\text{NaHCO}_3$  dosage (grams) and pedal resistance (kiloponds). The  $\text{NaHCO}_3$  dosage for the group ranged from 10.4 to

13.9 grams with a group mean of 12.3 grams. The pedal resistance ranged from 3.9 to 5.2 kiloponds with a group mean of 4.6 kiloponds (see Appendix E for individual data).

Table 3. Means and standard deviations for physical characteristics of subjects (N=15).

	Age (yr)	Height (cm)	Weight (kg)
$\bar{X}$	24.1	166.8	61.3
S.D.	3.8	5.9	5.0

#### Power Output for 30 Second Tests

A dependent t-test comparing the effects of  $\text{NaHCO}_3$  and  $\text{NaCl}$  ingestion on power output for the 30 second tests found no significant ( $p < .05$ ) difference between the mean power output values following  $\text{NaHCO}_3$  or  $\text{NaCl}$  ingestion. The calculated test value was 1.443 compared to the critical value of 2.145 with 14 degrees of freedom. The individual data can be found in Table 4.

Figure 1 shows the five-second-by-five-second mean power output values for the 30 second tests following  $\text{NaHCO}_3$  or  $\text{NaCl}$  ingestion. An analysis of variance revealed no significant ( $p < .05$ ) difference between conditions for each five-second interval of the 30 second tests.

Table 4. Power output values ( $\text{kgm} \cdot 30 \text{ seconds}^{-1}$ ) for the 30 second tests.

Subject	$\text{NaHCO}_3$ Treatment	$\text{NaCl}$ Treatment
1	1108.8	1135.2
2	1267.2	1094.4
3	1341.6	1279.2
4	1297.2	1297.2
5	1161.6	1161.6
6	1381.8	1381.8
7	1346.4	1377.0
8	1296.0	1324.8
9	1184.4	1159.2
10	1135.2	1082.4
11	1293.6	1234.8
12	1186.8	1135.8
13	1320.0	1350.0
14	1264.2	1290.0
15	1099.8	1076.4
$\bar{X}$	1245.6	1225.3
S.D.	91.9	110.1

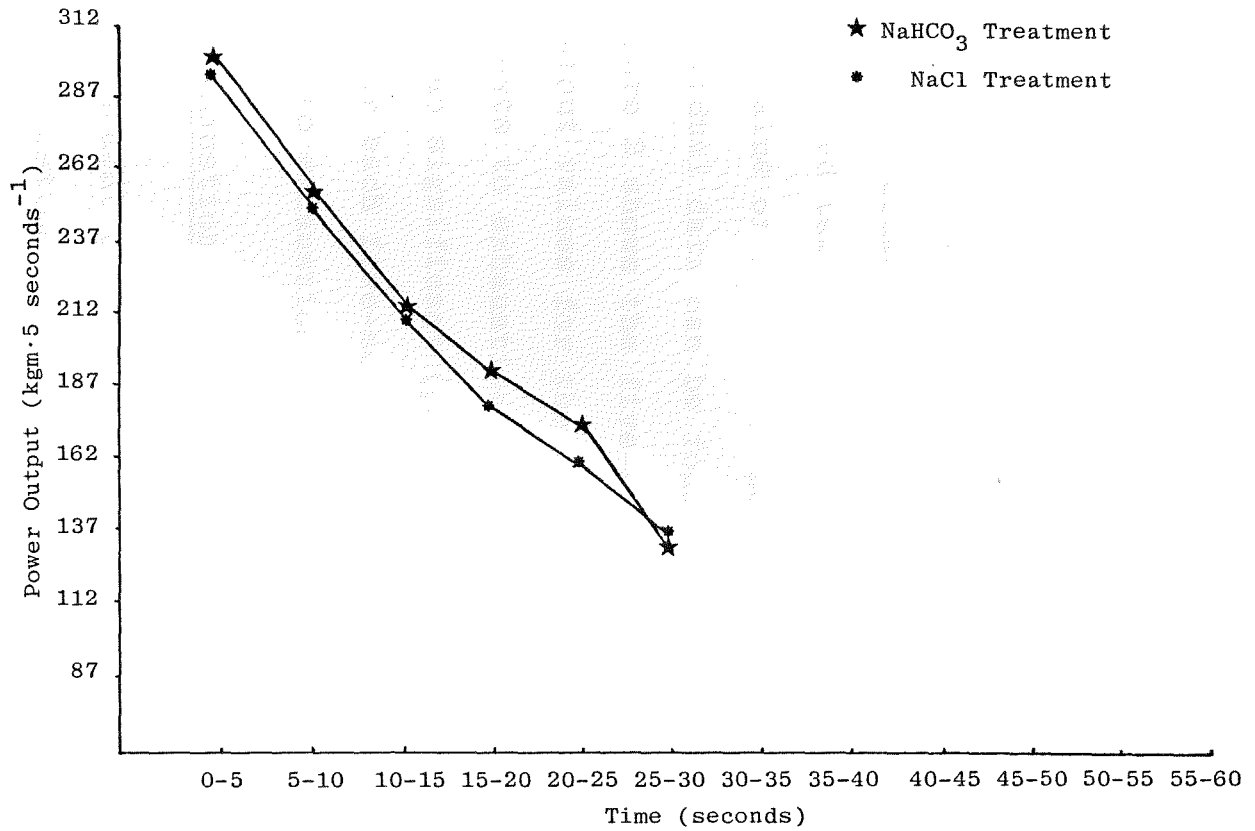


Figure 1. Five-second-by-five-second mean power output values for the 30 second tests (N=15).

### Power Output for 60 Seconds of the Tests to Exhaustion

Only eight of the 15 subjects involved in the study could reach 60 seconds of the exhaustion tests following both  $\text{NaHCO}_3$  and  $\text{NaCl}$  ingestion. A dependent t-test comparing the effects of  $\text{NaHCO}_3$  and  $\text{NaCl}$  ingestion on power output for 60 seconds of the tests to exhaustion found no significant ( $p < .05$ ) difference between the mean power output values following  $\text{NaHCO}_3$  or  $\text{NaCl}$  ingestion. The calculated test value was 1.078 compared to the critical value of 2.365 with seven degrees of freedom. The individual data can be found in Table 5.

