ERSING, Walter Fritz, 1932—
A COMPARISON OF OXYGEN CONSUMPTION DURING STRENuous WORK FOR THREE PATTERNS OF INTENSITY.

The Ohio State University, Ph.D., 1964
Education, physical

University Microfilms, Inc., Ann Arbor, Michigan
A COMPARISON OF OXYGEN CONSUMPTION DURING STRENuous
WORK FOR THREE PATTERNS OF INTENSITY

DISSERTATION

Presented in Partial Fulfillment of the Requirements for
the Degree Doctor of Philosophy in the Graduate
School of The Ohio State University

By

Walter Fritz Ersing, B.S., M.A.

The Ohio State University
1964

Approved by

[Signature]

Adviser

Department of Physical
Education
To Maryalyce,

Stephen, Curtis and Kristen
ACKNOWLEDGEMENTS

The author is sincerely appreciative of the valuable assistance received from several individuals in the preparation of this dissertation. He gratefully acknowledges the contributions of Dr. Donald K. Mathews, who, as adviser, provided the inspiration and valuable guidance for the development and completion of this study. For his interest in my professional growth, I am deeply indebted.

For their valuable technical assistance and contributions to this research, I express deepest gratitude to Richard Bowers, Edward Fox and Fritz Hagerman.

I extend sincerest thanks to subjects Senor Calis, William Davis, Richard Koehler, Edward Porter, Neil Schmotzlach and David Timm for giving so generously of their time and effort throughout the experiment.

The author also wishes to take this means of expressing his appreciation to Dr. Willard P. Ashbrook for his assistance throughout my doctoral program and to Dr. Bruce L. Bennett for his editorial assistance as a member of the Reading Committee.
June 7, 1932 Born - Springfield, Massachusetts

1954 . . . B.S., Springfield College, Springfield, Massachusetts

1954-1957 . . Graduate Assistant, Department of Physical Education, The Ohio State University, Columbus, Ohio

1955 . . . M.A., The Ohio State University, Columbus, Ohio

1957-1964 . . Instructor and Supervisor of Adapted Physical Education, Department of Physical Education, The Ohio State University, Columbus, Ohio

Major Field: Physical Education

Professors Millard P. Ashbrook, Arthur R. Daniels, Donald K. Mathews and Delbert Oberteuffer

Minor Field: Higher Education

Professors Earl Anderson and Warren Kirchner
TABLE OF CONTENTS

ACKNOWLEDGEMENTS ........................................ iii
VITA .............................................................. iv
LIST OF TABLES ............................................. vii
LIST OF FIGURES ............................................. vii

Chapter

I. INTRODUCTION ............................................. 1

   Statement of the Problem
   Limitations of the Study
   Significance of the Study

II. REVIEW OF RELATED LITERATURE ...................... 14

   Summation of Related Literature

III. METHODS AND PROCEDURES ............................. 25

   Subjects
   Apparatus
   Orientation
   Procedures
   Heart Rates
   Computations

IV. ANALYSIS OF DATA ........................................ 32

   Description of Data
   Discussion

V. SUMMARY AND CONCLUSIONS .............................. 42

   Summary
   Conclusions
   Recommendations
APPENDIXES  ........................................... 46
BIBLIOGRAPHY ........................................... 50
LIST OF TABLES

Table       Page
1. Age, Height and Weight of Subjects  ............... 25
2. Work Output per Minute  ......................... 30
3. Net Oxygen Cost for Each of the Three Patterns of Intensity in ML./Kg. Body Weight  .... 32
4. Analysis of Variance  ................................. 33
5. VO_2 in ML./Kg. Body Weight for Rest and Post Recovery  ......................... 39
6. V in ML./Kg. Body Weight for Rest and Post Recovery  ......................... 41

LIST OF FIGURES

Figure       Page
1. Mean Heart Rates Plotted for 5 Minutes of Rest, Six Minutes Exercise, and Thirty Minutes of Recovery  ............... 36
2. Mean Met VO_2 in ML. for Two Minute Intervals During Exercise and Thirty Minute Recovery  ............................. 38
3. Comparison of Pre-Exercise and Post Recovery VO_2 and V in ML./Kg. Body Weight  ......................... 40
CHAPTER I

INTRODUCTION

A cursory review of the world and Olympic track records for the past seventy-five years reveals that there has been a general improvement in running performances. Improvement over the years probably can be attributed to better techniques of training, better and more track facilities, and an increase in the physical qualities of the participant.

