Effects of a preexercise glucose ingestion upon exhaustive intermittent exercise
by Kirk Douglas Keller

A thesis submitted in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE
in Physical Education
Montana State University
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Abstract:
The purpose of this study was to determine the effects of an ingested glucose solution upon exhaustive
intermittent exercise ' performance using exercise duration, blood lactate concentration, and blood
glucose as measured parameters. Five male college athletes, all trained distance runners, served as the
sample.

Subjects exercised to exhaustion on a bicycle ergometer at a resistance of approximately 85 percent
VO2 max with intermittent work and rest intervals, two to one minutes respectively, on two separate
test trials separated by several days. Subjects reported to the laboratory three to four hours
postabsorptive of the breakfast meal, and received either the glucose solution (experimental ride, ER),
(10 ounces, 100 g of glucose, commercial product, Glucola, diluted with two ounces of H2O), or
placebo (control ride, CR), (12 ounces, sugar free, caffeine free, commercial product Craigmont Diet
Cola).

Both drinks were served cold and decarbonated.

Blood samples were drawn fifty minutes following ingestion of either solution and at five minutes post
exercise. The first blood sample (PBG) measured blood glucose preexercise and the second
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A warmup period of five minutes exercise at fifty percent VO2 max (70 rpm) followed by a three to
four minute rest preceeded the intermittent exercise. Excerise was terminated when the subject failed to
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A standardized sequence of testing was followed for each test. Guidelines concerning training and diet
were given and followed by each subject prior to both tests. Training the two days prior to testing was
low intensity and short duration. A balanced meal high in carbohydrate was recommended for dinner
and a breakfast consisting primarily of carbohydrate was prescribed.

The ER compared to the CR produced a 35 percent decrease in total work time. The PBG values were
above normal, following ingestion of the glucose solution. Blood glucose values decreased during the
experimental ride and increased during the control ride. The blood lactate ER was higher than CR
despite a 35 percent shorter duration at the same intensity. The RPE of the ER reached a peak value
similar to the CR, however, the peak was maintained longer during the CR.
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Date: July 29, 1982
EFFECTS OF A PREEXERCISE GLUCOSE INGESTION
UPON EXHAUSTIVE INTERMITTENT EXERCISE

by
KIRK DOUGLAS KELLER

A thesis submitted in partial fulfillment of the requirements for the degree of
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in
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TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Chapter</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>VITA.</td>
<td>ii</td>
</tr>
<tr>
<td>ACKNOWLEDGEMENTS</td>
<td>iii</td>
</tr>
<tr>
<td>TABLE OF CONTENTS</td>
<td>iv</td>
</tr>
<tr>
<td>LIST OF TABLES</td>
<td>vi</td>
</tr>
<tr>
<td>LIST OF FIGURES</td>
<td>vii</td>
</tr>
<tr>
<td>ABSTRACT.</td>
<td>viii</td>
</tr>
<tr>
<td>1 THE PROBLEM</td>
<td>1</td>
</tr>
<tr>
<td>Statement of Problem</td>
<td>2</td>
</tr>
<tr>
<td>Specific Objectives</td>
<td>2</td>
</tr>
<tr>
<td>Delimitations</td>
<td>3</td>
</tr>
<tr>
<td>Limitations</td>
<td>3</td>
</tr>
<tr>
<td>Definitions</td>
<td>3</td>
</tr>
<tr>
<td>2 REVIEW OF RELATED LITERATURE</td>
<td>5</td>
</tr>
<tr>
<td>3 PROCEDURE</td>
<td>17</td>
</tr>
<tr>
<td>Research Method</td>
<td>17</td>
</tr>
<tr>
<td>Sample</td>
<td>17</td>
</tr>
<tr>
<td>Testing Battery</td>
<td>18</td>
</tr>
<tr>
<td>Testing Procedures</td>
<td>19</td>
</tr>
<tr>
<td>Maximal Oxygen Consumption</td>
<td>19</td>
</tr>
<tr>
<td>Body Composition</td>
<td>20</td>
</tr>
<tr>
<td>Blood Samples</td>
<td>20</td>
</tr>
<tr>
<td>Experimental and Control Tests</td>
<td>22</td>
</tr>
<tr>
<td>Exhaustive Exercise</td>
<td>23</td>
</tr>
<tr>
<td>Relative Perceived Exertion</td>
<td>23</td>
</tr>
<tr>
<td>Analysis of Data</td>
<td>23</td>
</tr>
<tr>
<td>4 RESULTS</td>
<td>24</td>
</tr>
<tr>
<td>Bicycle Ride to Exhaustion</td>
<td>24</td>
</tr>
<tr>
<td>Blood Samples</td>
<td>26</td>
</tr>
<tr>
<td>Relative Perceived Exertion</td>
<td>31</td>
</tr>
<tr>
<td>5 ANALYSIS OF DATA</td>
<td>36</td>
</tr>
<tr>
<td>Duration of Exercise</td>
<td>36</td>
</tr>
<tr>
<td>Blood Samples</td>
<td>37</td>
</tr>
<tr>
<td>Relative Perceived Exertion</td>
<td>39</td>
</tr>
<tr>
<td>6 SUMMARY, CONCLUSIONS AND RECOMMENDATION</td>
<td>40</td>
</tr>
<tr>
<td>Summary</td>
<td>40</td>
</tr>
</tbody>
</table>
Table of Contents, Continued

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conclusions</td>
<td>41</td>
</tr>
<tr>
<td>Recommendations</td>
<td>42</td>
</tr>
<tr>
<td>APPENDICES</td>
<td>43</td>
</tr>
<tr>
<td>Appendix A</td>
<td>44</td>
</tr>
<tr>
<td>Appendix B</td>
<td>46</td>
</tr>
<tr>
<td>Appendix C</td>
<td>48</td>
</tr>
<tr>
<td>Appendix D</td>
<td>50</td>
</tr>
<tr>
<td>BIBLIOGRAPHY</td>
<td>52</td>
</tr>
</tbody>
</table>
### LIST OF TABLES