Figure 2 shows the five-second-by-five-second mean power output values for the eight subjects up to 60 seconds of the tests to exhaustion. An analysis of variance revealed no significant ( $p < .05$ ) difference between conditions for each five-second interval up to 60 seconds of the tests to exhaustion.

### Time to Exhaustion

A dependent t-test comparing the effects of  $\text{NaHCO}_3$  and  $\text{NaCl}$  ingestion on time to exhaustion found no significant ( $p < .05$ ) difference between the mean times to exhaustion following  $\text{NaHCO}_3$  or  $\text{NaCl}$  ingestion. The calculated test value was 1.231 compared to the critical value of 2.145 with 14 degrees of freedom. The individual

Table 5. Power output values ( $\text{kgm} \cdot 60 \text{ seconds}^{-1}$ ) for 60 seconds of the exhaustion tests.

Subject	$\text{NaHCO}_3$ Treatment	$\text{NaCl}$ Treatment
2	2102.4	1814.4
5	1821.6	1716.0
6	2199.6	2058.6
8	2102.4	2131.2
9	1814.4	1864.8
13	2070.0	2130.0
14	1960.8	1960.8
15	1708.2	1731.6
$\bar{X}$	1972.4	1925.9
S.D.	174.3	169.3

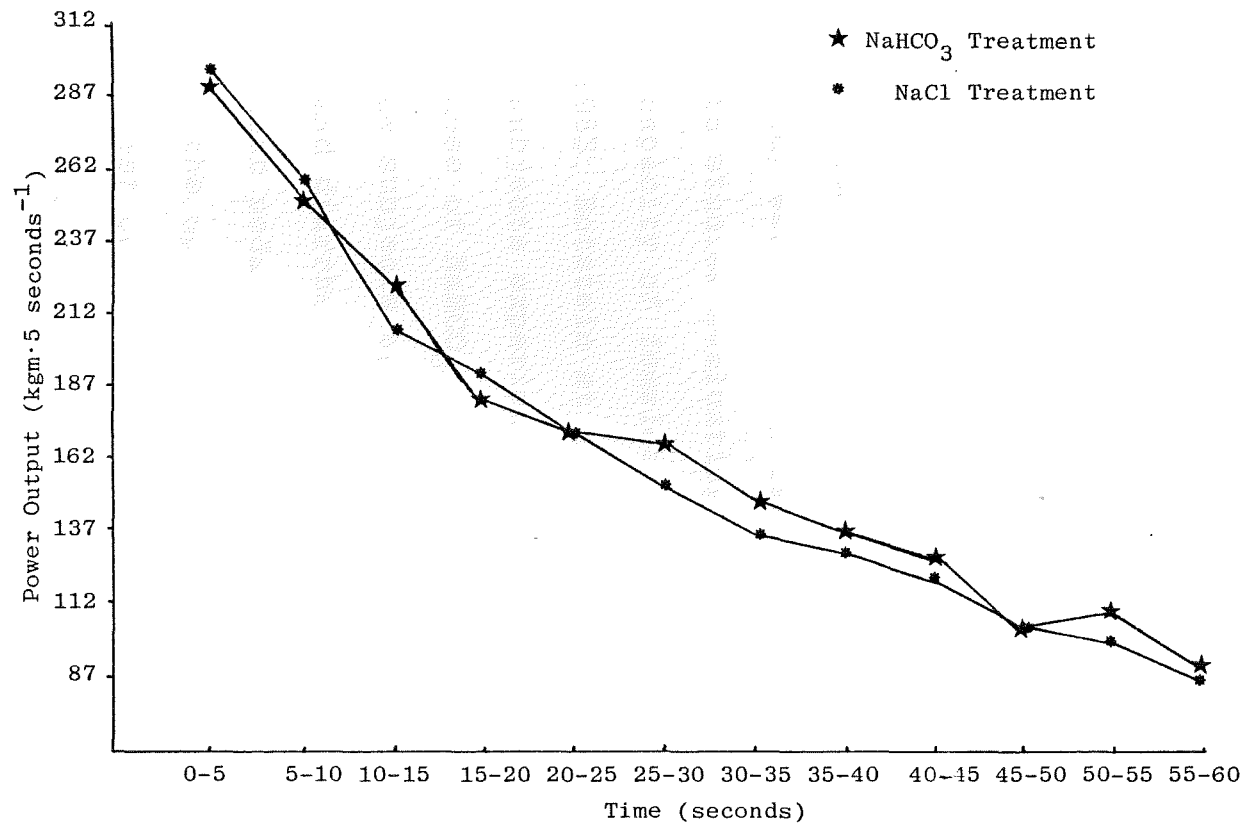


Figure 2. Five-second-by-five-second mean power output values up to 60 seconds of the exhaustion tests (N=8).

data can be found in Table 6.

## Discussion

### Subjects

The mean values for the physical characteristics of the subjects in the present study were similar to the mean values obtained in other studies involving females at the University of Wisconsin-LaCrosse (Milburn & Butts, 1983; Wilkinson, 1981). The mean values for the subjects in this study were also similar to the mean values obtained in studies evaluating short-duration maximal exercise capacity of females (Jacobs et al., 1982; Jacobs et al., 1983; Rotstein et al., 1982).

The subjects experienced no problems ingesting the required dose of  $\text{NaHCO}_3$ . However, following the tests, some of the subjects experienced minor acute gastrointestinal distress and diarrhea.

The mean pedal resistance for this study was slightly lower than the optimal pedal resistance for a maximal anaerobic test on a bicycle ergometer suggested by Katch, Weltman, Martin, and Gray (1977). However, Katch et al. (1977) used heavier subjects ( $\bar{X}$ =74.6 kilograms) in their study and no mention was made of the subjects' sex. Also, an all-out pedalling frequency has been shown to produce more revolutions in 0-30 seconds and 0-60 seconds than

Table 6. Time to exhaustion (seconds) for the tests to exhaustion.