In spite of the improvement in running records over the years, the problem of what type of running pattern or pace would produce the fastest time and be the most economical in terms of energy cost has not been solved. For example, track authorities are not in agreement regarding the most effective pace pattern in running middle distance and distance events.

In a discussion of the techniques for running the quarter mile, Murphy and Canham described two types of runners for this event. One is the "sprinter" who sprints as long as possible for the race. The other type is the "middle-distance" runner who maintains a more even gait for
the entire distance.\textsuperscript{1, 2} Murphy claimed that of the two types, the sprinter, provided he has the endurance, is more likely to be the record-breaker.\textsuperscript{3}

Gill explained the technique of running the quarter mile race as a "sprint-float-sprint" pattern in which the runner sprints away fast at the start until the end of the turn, sets a fast pace for the middle of the race, and then at the straightaway sprints for the finish.\textsuperscript{4} This pattern seems to agree with that advocated by Cromwell who stated: "The ideal manner is to cover the first furlong at very close to top speed, then stride through the next 100 to 120 yards at a slower pace and finally to pull up to top speed over the last 100 yards."\textsuperscript{5}

Clark, in 1920, advised the individual to run the quarter mile at almost top speed until the last fifty yards when he was to "squeeze his corks" and finish on what energy

---

\textsuperscript{1}Michael C. Murphy, \textit{Athletic Training} (New York: Charles Scribner's Sons, 1926), p. 46.

\textsuperscript{2}Donald Canham, \textit{Track Techniques Illustrated} (New York: The Ronald Press Co., 1952), p. 34.

\textsuperscript{3}Murphy, \textit{loc. cit.}


\textsuperscript{5}Dean B. Cromwell, \textit{Championship Technique in Track and Field} (New York: Whittlesey House, 1949), p. 77.
is remaining. 6 Gauthier and Haney, on the other hand, claimed the best approach to pacing the quarter mile is one in which the runner maintains the fastest pace that he can hold consistently over the entire race. 7

Some authorities believe the "fast to slow" pattern or the "maximum speed-minimum deceleration" method is the most desirable technique for running the quarter mile. In describing this type of running pattern, Doherty stated: "The quarter mile is an endurance sprint in which maximum acceleration is achieved first and then this momentum is maintained to the finish line with the least possible deceleration." 8 He noted that no world's records in the 440-yard or 400-meter dashes have produced an even pace. Brown, a former English quarter mile record holder, prescribed the same pattern, but maintained that the deceleration should be gradual and smooth—like a clock running down.

Bannister surveyed some of the research related to running patterns and argued that in middle-distance running the steady pattern of running may not be the most economical

---


in terms of energy cost. The first of the sub-four minute milers claimed that runners seem to achieve their best times in the 440-yard race by running the first part of the race considerably faster than the second.

In his treatment of the 440-yard race, Stampfl claimed that this event is essentially a sprinter's race because in a 440-yard event the race is completed before a runner of less speed, but greater stamina, can take command. As to the running pattern, he stated that even-pace running in the quarter mile is out of the question in first-class competition. Instead, Stumpfl advocated the runner to start the race as fast as any sprint start and then maintain a pace slightly slower than top speed that will result in the least possible deceleration in the last 100 yards of the race.10

Conger advocated the same "fast-to-slow" pattern; he thought that a 440-yard racing schedule requires the first 220 to be about two seconds faster than the second.11

A table of 440-yard running patterns by Bresnahan suggests

---


that there should be a difference of two to four and one-half seconds between the two halves of the event for runners of varying ability.\textsuperscript{12}