<table>
<thead>
<tr>
<th>Table</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.1</td>
<td>18</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>3.1</th>
<th>Individual Physical Characteristics and Group Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Figure</td>
<td>Description</td>
</tr>
<tr>
<td>--------</td>
<td>-----------------------------------------------------------------------------</td>
</tr>
<tr>
<td>3.1</td>
<td>Blood Sample Time Schedule</td>
</tr>
<tr>
<td>4.1</td>
<td>Duration of Exercise for Control and Experimental Tests</td>
</tr>
<tr>
<td>4.2</td>
<td>Test Protocol for Blood Samples</td>
</tr>
<tr>
<td>4.3</td>
<td>Preexercise and Post-exercise Blood Glucose, Experimental Test (PBG&lt;sub&gt;E&lt;/sub&gt; and EBG&lt;sub&gt;E&lt;/sub&gt;)</td>
</tr>
<tr>
<td>4.4</td>
<td>Preexercise and Post-exercise Blood Glucose, Control Test (PBG and EBG)</td>
</tr>
<tr>
<td>4.5</td>
<td>Preexercise Blood Glucose, Control and Experimental Tests (PBG)</td>
</tr>
<tr>
<td>4.6</td>
<td>Post-exercise Blood Glucose, Control, Experimental Tests (EBG)</td>
</tr>
<tr>
<td>4.7</td>
<td>Post-exercise Lactic Acid, Control and Experimental Tests (ELA)</td>
</tr>
<tr>
<td>4.8</td>
<td>Relative Perceived Exertion Control and Experimental Ride Mean Comparison</td>
</tr>
</tbody>
</table>
ABSTRACT

The purpose of this study was to determine the effects of an ingested glucose solution upon exhaustive intermittent exercise performance using exercise duration, blood lactate concentration, and blood glucose as measured parameters. Five male college athletes, all trained distance runners, served as the sample.

Subjects exercised to exhaustion on a bicycle ergometer at a resistance of approximately 85 percent VO2 max with intermittent work and rest intervals, two to one minutes respectively, on two separate test trials separated by several days. Subjects reported to the laboratory three to four hours postabsorptive of the breakfast meal, and received either the glucose solution (experimental ride, ER), (10 ounces, 100 g of glucose, commercial product, Glucola, diluted with two ounces of H2O), or placebo (control ride, CR), (12 ounces, sugar free, caffeine free, commercial product Craigmont Diet Cola). Both drinks were served cold and decarbonated.

Blood samples were drawn fifty minutes following ingestion of either solution and at five minutes post exercise. The first blood sample (PBG) measured blood glucose preexercise and the second (EBG, ELA) measured blood glucose and lactic acid post exercise.

A warmup period of five minutes exercise at fifty percent VO2 max (70 rpm) followed by a three to four minute rest preceded the intermittent exercise. Exercise was terminated when the subject failed to maintain 70 rpm. The subject's relative perceived exertion (RPE) of each two minute work intervals was also recorded.

A standardized sequence of testing was followed for each test. Guidelines concerning training and diet were given and followed by each subject prior to both tests. Training the two days prior to testing was low intensity and short duration. A balanced meal high in carbohydrate was recommended for dinner and a breakfast consisting primarily of carbohydrate was prescribed.

The ER compared to the CR produced a 35 percent decrease in total work time. The PBG values were above normal, following ingestion of the glucose solution. Blood glucose values decreased during the experimental ride and increased during the control ride. The blood lactate ER was higher than CR despite a 35 percent shorter duration at the same intensity. The RPE of the ER reached a peak value similar to the CR, however, the peak was maintained longer during the CR.
Chapter 1

THE PROBLEM

Coaches and athletes are continually seeking and practicing measures to optimize performance. The additional one-half inch gained, or the decrease of a tenth of a second may result in the difference between a mediocre and champion performance. Efforts to gain this edge when competing include those aids practiced in addition to the training or workout regimen of the athlete. Attempts to optimize performance include various ergogenic aids: substances such as drugs, diet manipulation, and oxygen, and phenomena such as music, mental practice, biofeedback and hypnosis (21).

Many ergogenic aids are questioned from an ethical and/or legal aspect. Nutrition is an ergogenic aid that has not suffered moral or ethical restrictions. For that reason many coaches and researchers are experimenting with diet alterations. The clear objective of this is to provide the athlete with an optimal elevated source of fuel for his/her particular competitive event.

Recent experimental studies have compared the result of exercise duration and other physiological parameters following diets high in carbohydrates (8, 12, 22), fats (8), mixed meals balanced in carbohydrates (12), and water or fluid intake (12).

It has long been accepted that carbohydrates are a main fuel
source particularly in endurance events (12, 18). Elevation of stored carbohydrates known as muscle glycogen, has been proven to enhance performance (3, 18, 20). However, in an effort to ensure adequate energy for exercise, many athletes consume sugar prior to an athletic event. This dietary manipulation could have been initiated from fallacies relating to the physiological, metabolic, or energy requirements of physical activity and inadequate research. Studies conducted concerning the ingestion of carbohydrate before or during competition have reported mixed results (12, 22). This study will attempt to clarify earlier findings on the effects of consuming sugars prior to exercise.

Statement of Problem

The purpose of this study was to determine the effects of an ingested glucose solution upon exhaustive intermittent exercise (of a two to one ratio, exercise to rest) performance using exercise duration, blood lactate concentration, and blood glucose as measured parameters.

Specific Objectives

1. To measure each subject's duration of exercise to exhaustion during intermittent bicycle ergometer exercise (approximately 85 percent \( \dot{V}O_2 \) max, for two minutes exercise followed by one minute rest in a cross-over single-blind protocol with the ingestion of 100g of glucose solution sixty minutes prior to
exercise, the experimental variable).

2. To measure each subject's blood glucose levels prior to and after exhaustive exercise.
3. To measure each subject's blood lactic acid concentration five minutes after exhaustive exercise.

Delimitations
This study was delimited to a group of five selected distance runners attending Montana State University, 1981-82.

Limitations
1. The five subjects were all males.
2. Subjects were highly trained distance runners.
3. A bicycle ergometer provided the exercise load.
4. 100 g of glucose diluted in 12 ounces of fluid was the type and quantity of simple carbohydrate used.
5. A one hour time delay between ingestion and commencement of exercise.

Definitions
1. Carbohydrate. Class of foods including sugars and starches.
2. Bicycle Ergometer. A calibrated instrument used to administer a known reproducible exercise task.
3. Ergogenic Aid. A substance or phenomena which facilitates
4. **Exhaustion.** For the purpose of this study, exhaustion refers to that state of physical condition during intense work at which the subject is no longer able to continue at the same exercise intensity.