Subject	NaHCO <sub>3</sub> Treatment	NaCl Treatment
1	37	34
2	97	105
3	57	55
4	55	69
5	110	80
6	103	91
7	51	62
8	150	130
9	68	145
10	65	36
11	36	56
12	243	50
13	75	133
14	277	71
15	193	123
$\bar{X}$	107.8	82.7
S.D.	75.3	36.5

under a pacing plan (Katch, Weltman, & Traeger, 1976). Thus, the exercise test used in this study could be considered a maximal anaerobic test.

#### Power Output for 30 Second Tests

The result of the present study that  $\text{NaHCO}_3$  ingestion prior to exercise had no significant ( $p < .05$ ) effect on power output for the 30 second tests is in agreement with the work of McCartney et al. (1983) who reported small, non-significant differences in power output for a 30 second work test following  $\text{NaHCO}_3$ ,  $\text{NH}_4\text{Cl}$ ,  $\text{CaCO}_3$  ingestion, and  $\text{CO}_2$  inhalation in males. They felt that the most likely explanation for their results was that the alteration in blood acid-base balance had little influence on muscle pH.

The result of the present study is in contrast with the findings of many other investigators who reported that  $\text{NaHCO}_3$  improved performance (Costill et al., 1983; Jones et al., 1975, 1977; Rupp et al., 1983; Sutton et al., 1981). These investigators had their subjects exercise at various intensities prior to an endurance test. This subsequent exercise could have lowered muscle pH enough to affect performance by the mechanisms previously discussed in Chapter II of this paper. These mechanisms were related to the contraction process of the muscle and the inhibition of glycolysis. In the above studies,  $\text{NaHCO}_3$  ingestion improved performance by possibly delaying a further

reduction in muscle pH by promoting the efflux of lactate from the muscle.

Blood lactates were measured in the present study in conjunction with another project. Following 30 seconds of maximal bicycle exercise, mean blood lactate values for the  $\text{NaHCO}_3$  and  $\text{NaCl}$  treatment were 8.1 and 6.8  $\text{mmol}\cdot\text{L}^{-1}$  blood, respectively ( $p < .05$ ). This result suggested that  $\text{NaHCO}_3$  ingestion promoted the efflux of lactate across the muscle cell membrane. This finding is in contrast with the work of McCartney et al. (1983) who reported no significant difference in blood lactate values with  $\text{NaHCO}_3$  ingestion when compared to the control following 30 seconds of maximal bicycle exercise. The reason for the difference between McCartney et al. (1983) and the present study is not clear. It may be related to the larger number subjects used in the present study or differences in lactate analysis.

In summary, it appeared that  $\text{NaHCO}_3$  ingestion did not improve performance of the 30 second work test despite a significant difference between blood lactate values. A possible reason for this was that the alteration in blood acid-base balance (due to  $\text{NaHCO}_3$  ingestion) had little influence on muscle pH. The measurement of muscle pH and muscle lactate in this study could have provided additional information concerning this statement.

### Power Output for 60 Seconds of the Tests to Exhaustion

The result of the present study that  $\text{NaHCO}_3$  ingestion prior to exercise had no significant ( $p < .05$ ) effect on power output for 60 seconds of the tests to exhaustion is in agreement with the work of other investigators who found no improvement in performance lasting approximately 60 seconds following induced alkalosis (Balberman & Roby, 1983; Kindermann et al., 1977; Margaria et al., 1970). Balberman and Roby (1983) found a slightly higher mean value for total work following  $\text{NaHCO}_3$  ingestion in males who performed 60 seconds of maximal isokinetic contractions of the quadriceps and hamstrings. This was not significant when compared to the control. These investigators also reported a higher mean blood lactate value with  $\text{NaHCO}_3$  ingestion, however, it was not considered significant when compared to the control. Blood lactate was not measured following 60 seconds of exercise in the present study.

Kindermann et al. (1977) showed no improvement in performance times for a 400 meter run following bicarbonate infusion. This event lasted approximately 60 seconds in their study. They also found similar mean blood lactate values between the infusion condition and control, which led them to conclude that the pH of the muscle was not the limiting factor in exercise of this duration.

Margaria et al. (1970) showed no improvement in the performance of a supramaximal treadmill run in males

following the ingestion of an alkali mixture. However, the dosage employed in their study was less than half the dosage used in the present study. The dosage used in the present study was the same used by Costill et al. (1983), who showed an improvement in performance with  $\text{NaHCO}_3$  ingestion.

The result of the present study is in contrast with the findings of many other investigators who reported that  $\text{NaHCO}_3$  improved performance (Costill et al., 1983; Jones et al., 1975, 1977; Rupp et al., 1983; Sutton et al., 1981). The reason for the differences between these studies and the present study may be that the alteration in blood acid-base balance had little influence on muscle pH in the present study.

Wilkes et al. (1983) showed that  $\text{NaHCO}_3$  ingestion improved performance times in a 800 meter run. This event lasted approximately two minutes in their study. This is in contrast to the present study which showed no improvement in performance for maximal exercise lasting 60 seconds. Based on these results, it may be of value in future studies to measure muscle pH to determine if there is a critical pH level at which performance is impaired and if  $\text{NaHCO}_3$  ingestion could help maintain the muscle pH within non-critical levels.

In summary, it appeared that  $\text{NaHCO}_3$  ingestion did not improve performance for 60 seconds of the tests to exhaustion. A possible reason for this may be that the

pH of the muscle was not the decisive limiting factor in maximal exercise of this duration. Thus, the alteration in blood acid-base balance would have had little influence on muscle pH.

### Time to Exhaustion

The result of the present study that  $\text{NaHCO}_3$  ingestion prior to exercise had no significant ( $p < .05$ ) effect on time to exhaustion is in contrast with the findings of many other investigators who reported that  $\text{NaHCO}_3$  increased time to exhaustion (Costill et al., 1983; Jones et al., 1975, 1977; Rupp et al., 1983; Sutton et al., 1981). However, the results of the present study should be regarded with discretion. Although the mean value for time to exhaustion appeared to be higher following  $\text{NaHCO}_3$  ingestion compared to NaCl (107.8 versus 82.7 seconds), the standard deviations were also much higher for the  $\text{NaHCO}_3$  treatment compared to NaCl, suggesting a larger variation in those scores. After careful scrutiny of the data, it appeared that a learning factor could have influenced the results even though practice sessions were required prior to data collection. The subjects were interviewed following the study to see if they felt that there was a learning factor. The subjects that performed longer on the second exhaustion test, whether they were given  $\text{NaHCO}_3$  or NaCl, felt that they may have stopped too early on the first test (see Appendix F for

discussion on the use of the Wingate Test for short-duration maximal exercise).

### Summary

Based on the data obtained in this study, it was concluded that  $\text{NaHCO}_3$  ingestion prior to exercise had no significant ( $p < .05$ ) effect on power output for 30 and 60 seconds of maximal exercise. One reason for this may be that the alteration in blood acid-base balance (due to  $\text{NaHCO}_3$  ingestion) had little influence on muscle pH. Another reason may be that the pH of the muscle was not the decisive limiting factor in maximal exercise of this duration.

It was also found that  $\text{NaHCO}_3$  ingestion prior to exercise had no significant ( $p < .05$ ) effect on time to exhaustion. However, this data must be regarded with discretion, because it appeared that a learning factor was involved when working to exhaustion.

## CHAPTER V

### SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

#### Summary

The purpose of this investigation was to ascertain whether the ingestion of  $\text{NaHCO}_3$  enhanced performance during short-duration maximal exercise of trained females. The subjects in the investigation were 15 trained female volunteers from the University of Wisconsin-LaCrosse.

After two practice sessions, each subject participated in four trials on a Monark bicycle ergometer. Two trials involved a work test of 30 seconds duration, 60 minutes after ingesting a drink containing either  $.2\text{g}\cdot\text{kg}^{-1}$  body weight of  $\text{NaHCO}_3$  or 5 grams of  $\text{NaCl}$ . The other two trials involved a work test to exhaustion 60 minutes after ingesting either  $\text{NaHCO}_3$  or  $\text{NaCl}$ .

The number of pedal revolutions were counted during each test and from this the following indices were derived; power output ( $\text{kgm}\cdot 30 \text{ seconds}^{-1}$ ) for the 30 second tests, power output for 60 seconds ( $\text{kgm}\cdot 60 \text{ seconds}^{-1}$ ) of the tests to exhaustion; and, power output for each five-second interval ( $\text{kgm}\cdot 5 \text{ seconds}^{-1}$ ) of the 30 second tests and up to 60 seconds of the tests to exhaustion. Time to exhaustion

was also recorded.

Dependent "t" tests were used to analyze the effect of  $\text{NaHCO}_3$  and  $\text{NaCl}$  ingestion on power output for the 30 second tests, power output for 60 seconds of the tests to exhaustion and time to exhaustion. An analysis of variance was used to analyze the effect of  $\text{NaHCO}_3$  and  $\text{NaCl}$  ingestion on the power output for each five-second interval of the 30 second tests and up to 60 seconds of the tests to exhaustion.

### Conclusions

Within the limitations of this study and based on the statistical analysis of the data, the following conclusion was made: the null hypothesis, stating that the ingestion of sodium bicarbonate will have no significant effect upon the performance of short-duration maximal exercise of trained females, was accepted. These additional conclusions were also made:

1) There was no significant ( $p < .05$ ) difference between mean power outputs ( $\text{kgm} \cdot 30 \text{ seconds}^{-1}$ ) for the 30 second tests following  $\text{NaHCO}_3$  or  $\text{NaCl}$  ingestion.

2) There was no significant ( $p < .05$ ) difference between mean power outputs ( $\text{kgm} \cdot 60 \text{ seconds}^{-1}$ ) for 60 seconds of the tests to exhaustion following  $\text{NaHCO}_3$  or  $\text{NaCl}$  ingestion.

3) There was no significant ( $p < .05$ ) difference between mean times to exhaustion for the tests to exhaustion

following  $\text{NaHCO}_3$  or  $\text{NaCl}$  ingestion.

4) There was no significant ( $p < .05$ ) difference between conditions for each five-second interval ( $\text{kgm} \cdot 5 \text{ seconds}^{-1}$ ) of the 30 second tests.

5) There was no significant ( $p < .05$ ) difference between conditions for each five-second interval ( $\text{kgm} \cdot 5 \text{ seconds}^{-1}$ ) up to 60 seconds of the tests to exhaustion.

6) A possible reason for the result that  $\text{NaHCO}_3$  ingestion did not improve the performance of short-duration maximal exercise in this study may be that the alteration in blood acid-base balance (due to  $\text{NaHCO}_3$  ingestion) had little influence on muscle pH.

7) Another possible reason for the result that  $\text{NaHCO}_3$  ingestion did not improve the performance of short-duration maximal exercise in this study may be that the pH of the muscle was not the decisive limiting factor in maximal exercise of 30 or 60 seconds duration.

8) The ingestion of  $\text{NaHCO}_3$  prior to maximal exercise of 30 or 60 seconds duration had no ergogenic benefit in trained females.

#### Recommendations for Further Study

It is recommended that the following factors be incorporated in future studies: an aerobically trained male population; anaerobically trained subjects, male and female; untrained subjects, male and female; muscle and

blood lactate measurements; muscle and blood pH measurements; standard bicarbonate concentration and base excess measurements in the blood.

It may be difficult to apply the results from the present study to other activities that last from zero to 60 seconds. Thus, it is further recommended that additional studies, which involve the effect of  $\text{NaHCO}_3$  ingestion on short-duration exercise, incorporate the specific event in the study to which the results can be applied.