5. **Fatigue.** Condition of a muscle characterized by an inadequate oxygen supply, accumulation of lactic acid and/or glycogen depletion.

6. **Glucose.** A simple sugar which is monosaccharide.

7. **Glycogen.** Storage form of glucose in the liver and muscles.

8. **Insulin.** A hormone secreted by the pancreas whose function is regulation of blood glucose concentration.

9. **Intermittent Exercise.** Alternating periods of work and rest.

10. **Distance Runner.** For the purpose of this study, one training at fifty or more miles per week and competing at distances of 5,000 meters and longer.
Chapter 2

REVIEW OF RELATED LITERATURE

As long as world records are attempted and championships sought, efforts to gain an edge over other competitors will be practiced by many athletes. Efforts to gain that edge may include special diets, drug usage, psychic alterations and supplemental hormone intake. Substances or phenomena that improve performance above expectations are known as ergogenic aids (21).

Ergogenic aids that have been found to improve performance include caffeine, amphetamines, anabolic steroids, blood doping and nutrition supplements (26). Governing athletic bodies have taken measures to detect and restrict the use of most ergogenic aids, however diet alterations are relatively free of any restrictions and therefore are accepted and practiced.

One dietary practice that has gained wide acceptance as a result of studies conducted on endurance athletic performances is that of increasing carbohydrate intake prior to competition. It has long been recognized that carbohydrates are the main source of energy for intensive exercise (3, 14). Diet and training alterations have been shown to increase or decrease carbohydrate reserves known as glycogen (18). Elevation of muscle glycogen stores above normal can be achieved by first depleting existing glycogen stores in the muscles to be used
in an endurance event through prolonged exercise followed by a low carbohydrate diet, continued training, and finally, ingesting a diet high in carbohydrate combined with a very minimal amount of training (16). Elevated glycogen stores have been shown to increase exercise time to exhaustion (9, 16, 18, 20). More recently the study of the type of carbohydrate ingested during the high carbohydrate intake phase has been investigated and produced mixed results (12, 22).

Depleted glycogen stores have been shown to decrease exercise time to exhaustion (18). Once the liver glycogen stores are depleted the rate of glucose production cannot meet the consumption rate and blood glucose levels begin to drop (1, 2). However, exhaustive exercise at a lower intensity was not found to be directly related to a lowered blood glucose level (10).

A favorite practice among athletes is to ingest sugar in some form prior to competition. Previous studies have provided limited information on the effects of orally ingested glucose on exercise performance. This review will focus on those studies using sugar as a controlled variable in relation to exercise performance.

Ivy, et al. studied the effects of caffeine and carbohydrate feedings on endurance performance (17). Nine trained cyclists, seven male and two female were studied while performing a two hour cycling exercise (80 rpm). Test rides were: caffeine, glucose polymer, and a control ride without any feedings during the test ride.
Compared to the control ride, the caffeine ride increased work production by 7.4 percent and \( \dot{V}O_2 \) max by 7.3 percent. Fat oxidation was increased by 31 percent in the last seventy minutes of exercise in the caffeine trial. Ingestion of the glucose polymer (Polycose, app. 90 g), resulted in reducing the rate of fatigue in the last thirty minutes of the exercise trial. The elevated glucose level seemed to be the reason for the fatigue reduction in the last thirty minutes of exercise whereas the increase found in the work production of the caffeine trial was related to the increased rate of lypolysis. Total work production and \( \dot{V}O_2 \) max remained unchanged in the glucose trial. Blood glucose and insulin levels of the glucose trial were above the level of the control and caffeine trials. This study concluded that the caffeine ingested before and during prolonged exercise increased free fatty acid level delaying exhaustion by sparing muscle glycogen.

Twenty male athletes were studied by Orava, et al. (22) in regard to the effects of ingesting a carbohydrate rich solution (Sportti-C, 25 g of glucose per 100 ml of solution) and a placebo (Coca-Cola soft drink), prior to a bicycle ergometer and running test. This study was a cross-over single blind design. The subjects performed a bicycle ergometer test three to four hours postabsorptive at 600, 900 and 1,200 kg-m for five minutes per work load (Kg-m and Kpm are used to denote the calibrated resistance on a bicycle ergometer). Immediately following the first ride each subject received either the carbohydrate
rich solution or placebo. Subjects rested ten minutes, then performed the same ride as before. For the running test each subject reported three to four hours postabsorptive, received the appropriate solution and rested fifteen minutes. Following rest each subject performed a thirty minute submaximal run. Measured parameters of both tests were heart rate and arterial blood pressure taken before, during and after each test. Blood samples were taken before the test, twice during, following the test, and at the end of a fifteen minute rest period and measured for BG and serum FFA. Results of the bicycle test showed no significant differences between the carbohydrate and placebo groups for heart rate and systolic arterial blood pressure. During the two tests (bicycle ergometer and running), blood glucose levels did not significantly differ but hyperglycemia in the carbohydrate group was found during the rest period. The running test resulted in no significant differences in heart rate and systolic blood pressure between the carbohydrate and placebo groups at any time. The blood glucose levels of the carbohydrate group reached a peak prior to the onset of exercise and was elevated again during the recovery period. The carbohydrate group reported higher blood glucose values following the test than the placebo group. Orava, et al. also reported that serum free fatty acid values were higher in the placebo group than the carbohydrate group. The authors summarized their findings by stating "... the intake of a carbohydrate-rich solution in a
dose of one g per kg of body weight shortly before exercise of sub-maximal intensity seems to have favourable effects on the biomechanical parameters tested”.