## REFERENCES CITED

- American College of Sports Medicine. The recommended quantity and quality of exercise for developing and maintaining fitness in healthy adults. Medicine and Science in Sports, 1978, 10(3), vii-x.
- Astrand, I. Aerobic work capacity in men and women with specific reference to age. Acta Physiologica Scandinavica, 1960, Supplement 49, 1-92.
- Astrand, P.O., Hallback, I., Hedman, R., & Saltin, B. Blood lactates after prolonged severe exercise. Journal of Applied Physiology, 1963, 18(3), 619-622.
- Astrand, P.O., & Rodahl, K. Textbook of Work Physiology. New York: McGraw-Hill, 1977.
- Ayalon, A., Inbar, O., & Bar-Or, O. Relationships among measurements of explosive strength and anaerobic power. In R.C. Nelson & C.A. Morehouse (Eds.), International Series on Sport Sciences (Vol. 1). Baltimore: University Press, 1974.
- Balberman, S.E., & Roby, F.B. The effects of induced alkalosis and acidosis on the work capacity of the quadriceps and hamstrings muscle groups. International Journal of Sports Medicine, 1983, 2(4), 143. (Abstract)
- Bosco, C., Luhtanen, P., & Komi, P.V. A simple method for measurement of mechanical power in jumping. European Journal of Applied Physiology, 1983, 50, 273-282.
- Costill, D.L., Barnett, A., Sharp, R., Fink, W.J., & Katz, A. Leg muscle pH following sprint running. Medicine and Science in Sports and Exercise, 1983, 15(4), 325-329.
- Costill, D.L., Verstappen, F., Kuipers, H., Jansson, E., & Fink, W.J. Acid-base balance during repeated bouts of exercise: Influence of  $\text{HCO}_3^-$ . Medicine and Science in Sports and Exercise, 1983, 15(3), 115. (Abstract)
- Cunningham, D.A., & Faulkner, J.A. The effect of training on aerobic and anaerobic metabolism during a short exhaustive run. Medicine and Science in Sports, 1969, 1(2), 65-69.

- Dennig, H., Talbot, J.H., Edwards, H.T., & Dill, D.B. Effect of acidosis and alkalosis upon capacity for work. Journal of Clinical Investigation, 1931, 9, 601-613.
- Fink, W.J. Personal communication, 1983.
- Fox, E., & Mathews, D. The physiological basis of physical education and athletics (3rd ed.). Philadelphia: Saunders, 1981.
- Fujitsuka, N., Yamamoto, T., Ohkuwa, T., Saita, M., & Miyamura, M. Peak blood lactate after short periods of maximal treadmill running. European Journal of Applied Physiology, 1982, 48, 289-296.
- Gollnick, P.D., & Hermansen, L. Biochemical adaptations to exercise: Anaerobic metabolism. In J. Wilmore (Ed.), Exercise and Sport Sciences Reviews (Vol. 1). New York: Academic Press, 1973.
- Hagerman, F., Fox, E., Connors, M., & Pompei, J. Metabolic responses of women rowers during ergometric rowing. Medicine and Science in Sports, 1974, 6(1), 87. (Abstract)
- Hermansen, L., & Osnes, J.B. Blood and muscle pH after maximal exercise in man. Journal of Applied Physiology, 1972, 32(3), 304-308.
- Hirche, H., Hombach, V., Langhor, H.D., Wacker, U., & Busse, J. Lactic acid permeation rate in working gastrocnemii of dogs during metabolic alkalosis and acidosis. Pflugers Archives, 1975, 356, 209-222.
- Hultman, E., & Sahlin, K. Acid-base balance during exercise. In R.S. Hutton & D.I. Miller (Eds.), Exercise and Sport Science Reviews (Vol. 8). Philadelphia: The Franklin Institute Press, 1980.
- Inbar, O., Dotan, R., & Bar-Or, O. Aerobic and anaerobic components of a 30sec supramaximal cycling test. Medicine and Science in Sports, 1976, 8, 51. (Abstract)
- Inbar, O., Kaiser, P., & Tesch, P. Relationships between leg muscle fiber type distribution and leg exercise performance. International Journal of Sports Medicine, 1981, 2, 154-159.

- Jacobs, I. The effects of thermal dehydration on performance of the Wingate Anaerobic Test. International Journal of Sports Medicine, 1980, 1, 21-24.
- Jacobs, I. Lactate concentrations after short, maximal exercise at various glycogen levels. Acta Physiologica Scandinavica, 1981, 111, 465-469.
- Jacobs, I., Bar-Or, O., Karlsson, J., Dotan, R., Tesch, P., Kaiser, P., & Inbar, O. Changes in muscle metabolites in females with 30s exhaustive exercise. Medicine and Science in Sports and Exercise, 1982, 14(6), 457-460.
- Jacobs, I., Tesch, P.A., Bar-Or, O., Karlsson, J., & Dotan, R. Lactate in human skeletal muscle after 10 and 30s of supramaximal exercise. Journal of Applied Physiology: Respiratory, Environmental, Exercise Physiology, 1983, 55(2), 365-367.
- Johnson, W.R., & Black, D.H. Comparison of effects of certain blood alkalinizers and glucose upon competitive endurance performance. Journal of Applied Physiology, 1953, 5, 577-578.
- Jones, N.L., & Ehrsam, R.E. The anaerobic threshold. In R.L. Terjung (Ed.), Exercise and Sport Sciences Reviews (Vol. 10). Philadelphia: The Franklin Institute Press, 1982.
- Jones, N.L., Sutton, J.R., Taylor, R., & Toews, C.J. Effect of acidosis and alkalosis on exercise performance and metabolism. Federations Proceedings, 1975, 34, 444.
- Jones, N.L., Sutton, J.R., Taylor, R., & Toews, C.J. Effect of pH on cardiorespiratory and metabolic response to exercise. Journal of Applied Physiology, 1977, 43(6), 959-964.
- Jorfeldt, L., Juhlin-Dannfelt, A., & Karlsson, J. Lactate release in relation to tissue lactate in human skeletal muscle during exercise. Journal of Applied Physiology: Respiratory, Environmental, Exercise Physiology, 1978, 44(3), 350-352.
- Kaiser, P., Rossner, S., & Karlsson, J. Effects of B-adrenergic blockade on endurance and short-time performance in respect to individual muscle fiber composition. International Journal of Sports Medicine, 1981, 2(1), 37-42.