Costill, et al. (8) studied seven subjects with respect to the effects of increased plasma insulin on glycogen utilization as a result of running. Three running trials were performed on a treadmill with an average of thirty minutes of work for each test. Each subject was five to six hours postabsorptive prior to testing for the control run. A second trial using the same protocol was conducted but included a 45 minute wait after each subject had ingested 75 g of glucose in 300 ml of water. A third trial compared the effect of ingesting a fatty meal four and one-half to five hours before exercise. In each separate trial two thousand units of heparin were injected into the forearm thirty minutes prior to exercise to “promote the breakdown of plasma triglyceride, thereby elevating plasma free fatty acids and glycerol.” Blood samples were drawn before, at ten, twenty, and thirty minutes of exercise. Blood samples were analyzed for serum glucose, free fatty acid, glycerol, triglyceride, lactic acid and insulin. Results showed that oxygen consumption was higher during the runs following the fatty meal in comparison to the glucose trial. The ratio of exchanged carbon dioxide and oxygen (respiratory quotient) was the lowest following the fatty meal. Blood glucose and plasma insulin values rose following the glucose ingestion from resting.
values until the onset of exercise, and then both values began to fall. An increase of blood glucose and insulin experienced in the glucose trial was responsible for the increased rate of carbohydrate metabolism. Demands on muscle glycogen were inversely related to the availability of blood glucose.

In a similar study conducted by Foster, et al. (12) sixteen subjects were studied for exercise performance following the ingestion of water, a glucose load, and a balanced liquid meal. Each subject visited the laboratory on six separate occasions and performed a bicycle ergometer ride to exhaustion on each visit. Subjects were required to ride at 80 percent \( \dot{V}O_2 \) max for three rides and at 100 percent \( \dot{V}O_2 \) max for the other three rides. Diet and exercise variables were controlled prior to each test to ensure high levels of muscle glycogen for each test ride. Each test followed a randomly selected 300 ml fluid intake: 75 g of glucose, a liquid meal; 10 g protein, 12.5 g fat, 15 g carbohydrate; or water. A fifty minute rest period followed the meal. Blood samples were taken before, at ten minutes, thirty minutes, and upon completion of each ride. Blood samples were analyzed for glucose, lactate and glycerol. Results showed that the mean time to exhaustion for the glucose trials compared to the water trials were decreased, four and nineteen percent for the 100 percent and 80 percent \( \dot{V}O_2 \) max rides respectively. The results of the mixed composition liquid meal showed no effect on exercise performance.
Blood glucose values for the glucose and mixed composition liquid meal tests at 80 percent $\dot{V}O_2$ decreased significantly during the first twenty minutes of exercise but were not significantly different from the water trial at exhaustion. Blood lactate values rose significantly for the first ten minutes of all three 80 percent $\dot{V}O_2$ max rides and then remained constant during the rest of the ride. Blood lactate results of the 100 percent $\dot{V}O_2$ max trials were found to be higher in comparison to the 80 percent $\dot{V}O_2$ max rides. Foster, et al. summed up the findings: endurance performance may be determined by the rate of muscle glycogen utilization along with preexercise muscle glycogen content. This conclusion is based on the impaired exercise performance following the glucose ingestion and lowered blood glucose during the early stages of the exercise.

Hermanson, et al. studied the effects of blood glucose and plasma insulin concentrations upon maximal exercise of short duration (15). A ten minute warmup period at 50-60 percent $\dot{V}O_2$ max on a motor driven treadmill preceded a run at a three percent incline and the highest possible speed the subject could maintain for approximately sixty seconds. The sixty second run was followed by a four minute rest period and then repeated. This sequence of a ten minute run and four minutes rest were repeated a total of five times. The entire test protocol was performed in duplicate on non-consecutive days. Two females and three males were used as subjects for the two tests; a
control test without any supplement administered and an experimental test where a glucose solution of 300 mg/kg body weight was used as the experimental variable. The glucose solution was administered over a four minute period, but the authors made no report as to the time interval between ingestion and exercise. Variables measured were blood glucose and plasma insulin concentrations. Venous blood samples were drawn during the rest and recovery periods following exercise. Results from the experiment showed that the blood glucose concentration following the first run increased from a preexercise value of 82.6 to 91.2 mg/100 ml of plasma with the plasma insulin values unchanged. Following the second run both parameters increased. Blood glucose values continued to increase with each run reaching a peak at an average of seven minutes following the fifth run. Blood glucose and plasma insulin values increased 108.9 and 273 percent of resting values respectively (mean values). Following the glucose load test, blood glucose and plasma insulin values increased 117.6 and 179 percent of resting values respectively (mean values). The authors concluded that the intermittent maximal exercise of short duration increased blood sugar and plasma insulin of both tests.

In the study by Costill, et al. (7) the effects of the administration of oral glucose at rest and during physical activity were investigated. Seven male subjects reported for testing in a twelve hour postabsorptive state. Exercise experiments were conducted on a
treadmill or bicycle ergometer for ninety minutes of work at 60-72 percent \( \dot{V}O_2 \) max. Subjects ran or cycled for thirty minutes prior to a glucose ingestion and then continued for the remaining sixty minutes. A control test at rest was conducted in a comfortably controlled air-conditioned room. The authors did not specify environmental conditions experienced for the exercise trial. During the resting test two blood samples were taken and analyzed for blood glucose, lactic acid, plasma free fatty acids and triglycerides. Blood samples were taken intermittently throughout and following both exercise test periods. Expired air was collected, measured and analyzed for \( O_2 \), \( CO_2 \) and \( ^{14}CO_2 \). Results based on the gas exchange disclosed an average energy expenditure of 1.4 kcal/min resting and 13.8 kcal/min exercising; 35.5 g of carbohydrate was oxidized during rest and 127 g of carbohydrate oxidized during exercise. Blood lactate, free fatty acids and triglycerides remained relatively constant following the glucose load during exercise. Blood lactate values were found to be unchanged at the submaximal workload of less than 70 percent \( \dot{V}O_2 \) max. [The analysis for \( ^{14}CO_2 \) was used to determine the concentration of serum glucose derived from the glucose administration during exercise.] Free fatty acid levels were elevated at the completion of exercise and continued to rise during the sixty minutes following. The triglyceride level rose from a resting level of 68 mg/100 ml to 78 at the completion of exercise then declined rapidly in the next thirty minutes.
Values for blood lipids seemed to be unaffected by the glucose load. Blood glucose values rose in the first thirty minute exercise bout compared to rest, 92 mg/100 ml and 85 mg/100 ml respectively. Following the glucose load, blood glucose values followed a normal glucose tolerance curve reaching a peak between thirty and forty minutes following ingestion. Blood glucose values returned to normal levels at fifty minutes post exercise in the exercise trial and 75 minutes in the rest trial. Using the 14CO2 results it was found that orally administered blood glucose was utilized 6.5 times faster during exercise than rest. The authors summarized their findings by stating that orally ingested carbohydrate during prolonged exercise has limited effects on muscle metabolism, however, liver glycogen contributions to blood glucose declined following the ingestion of glucose indicating liver glycogen depletion during prolonged maximal physical exercise may be prevented.