- Karlsson, J. Lactate and phosphagen concentrations in working muscle in man. Acta Physiologica Scandinavica, 1971, Supplement 358, 1-72.
- Karlsson, J. Localized muscular fatigue: Role of muscle metabolism and substrate depletion. In R.S. Hutton & D.I. Miller (Eds.), Exercise and Sport Science Reviews (Vol. 7). Philadelphia: The Franklin Institute Press, 1979.
- Karlsson, J., & Jacobs, I. Onset of blood lactate accumulation during muscular exercise as a threshold concept: 1. Theoretical considerations. International Journal of Sports Medicine, 1982, 3, 190-201.
- Katch, V., Weltman, A., & Traeger, L. All-out versus a steady paced cycling strategy for maximal work output of short duration. Research Quarterly, 1976, 47(2), 164-168.
- Katch, V., Weltman, A., Martin, R., & Gray, L. Optimal test characteristics for maximal anaerobic work on the bicycle ergometer. Research Quarterly, 1977, 48(2), 319-327.
- Kindermann, W., Keul, J., & Huber, G. Physical exercise after induced alkalosis (bicarbonate or tris buffer). European Journal of Applied Physiology, 1977, 37, 197-204.
- Komi, P.V., & Karlsson, J. Skeletal muscle fiber types, enzyme activities and physical performance in young males and females. Acta Physiologica Scandinavica, 1978, 103, 210-218.
- Komi, P., & Karlsson, J. Physical performance, skeletal muscle enzyme activities, and fibre types in monozygous and dizygous twins of both sexes. Acta Physiologica Scandinavica, Supplement 462, 1979, 1-28.
- Mainwood, G.W., Worsley-Brown, P., & Paterson, R.A. The metabolic changes in frog sartorius muscles during recovery from fatigue at different external bicarbonate concentrations. Canadian Journal of Physiology and Pharmacology, 1972, 50, 143-155.

- Margaria, R., Aghemo, P., & Sassi, G. Effect of alkalosis on performance and lactate formation in supramaximal exercise. Internationale Zeitschrift fur Angewandte Physiologie Einschliesslich Arbeitsphysiologie, 1971, 29, 215-223.
- Margaria, R., Cerretelli, P., & Mangili, F. Balance and kinetics of anaerobic energy release during strenuous exercise in man. Journal of Applied Physiology, 1964, 19(4), 623-628.
- McCartney, N., Heigenhauser, G.J.F., & Jones, N.L. Effects of pH on maxiaml power output and fatigue during short-term dynamic exercise. Journal of Applied Physiology: Respiratory, Environmental, Exercise Physiology, 1983, 55(1), 225-229.
- Milburn, S., & Butts, N.K. A comparison of the training responses to aerobic dance and jogging in college females. Medicine and Science in Sports and Exercise, 1983, 15(6), 510-513.
- Nygaard, E. Skeletal muscle fibre characteristics in young women. Acta Physiologica Scandinavica, 1981, 112, 299-304.
- Osnes, J.B., & Hermansen, L. Acid-base balance after maximal exercise of short duration. Journal of Applied Physiology, 1972, 32(1), 59-63.
- Poulus, A.J., Docter, H.J., & Westra, H.G. Acid-base balance and subjective feelings of fatigue during physical exercise. European Journal of Applied Physiology, 1974, 33, 207-213.
- Rotstein, A., Bar-Or, O., & Dlin, R. Hemoglobin, hematocrit, and calculated plasma volume changes induced by a short, supramaximal task. International Journal of Sports Medicine, 1982, 3(4), 230-233.
- Rupp, J.C., Bartels, R.L., Zuelzer, W., & Fox, E.L. Effect of sodium bicarbonate ingestion on blood and muscle pH and exercise performance. Medicine and Science in Sports and Exercise, 1983, 15(3), 115. (Abstract)

- Sahlin, K., Alverstrand, A., Brandt, R., & Hultman, E. Acid-base balance in blood during exhaustive bicycle and the following recovery period. Acta Physiologica Scandinavica, 1978, 104, 370-372.
- Sahlin, K., Harris, R.C., Nylind, B., & Hultman, E. Lactate content and pH in muscle samples obtained after dynamic exercise. Pflugers Archives: European Journal of Physiology, 1976, 367, 143-149.
- Sutton, J.R., Jones, N.L., & Toews, C.J. Effect of pH on muscle glycoysis during exercise. Clinical Science, 1981, 61, 331-338.
- Tesch, P. Local lactate and exhaustion. Acta Physiologica Scandinavica, 1978, 104, 373-374.
- Tesch, P., Sjodin, B., & Karlsson, J. Relationship between lactate accumulation, LDH isoenzyme and fibre type distribution in human skeletal muscle. Acta Physiologica Scandinavica, 1978, 103, 40-46.
- Wilkes, D., Gledhill, N., & Smyth, R. Effect on acute induced metabolic alkalosis on 800-m racing time. Medicine and Science in Sports and Exercise, 1983, 15(4), 277-280.
- Wilkinson, C.L. The effect of arm training versus leg training on maximal oxygen uptake and cardiac output in females. Unpublished masters thesis, University of Wisconsin-LaCrosse, 1981.

APPENDIX A

Activity Questionnaire

Activity Questionnaire

Name \_\_\_\_\_

Date \_\_\_\_\_

Height \_\_\_\_\_

Weight \_\_\_\_\_

Age \_\_\_\_\_

Telephone \_\_\_\_\_

1. Are you presently engaged in some form of regular exercise or activity?(3 times per week) \_\_\_\_\_
2. If yes, have you engaged in it regularly for the last 3 weeks? \_\_\_\_\_
3. Were you active in the last 3 months?(prior to the last 3 weeks) \_\_\_\_\_
4. How frequently and how intensely do you engage in the following activities?

Intensity

Strenuous	60% of max HRR	(max HR=220-age)
		(max HRR=max HR-RHR)
Moderate	50-60% max HRR	(THR=max HRR x ?% + RHR)
Light	0-50% max HRR	

<u>Activity</u>	<u>days/week</u>	<u>min./session</u>	<u>intensity</u>
aerobic dance	_____	_____	_____
basketball	_____	_____	_____
bicycling(outdoor)	_____	_____	_____
bicycling(stationary)	_____	_____	_____
bowling	_____	_____	_____
calisthenics	_____	_____	_____
x-country skiing	_____	_____	_____
down-hill skiing	_____	_____	_____
golf	_____	_____	_____

<u>Activity</u>	<u>days/week</u>	<u>min./session</u>	<u>intensity</u>
gymnastics	_____	_____	_____
handball	_____	_____	_____
hiking	_____	_____	_____
ice skating	_____	_____	_____
jogging	_____	_____	_____
racketball	_____	_____	_____
rebounding	_____	_____	_____
rollerskating	_____	_____	_____
rowing	_____	_____	_____
running	_____	_____	_____
snowshoeing	_____	_____	_____
softball	_____	_____	_____
swimming	_____	_____	_____
squash	_____	_____	_____
tennis	_____	_____	_____
volleyball	_____	_____	_____
walking	_____	_____	_____
weightlifting	_____	_____	_____
other	_____	_____	_____

Have you had a max  $\dot{V}O_2$  test? \_\_\_\_\_ when? \_\_\_\_\_

Was it done on the treadmill or bicycle? \_\_\_\_\_

What was your value? \_\_\_\_\_  $\text{ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$

Are you presently lifting weights? \_\_\_\_\_ How often? \_\_\_\_\_

APPENDIX B

Informed Consent Form

## INFORMED CONSENT FOR SODIUM BICARBONATE STUDY

I, \_\_\_\_\_, being of sound mind and \_\_\_\_\_ years of age, volunteer to be a subject in a study to determine the effects of sodium bicarbonate on power output and blood lactate levels during short-duration maximal exercise. I understand participation in this project will require that I ingest either sodium bicarbonate (baking soda), or sodium chloride (table salt) prior to riding on a bicycle ergometer for a specified period of time.

I will be asked to participate in four trials on a Monark bicycle ergometer. Two trials will involve a work test of 30 seconds following ingestion of either sodium bicarbonate or sodium chloride. Two trials will involve a work test to exhaustion following ingestion of either sodium bicarbonate or sodium chloride. The workload on the bicycle will be determined based on my body weight. I will then pedal at an all-out rate for the required time.

One hour prior to each ride I will be required to consume either  $.2\text{g}\cdot\text{kg}^{-1}$  body weight of sodium bicarbonate or 5 grams of sodium chloride dissolved in a drink with 18 ounces of water. I will not be informed which drink I have consumed. I will then exercise maximally at my individually calculated workload. Prior to this exercise I agree to abstain from food, drink, and aspirin at least 8 hours and will attempt to keep my diet the same for the 72 hours between tests.

I also understand that preceeding and following each bicycle test I will have 4ml of blood drawn from the antecubital vein in my arm. The area will be sterilized with alcohol preceeding the draw and the blood will be drawn by a trained phlebotomist. Since there are 4 bicycle tests, a total of 8 draws will be taken. This blood will be analyzed for lactate content.

As with any exercise, there exists the possibility of adverse changes occurring (staggering, difficulty in breathing, dizziness, etc.) during the tests. In addition, I will feel tired at the end of the exercises. If any abnormal observations are noted the test will be immediately terminated. Also, the dosage of sodium bicarbonate has been determined to be well within safe levels, however, there may exist the possibility of some slight gastric discomfort immediately following the exercise.

The tests will be conducted by Doug Crowell and Ellen Brewster. These individuals are graduate students in the Adult Fitness-Cardiac Rehabilitation graduate program at UW-LaCrosse, and will be under the supervision of N.K. Butts, Ph.D., Professor of Physical Education.

I consider myself to be in good health and to my knowledge I am not infected with a contagious disease or have any limiting physical condition or disability, especially with respect to my heart, that would preclude my participation in the tests described.

I have read and I understand the above document and understand the procedure. Any questions which may have occurred to me have been answered to my satisfaction. I have been fully advised of the nature, the possible risks, and complications involved in it, all of which risks and complications I hereby assume voluntarily.

I hereby acknowledge that no representations, warranties, guarantees or assurances of any kind pertaining to this project have been made to me by the University of Wisconsin-LaCrosse, the officers, administration, employees or by anyone on behalf of any of them.

I understand that I may withdraw from the study at any time.

Signed \_\_\_\_\_ this \_\_\_\_\_ day of \_\_\_\_\_, 19\_\_\_\_, in the presence of the witnesses whose signatures appear opposite my signature.

\_\_\_\_\_  
(subject)

Witnessed by:

\_\_\_\_\_  
\_\_\_\_\_

APPENDIX C

Data Collection Form

NAME: \_\_\_\_\_ AGE: \_\_\_ yrs. HT. \_\_\_ in. \_\_\_ cm. WT. \_\_\_ lbs. \_\_\_ kg. POST ABSORP. \_\_\_ hrs.