Bonen, et al. (4) studied the effects of glucose ingestion before and during intense exercise. Thirty-one male subjects participated in the experimental study. Prior to testing all subjects first reduced muscle glycogen stores by a combination of fasting and exercise. The subjects were then divided into four experimental groups: exercise with no glucose, exercise with glucose prior to exercise, exercise with glucose during exercise, and no exercise with glucose. The authors made no indication how the subjects were divided into the
four groups. The exercise groups performed bicycle ergometer rides at a workload of approximately 78 percent \( \dot{V}O_{2} \) max. Glucose was ingested fifteen minutes prior to exercise for one exercise group and at three to five minute intervals during exercise for the other exercise group. The amount of glucose ingested was 1.5 g/kg body weight. The bicycle ergometer rides were set at thirty minutes total work time, however some subjects were unable to endure the total time and the point of voluntary exhaustion was designated as the end of exercise. Venous blood samples were taken twice before, once during and again following exercise. Blood samples were analyzed for glucose, insulin and lactate values. The exercise group that did not receive any glucose produced the highest mean total work time and lowest percentage of carbohydrate utilization of the three exercise groups. The exercise group that received the glucose infusion during exercise produced the lowest mean total work time. Blood glucose values for the group that ingested the glucose solution prior to exercise rose rapidly until the tenth minute of exercise and then continually declined to a level at completion of exercise equal to the exercise group that did not ingest any glucose. The exercise group that ingested the glucose solution during exercise produced significantly greater levels of blood glucose during exercise and the recovery period following. Insulin levels for the group that ingested glucose prior to exercise were significantly elevated at the onset of exercise. For the group that ingested glucose
during exercise insulin levels produced no significant change. Lactate levels of both glucose ingested exercise groups were significantly elevated above the no glucose exercise groups. In summary the authors stated that in "... the glycogen depleted subjects glucose was rapidly metabolized by the exercising muscle, irrespective of whether glucose was consumed before or during intense exercise":

In summarizing the review of related literature, it may be concluded that:

1. elevated glycogen stores have been shown to increase exercise time to exhaustion (14);
2. an elevated free fatty acid concentration can extend work production (17);
3. administration of a liquid glucose solution before and/or during exercise has produced mixed results (12, 72);
4. elevated amounts of blood glucose and insulin increase the rate of carbohydrate metabolism (8); and
5. endurance performance may be determined by the rate of muscle glycogen utilization along with preexercise muscle glycogen content (12).
Research Method

The experimental research design used for this study was a cross-over single-blind protocol with five subjects acting as their own control. The study was designed to measure the effects of ingesting a glucose solution prior to exercise on exercise duration and selected blood parameters of each subject.

Sample

The sample consisted of four male athletes who volunteered from the Men's Varsity Cross Country and Track teams and one unattached athlete attending Montana State University during the 1981-82 academic year. Physical characteristics, VO₂ max and body composition of each subject and the sample total are included in Table 3.1. All subjects had competition experience at the high school and college levels in distance running. There were no reported diabetes mellitus cases in the subjects' immediate family. None of the athletes reported taking any type of prescriptive drugs during the testing period. Each subject reported healthy prior to initial testing and remained healthy throughout all tests. All were informed (during a group meeting) of the intensity required with each test before giving written and verbal consent to participate. Each subject had training average of fifty or
Table 3.1. Individual Physical Characteristics and Group Mean

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<th>Subject</th>
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<th>JW</th>
<th>RK</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
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<td>Age/yr.</td>
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<td>19</td>
<td>18</td>
<td>26</td>
<td>27</td>
<td>21.6</td>
</tr>
<tr>
<td>Wt./kg</td>
<td>70.5</td>
<td>67.3</td>
<td>69.1</td>
<td>63.6</td>
<td>63.6</td>
<td>66.8</td>
</tr>
<tr>
<td>Ht./cm</td>
<td>176.5</td>
<td>182.9</td>
<td>185.4</td>
<td>175.3</td>
<td>185.4</td>
<td>181.0</td>
</tr>
<tr>
<td>% Body Fat</td>
<td>8.9</td>
<td>8.1</td>
<td>8.9</td>
<td>5.0</td>
<td>8.9</td>
<td>7.9</td>
</tr>
<tr>
<td>( \dot{V}O_2 ) max ml/kg X ml</td>
<td>77</td>
<td>60.4</td>
<td>71.7</td>
<td>77.5</td>
<td>70.2</td>
<td>71.3</td>
</tr>
</tbody>
</table>

more miles per week for the past six months. A sample questionnaire is found in Appendix D.

Testing Battery

The testing parameters are as follows:

1. Maximal oxygen consumption (\( \dot{V}O_2 \) max).
2. Anthropometric measurements.
   A. Chest skinfold (CH).
   B. Axilla skinfold (AX).
   C. Tricep skinfold (TR).
   D. Subscapular skinfold (SS).
   E. Abdominal skinfold (AB).
   F. Suprailiac skinfold (SU).
G. Thigh skinfold (TH).
H. Body weight (BW).
I. Height (HT).

   A. Blood glucose levels (BGL).
   B. Blood lactic acid concentration (BLA).

4. Bicycle ride to exhaustion.
   A. Experimental ride (ER).
   B. Control ride (CR).

5. Relative perceived exertion (RPE).

Testing Procedures

Maximal Oxygen Consumption

\( \text{\( \dot{V}O_2 \)} \) max was measured using a standardized open circuit procedure patterned after Fox, et al. (13) on a Monarch bicycle ergometer with a pedal frequency of 70 rpm. Gases were collected in a 350 liter Collins Tissot and analyzed with a Beckman E2 (Oxygen) and LB2 (Carbon dioxide) analyzer calibrated with standard gases prior to each test. Criteria for a maximal value was a plateau or decline in oxygen consumption in a subsequent higher intensity exercise bout and a respiratory exchange ratio greater than 1.0. Standard calculation procedures were followed for computation of \( \dot{V}O_2 \) max (l/min, ml/kg min, corrected for standard temperature and pressure dry (STPD)) (24). A
sample calculation form is found in Appendix A.

Body Composition

Skinfold measurements were performed by a trained laboratory technician using Lange skinfold calipers. [The sites described by Pollack, et al. were used to collect skinfold data (23)]. Three measurements were taken at each site to the nearest 0.5 mm. The average of the three scores were recorded unless one deviated by more than 1.0 mm, in which case the site was remeasured. Calculations of density used the formula of Forsyth and Sinning (11) and percent body fat from Brozek (6). Calculation form can be found in Appendix B.

Blood Samples

Blood samples were drawn according to the time schedule shown in Figure 3.1. Each sample was drawn and manually diluted by the same medical technologist. Blood samples were drawn for each test fifty minutes following ingestion of a glucose solution or placebo, pre-blood glucose (PBG) and five minutes following completion of each test, exercise blood glucose (EBG), exercise lactic acid (ELA). Blood samples were analyzed using the Worthington Diagnostics Statzyme Glucose Kit performed by the same medical technologist. The preexercise sample was analyzed for glucose level and the post exercise sample was analyzed for lactic acid concentration and glucose level. The Sigma Chemical Lactic Acid Kit was used for lactic acid analysis.
Figure 3.1. Blood Sample Time Schedule
using Perchloric acid and NAD as reagents.

Experimental and Control Tests

A standardized sequence was followed for each test with a minimum of 48 hours and a maximum of one week between tests. Preconditions necessary for controlled testing were followed by each subject prior to each test.

Each subject reported to the laboratory following a normal night's rest and three to four hours postabsorptive. Recommendations were given each subject concerning the quantity and content of the dinner and breakfast meal prior to testing. A balanced meal high in carbohydrate was recommended for dinner and a breakfast consisting primarily of complex carbohydrate was prescribed. Instructions were given to abstain from the ingestion of any foods or liquids (other than water) between the breakfast meal and each test. Guidelines for training concerning the amount, duration, and intensity for the two days preceding each test were given to each subject. Training was conducted on both days prior to each test, however, neither day consisted of a high intensity or long duration period. Each training period was of low intensity and short duration in an effort to prevent depletion of stores.

Subjects upon reporting to the laboratory received either the glucose solution (10 ounces, 100 g of glucose, commercial product
Glucola, diluted with two counces of H₂O) or placebo (12 ounces, sugar free, caffeine free, commercial product, Craigmont Diet Cola) in a randomized order with instructions to ingest the solution within five minutes. Both solutions were served cold. The subjects were not informed of the content of the solution for either test. The subjects were then placed in a quiet study atmosphere for 45 minutes. At this time they returned to the laboratory and PBG (CR or ER) was taken.

A warmup of five minutes exercise at fifty percent VO₂ max 70 rpm followed by three to four minutes rest was used prior to the exhaustive test.

Exhaustive Exercise

Intermittent workloads of two minutes work at approximately 85 percent VO₂ max and one minute rest were initiated and alternately continued until each subject reached a state of exhaustion.

Relative Perceived Exertion

A perceived exertion scale developed by Borg (5) was used to rate each subject's perceived exertion following each work interval. A sample is found in Appendix C.

Analysis of Data

Within group comparisons were made, using a paired T, mean comparison test as the statistical analysis. Significant differences were accepted at the 0.05 level.
RESULTS

Results are presented in Chapter 4. Discussion of the results are found in Chapter 5. The following headings are used in presenting the findings of this investigation:

1. Bicycle Ride to Exhaustion.
2. Blood Sample.
3. Relative Perceived Exertion.

Bicycle Ride to Exhaustion

Five male college students, all trained distance runners, exercised to exhaustion on a bicycle ergometer for two trail rides separated by several days, a control ride (CR) and experimental ride (ER). Subjects cycled at approximately 85 percent $\dot{V}O_2$ max at work intervals of two minutes followed by a one minute rest. The tested variable was a glucose solution consumed prior to the ER and a placebo solution for the CR in a randomized single blind protocol. Exercise was terminated when the subject failed to maintain 70 rpm.

Duration of a ride to exhaustion under CR and ER conditions are presented in Figure 4.1. All subject's exercise time to exhaustion was longer on the CR than the ER. The CR mean duration exceeded the ER by 35 percent ($P > 0.05$).
Figure 4.1. Duration of Exercise for Control and Experimental Tests
Blood Samples

The protocol for blood samples is illustrated in Figure 4.2. Blood samples (each sample equaled five cc) were taken prior to exercise and five minutes following termination of the exhaustive ride for the CR and ER. Samples were analyzed for blood glucose before and both blood glucose and blood lactate levels five minutes after exercise.

Blood glucose values for the ER, preexercise blood glucose experimental and exercise blood glucose experimental (PBG$_E$ and EBG$_E$) are presented in Figure 4.3. All subjects with one exception (BO) had lower blood glucose levels post exercise (EBG$_E$) compared to the preexercise sample (PBG$_E$). Complications encountered prevented drawing subject RB on schedule; no value is reported. The group mean dropped from 111 to 103 mg/100 ml.

Blood glucose levels for the CR (PBG$_C$ and EBG$_C$) are presented in Figure 4.4. All subjects were found to have higher blood glucose values post exercise for the control ride. Subject RK had the lowest percent increase (0.5 percent). The group mean rose from 75 to 98 mg/100 ml.

Figure 4.5 presents the comparison of the CR and ER preexercise glucose values (PBG). The values recorded for the CR are regarded as normal values for blood glucose and are uniform for all subjects.
Solution Ingested

PBG = Preexercise Blood Glucose, CR and ER
EBG = Exercise Blood Glucose, CR and ER
ELA = Exercise Lactic Acid, CR and ER

Figure 4.2. Test Protocol for Blood Samples.
Figure 4.3. Preexercise and Post-exercise Blood Glucose, Experimental Test, \((PBG_E \text{ and } EBG_E)\).
Figure 4.4. Preexercise and Post-exercise Blood Glucose, Control Test (PBG and EBG).
Figure 4.5. Preexercise Blood Glucose, Control and Experimental Tests (PBG).
Blood glucose values for PBGE are elevated above normal resting values with subject RB reporting the lowest difference. The difference between the group mean value, ER to CR, was 36 mg/100 ml. The mean values of PBGE and EBGC resulted in a significant difference (P < 0.05).