SEAT HEIGHT: \_\_\_ holes EXERCISE ACTIVITY: \_\_\_\_\_ MALE: \_\_\_ FEMALE: \_\_\_

WORKLOAD: \_\_\_ kp. DOSAGE: NaHCO<sub>3</sub> \_\_\_ gms. NaCl \_\_\_ gms.

	rev.	at:	5 sec.	10	15	20	25	30	35	40	45	50	55	60	TOTAL REV.
TRIAL 1			65	70	75	80	85	90	95	100	105	110	115	120	_____

LACTATE VALUES: pre-ex. \_\_\_ post-ex. \_\_\_

TRIAL 2

LACTATE VALUES: pre-ex. \_\_\_ post-ex. \_\_\_

TRIAL 3

LACTATE VALUES: pre-ex. \_\_\_ post-ex. \_\_\_

TRIAL 4

LACTATE VALUES: pre-ex. \_\_\_ post-ex. \_\_\_

TREATMENT: TRIAL 1: NaHCO<sub>3</sub> or NaCl (circle one) 2: NaHCO<sub>3</sub> or NaCl 3: NaHCO<sub>3</sub> or NaCl

4: NaHCO<sub>3</sub> or NaCl

APPENDIX D

Physical Characteristics of Subjects

## Physical Characteristics of Subjects

Subject	Age(yrs.)	Height(cm.)	Weight(kg.)
1	32	163.8	59.1
2	24	170.8	63.6
3	21	180.9	69.5
4	20	170.2	60.9
5	27	160.0	58.9
6	22	162.6	63.1
7	20	170.8	68.0
8	20	165.7	64.2
9	21	163.2	55.5
10	28	167.6	59.1
11	24	171.4	64.8
12	25	167.6	57.3
13	22	165.7	66.8
14	29	165.7	56.6
15	27	155.6	51.8
$\bar{X}$	24.1	166.8	61.3
S.D.	3.8	5.9	5.0

APPENDIX E

Dosage and Pedal Resistance for Subjects

## Dosage and Pedal Resistance for Subjects

Subject	Dosage(gms.)	Resistance(kp.)
1	11.8	4.4
2	12.7	4.8
3	13.9	5.2
4	12.2	4.6
5	11.8	4.4
6	12.6	4.7
7	13.6	5.1
8	12.8	4.8
9	11.1	4.2
10	11.8	4.4
11	13.0	4.9
12	11.5	4.3
13	13.4	5.0
14	11.3	4.3
15	10.4	3.9
$\bar{X}$	12.3	4.6
S.D.	1.0	.37

APPENDIX F

The Use of the Wingate Test for Short-Duration Maximal Exercise

... pedalling ... in the ... for ... through ... have occurred ... which the ... 60 ... (Bosco et ... basketball players ... successfully. ... is the present ... subjects reached 60 seconds ... to exhaustion. The reason for ... Jacobs et al. (1983) used ... which involved both ... that males generally ... pond test, although ... their output been ... measurements were ... study. ... may have ... eight of ... subject ... reached 60 ... during ... Leg

The Use of the Wingate Test for Short-  
Duration Maximal Exercise

The Wingate Test has consisted of all-out pedalling for 30 seconds against a specified resistance. In the present study, this test was extended to exhaustion for two trials in order that the subjects would give an all-out performance through 60 seconds and minimize any pacing that might have occurred. However, only one study was found in which the Wingate Test had been extended to 60 seconds (Bosco et al., 1983). This was done with male basketball players. All of them completed the test successfully.

In the present study, only eight of the 15 female subjects reached 60 seconds both times during the tests to exhaustion. The reason for this was not clear.

Jacobs et al. (1983) used the 30 second test in a study which involved both male and female subjects. They found that males generated more power than females in the 30 second test, although this may not have been the case had power output been expressed relative to leg mass. Leg mass measurements were not performed in all the subjects in their study.

Leg mass may have been one reason that only eight of the 15 female subjects in the present study reached 60 seconds both times during the tests to exhaustion. Leg

mass may also have been one reason for the large variation in the time to exhaustion scores in the present study. There may have been other factors that influenced the results of the present study.

Inbar et al. (1981) have shown a significant positive correlation between the percent of fast-twitch muscle fibers and power decrease of the 30 second Wingate Test for males. Fast-twitch muscle fibers are known to have a high anaerobic capacity, which is useful in sprint-like activities (Karlsson, 1979).

Komi and Karlsson (1978) reported a positive correlation between the distribution of fast-twitch fibers and sprint capacity for males, but not for females. In a later study (1979), these same authors suggested that female skeletal muscle may not possess as high a glycolytic potential as male muscle.

The variability in performance of the females in the present study may have been due to the combination of a smaller leg mass, a lower distribution of fast-twitch fibers, and a lower glycolytic potential. The measurement of leg mass and the distribution and potential of muscle fiber types should be included in future studies involving work tests similar to the one in the present study.

Because of the variability in performance of the subjects in the tests to exhaustion, a test-retest reliability

was done on a group of males and females not involved in the present study. The group consisted of three males and three females (N=6). They were asked to pedal to exhaustion twice against a resistance of  $.075 \text{ kg} \times \text{kg}$  body weight. They were told not to pace themselves and to continue until they were at exhaustion. This was the same protocol used in the present study. A period of 72 hours existed between the two tests and two practice sessions were done using the same protocol as in the present study.

Correlations of 0.97, 0.97, and 0.74 were found for power output values of 30 seconds, power output values at 60 seconds and time to exhaustion, respectively. The 30 and 60 second values were significant ( $p < .05$ ) but the time to exhaustion was not. Five of these subjects reached 60 seconds both times and one of the females did not reach 60 seconds both times.

The high correlation ( $r = .97$ ) found for 30 seconds is supported by the work of Ayalon et al. (1974), who found a correlation of 0.91 for the test-retest reliability for the 30 second Wingate Test. The correlation of 0.97 did support its usage in the present study and the data obtained from it.

No data could be found on test-retest reliability for 60 seconds and time to exhaustion. Only one study was found that extended the Wingate Test to 60 seconds (Bosco et al.,

1983) and they did not report any test-retest reliability data. However, a correlation of 0.97 did support the extension of the Wingate Test to 60 seconds in the present study and the data obtained from it. The correlation of 0.74 obtained for time to exhaustion did not support the extension of the Wingate Test to exhaustion in the present study and the data obtained from it must be considered unreliable.

As a point of interest, the practice sessions that were done for each subject prior to the present study did not involve pedalling to exhaustion. This researcher asked six of the original subjects to participate in two more tests to exhaustion following the study. This was done to observe if a learning factor had existed in the study. A correlation of 0.99 ( $p < .05$ ) was found for a test-retest reliability for time to exhaustion with these six subjects. Thus, if the practice sessions in the present study involved the subjects to pedal to exhaustion, the learning factor that appeared might have been eliminated.