A comparison of blood glucose for post exercise CR and ER are presented in Figure 4.6. All subjects showed EBGE elevated above EBGC. Subject JW reported the greatest difference between the two values. Comparing the mean differences, EBGE at 103 to EBGC at 98 mg/100 ml, the values were not significantly different.

Figure 4.7 presents the values found for blood lactate. Complications previously mentioned prevented obtaining a blood sample for subject RB. The remaining subjects, with one exception (RK), had lower blood lactate values for the ELAC compared to the ELAE. Even though lactate values differed between ELAC and ELAE there was no significant difference.

Relative Perceived Exertion

The relative perceived exertion (RPE) for each two minute work bout during every test ride was recorded for each subject upon completion of the work interval. Borg's scale of relative perceived exertion was used as the testing instrument (5).

A comparison of the CR and ER means for RPE are found in Figure 4.8. The RPE for the CR and ER follow a similar pattern of a rise
Figure 4.6. Post-exercise Blood Glucose, Control, Experimental Tests (EBG).
Figure 4.7. Post-exercise Lactic Acid, Control and Experimental Tests (ELA).
Figure 4.8. Relative Perceived Exertion Control and Experimental Ride Mean Comparison.
over exercise time. The CR RPE continues beyond the termination of ER RPE due to a longer duration to exhaustion. However, RPE does not continue to climb.

From the results presented in this chapter we may conclude that:

1. all subjects' duration of exercise was longer in the CR to ER;
2. ER blood glucose decreased from $\text{PBG}_E$ to $\text{EBG}_E$;
3. CR blood glucose rose during exercise; exercise, ER blood glucose declined;
4. $\text{PBG}_E$ was significantly greater than $\text{PBG}_C$ ($P < 0.05$);
5. $\text{EBG}_E$ was greater than $\text{EBG}_C$;
6. mean $\text{ELA}_E$ exceeded mean $\text{ELA}_C$ lactic acid by 24 mg/100 ml; and
7. the RPE of both ER and CR produced ascending values with the CR reaching a peak later than the ER and continuing at peak values due to a longer exercise duration.
Chapter 5

ANALYSIS OF DATA

The purpose of this study was to determine the effects of an ingested glucose solution on exhaustive intermittent exercise performance using exercise duration, blood lactate concentration and blood glucose as measured parameters. Specifically this study measured five subjects' duration of exercise to exhaustion during intermittent exercise at approximately 85 percent \( \dot{V}_\text{O}_2 \text{ max} \) in a cross-over single blind protocol with 100 g of glucose solution used as the experimental variable. Each subject's blood glucose was measured from blood samples taken prior to and five minutes after exhaustive exercise. Blood lactate was also measured for each subject from the blood sample taken five minutes after exhaustive exercise. Results presented in Chapter 4 will be discussed relative to the measured parameters.

Duration of Exercise

Comparing exercise time to exhaustion between the two rides, the ER produced a 35 percent decrease in total work time. These results are in agreement with the study by Foster, et al. who found a decrease of nineteen percent for continuous exercise following a preexercise glucose ingestion (12).

Available carbohydrate (glucose) for exercise may be the primary
factor production exhaustion in this type of exercise. Insulin level produced by preexercise glucose ingestion may have been responsible for depressing blood glucose and therefore placed a greater dependence on muscle glycogen (8). An increased demand for muscle glycogen may have contributed to early exhaustion of the ER. The rise in blood glucose during exercise in the CR seemed to have a favourable effect in extending total work time. These results were found to be in agreement with similar results by Foster, et al., and others (8, 12, 15).

Therefore, this study and others have found that the ingestion of a simple carbohydrate shortly before exercise produces an abnormal fluctuation in blood glucose. The elevated blood glucose prior to exercise produces an insulin overshoot causing blood glucose to fall during exercise placing a greater reliance on muscle glycogen which may be depleted contributing to premature fatigue.

Blood Samples

The results discussed previously concerning exercise duration are, in general, confirmed by the blood sample results from this study. Glucose uptake and insulin output in fed, postabsorptive, non-exercised subjects produces a relatively constant blood glucose concentration (8). The ingestion of glucose for the experimental trial ride may have upset the blood glucose, insulin balance. Blood glucose was
elevated above normal in the preexercise blood test for ER as shown in Figure 4.5. The mean blood glucose values of PBG_E dropped from 111 to 103 mg/100 ml, EBG (Figure 4.3). This drop contrasted with a rise in mean blood glucose of 75 to 98 mg/100 ml for PBG_C to EBG_C. This rise found in the CR has previously been observed (7, 8, 12, 15, 20). The rise in the blood glucose values are related to exercise intensity and duration (25). The failure of the glucose values of the EBG_E to rise above the PBG_E values might be explained by "... exercise fails to overcome the inhibitory influence of glucose administration" (25).

From this data it may be hypothesized that elevated insulin and the fall in blood glucose during the ER was a contributing factor to premature fatigue. This evidence is in partial agreement with that of investigators (8, 12, 15) who found lower blood glucose at exhaustion compared to preexercise values. This study did not find as low a blood glucose compared to other studies (8, 12, 15), which may have been in part due to the different method of exercise.

Increased blood lactate at the completion of intensive exercise is directly related to the proportion of carbohydrate ingested in the pre trial meal or just prior to exercise (19, 20). In comparing blood values EBG_C to EBG_E, the mean difference of 106 to 82 mg/100 ml was found with demonstrating a lower value for EBL_E except RK.
(See Figure 4.5.) The differing lactate value of RK may be due to the subjects' training and physical fitness. Also, RK did not exhibit as wide a variation in blood glucose EBGc and EBGc as other subjects (Figure 4.6). This particular subject is a highly trained marathon competitor training primarily with long slow distance runs. In order to maintain training state and daily mileage, subject RK did not follow the guidelines for reduction of training duration between the two test periods. RK also reported encountering above normal stress during the testing week. Upon reporting to the laboratory muscle stores may have been below normal resulting in a greater dependance on blood glucose producing early exhaustion.

**Relative Perceived Exertion**

RPE results (Figure 4.8) for the ER produced slightly higher values, however, peak values were maintained longer in the CR. Similar results were reported by Costill (8, 10) who found no significant differences in RPE values of control and experimental tests. RPE increased at approximately the same rate ER and CR reaching a peak slightly sooner in the ER. A higher blood glucose level during the CR may have been a contributing factor in enabling the subjects to maintain exercise duration for an extended time at a maximum RPE.
Chapter 6

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

Summary

The purpose of this study was to determine the effects of an ingested glucose solution upon exhaustive intermittent exercise performance using exercise duration, blood lactate concentration and blood glucose as measured parameters.

The sample consisted of five male college athletes, all trained distance runners. Physical characteristics, \( \dot{V}O_2 \) max and body composition of each subject and the sample total were presented in Table 3.1. Subjects exercised to exhaustion on a bicycle ergometer at a resistance of approximately 85 percent \( \dot{V}O_2 \) max with intermittent work and rest intervals, two to one minutes respectively, on two trials separated by several days. Subjects received either a glucose solution for the experimental ride (ER), [10 ounces, 100 g of glucose, commercial product, Glucola, diluted with two ounces of H₂O] or a placebo for the control ride (CR) [12 ounces, sugar free, caffeine free, commercial product Craigmont Diet Cola].

Blood samples were drawn fifty minutes following ingestion of either solution and five minutes post exercise. The first blood sample (PBG) measured blood glucose preexercise and the second (EBG, ELA) measured blood glucose and lactic acid post exercise.
A standardized sequence of testing was followed for each test. Preconditions necessary for controlled testing were followed by each subject prior to each test. Controlled conditions were described in Chapter 3.

A perceived exertion scale developed by Borg (3) was used to rate each subject's exercise stress following each work interval.

Conclusions

Since this study was conducted with an elite sample group, broad generalizations could not be drawn. Considering the limitations of this study, and the trained individuals tested, the following conclusions seem justified.

1. Ingestion of the glucose solution prior to exercise decreased total work time by 35 percent.

2. Preexercise blood glucose values were elevated above normal following ingestion of the glucose solution (P < 0.05).

3. Blood glucose values decreased during the experimental ride.

4. Blood glucose values increased during the control ride.

5. The blood lactate ER was higher than CR despite a 35 percent shorter duration at the same intensity.

6. The RPE of the ER reached a peak value similar to the CR, however, the peak was maintained longer during the CR.
Recommendations

Based on the results of this study, further investigation in the area of ingesting a simple carbohydrate prior to exercise would be warranted. The following recommendations are presented:

1. It would be valuable to vary the amount of carbohydrate ingested prior to exercise to determine if a dose:response relationship exists.

2. The time of ingestion prior to exercise should be investigated to further determine the influence of blood glucose and blood insulin changes on performance.

3. The variation in work and rest intervals following a glucose load could determine the greatest and least affected duration of exercise.

4. Further study of the percent of VO\textsubscript{2} max in relation to exercise performance following a glucose intake to determine the interaction of blood glucose and exercise intensity.
APPENDICES
**APPENDIX A**

Gas Analysis Procedure

Human Performance Laboratory  
Montana State University  
Gas Analysis Calculations

<table>
<thead>
<tr>
<th>Name</th>
<th>Age</th>
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### Test Protocol

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<td>Duration (min)</td>
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<td>4</td>
<td>3</td>
<td>3</td>
<td>3</td>
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<tr>
<td>Sample (min)</td>
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<td>3-4</td>
<td>2-3</td>
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<td>3</td>
</tr>
<tr>
<td>Rest (min)</td>
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<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
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</table>

### Heart Rate

### Volume

1. $T_2 = \text{Tissot, final}$
2. $T_1 = \text{Tissot, initial}$
3. $\Delta T = \text{Tissot difference}$
4. $\Delta T \times 3.244 = \dot{V}_R$
   uncorrected

### Oxygen Consumption

5. $\text{BP} = \text{Barometric Press.}$
6. $T_0^C = \text{Tissot Temp.}$
7. $\text{STPD}$
8. $(7) \times (4) = \dot{V}_R$ corrected

9. $E_2$
10. $E_2 \times 21/1000 = O_2\%$
11. $20.88 - (10) = O_2 \text{ Extr.}$
12. $(11)/100 =
13. $(8) \times (12) = O_2 \text{ l/min}$
14. $(13) \times 1000 \div BW(Kg) = O_2 \text{ ml/Kg min}$

### RW

15. $\text{CO}_2\% = \text{CO}_2\% \text{ prod.}$
16. $(15)/(11) = \text{RQ}$

### VE

17. $(4)/(13) = \text{VE}$

$$\text{STPD} = \left(\frac{273}{273 + T}\right) \times \frac{\text{BP}}{760} \times \left(\frac{\text{BP} - \text{VP}}{\text{BP}}\right)$$

$\text{VP}$:
- $18^\circ = 15.5$
- $19^\circ = 16.5$
- $20^\circ = 17.5$
- $21^\circ = 18.7$
APPENDIX B

Body Density and Percent Body Fat Formulas

Body Density

\[ D_B = 1.1043 - 0.001327 \text{ (thigh skinfold)} - 0.00131 \text{ (subscapular skinfold)} \]

Percent Body Fat

Percent of Fat = \[ \left( \frac{4.570}{D_B} - 4.142 \right) \times 100 \]
APPENDIX C
APPENDIX C

Relative Perceived Exertion (Borg)

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51

APPENDIX D

Subject Questionnaire

Name ___________________________ Phone Number ________________________

Address __________________________

Age _______ Ht. _______ Wt. ______

1. Is anyone in your immediate family diabetic? Yes ___ No ___
   If yes, then who? (yourself, father, mother, sister, brother). Circle.

2. Average number of miles run per week? _______  Per day? _______

3. Where do you eat your meals? _______. (Home, dorm, other).
   If other, please explain.

4. Do you eat breakfast? ______. (yes, no). If yes, when? _______
   If yes, describe your normal or usual breakfast meal.

5. Do you plan on participating in any type of competition, (meets,
   races), between Feb. 18th to Mar. 19th? If so, please list the
   scheduled dates.

6. Are you using any type of prescriptive drug? If so, please list.

7. List your daily schedule for Tues., Thurs., Fri., and Sat. (for
   test scheduling purposes).

<table>
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BIBLIOGRAPHY


Effects of preexercise glucose ingestion upon exhaustive exercise.