Track authorities, considering patterns of running the half-mile event, display an inconsistency when discussing the most desirable manner for distributing a runner's energy. Certain authorities indicated that the first half of the 880-yard run be faster than the second. The amount of difference advocated by the track coaches ranged from two to four seconds.\textsuperscript{13, 14, 15, 16, and 17}

Canham contended that the most creditable performance in the half-mile is made when a runner distributes his energy properly by holding a constant pace according to his capacity.\textsuperscript{18} Mortensen agrees that a half-miler must

\begin{itemize}
  \item \textsuperscript{13} Gill, $\textit{op. cit.}$, p. 47.
  \item \textsuperscript{14} Conger, $\textit{op. cit.}$, p. 27.
  \item \textsuperscript{15} Cromwell, $\textit{op. cit.}$, p. 87.
  \item \textsuperscript{16} Lawson Robertson, \textit{Modern Athletics} (New York: Charles Scribner's Sons, 1932), p. 49.
  \item \textsuperscript{17} Bresnahan, Tuttle, and Cretzmeyer, \textit{op. cit.}, p. 132.
  \item \textsuperscript{18} Donald Canham, "Middle-Distance Strategy Tactics," \textit{Scholastic Coach}, Vol. 27, No. 7 (March, 1958), pp. 12-14.
\end{itemize}
maintain a constant, fast pace, but states the runner should finish the last 220 yards with a little extra "lift." 19

Contrary to the fast-to-slow and constant running patterns advocated by his professional colleagues, Doherty claims the first half of the 880-yard run should be run slightly slower than the second. He considers this approach as the ideal pattern of modern running. 20

A similar difference of opinions exists for the mile event also. Several track coaches maintain that a runner will usually perform better in the mile if he runs the first half of the race faster than the second. The recommended time difference ranged from three to five seconds. 21, 22, 23, 24, 25 While agreeing with the fast-to-slow pattern, Robertson further advised that the first quarter of a mile race should be the fastest, and the last quarter, the second fastest. 26


21 Clark, op. cit., p. 73.

22 Gill, op. cit., p. 55.

23 Gauthier and Haney, op. cit., p. 36.

24 Conger, op. cit., pp. 35-36.


26 Robertson, op. cit., p. 50.
Barba discussed the mile pace in terms of a rhythmic running pattern and recommended that in this event a runner should maintain a pre-set pace for four equal quarters.\(^{27}\) This pre-set or constant pace pattern is similar to that used by Paavo Nurmi of Finland in his training program prior to his world record run of four minutes, ten and two-fifth seconds in August, 1923. The utilization of pace-posts by Nurmi in his training preparations introduced for the first time the science of pace for the purpose of energy conservation to the track world.\(^{28}\)

In supporting the even pace pattern for the mile, Stampfl indicated that judgment of pace is more important to success in this race than in any other event. He claimed that a wide variation of pace is fatal and that the miler's aim must be to spread his speed and effort as evenly as possible over the whole distance.\(^{29}\)

Other track authorities consider the slow to fast pattern the ideal way to cover the one mile distance. Cromwell encouraged milers to strive for a faster second half than the first half.\(^{30}\) Doherty supported him and


\(^{29}\)Stampfl, *op. cit.*, p. 103.

indicated this is the pattern used in most present four-minute-miles.\textsuperscript{31} One example of the effectiveness of the slow to fast pattern was demonstrated by Snell in establishing the world record for the mile with a time of 3.54.4 seconds on January 27, 1962.\textsuperscript{32} His time for the last half of the race was three and six-tenths faster than the first half. The quarter-mile times for his record run were 60, 59, 59, and 56.4 seconds.

It is evident from the preceding discussion that a variety of running patterns for middle-distance and distance racing is advocated by track authorities. The reason for such diversity is primarily due to an evolution of their ideas based on the type of athlete available and personal observations of running times. Scientific evidence substantiating their method is limited.

In analyzing running patterns in terms of mechanical principles of movement and certain physiological factors, however, there is agreement at the theoretical level as to the most desirable running pattern. An analysis of running patterns based on mechanical principles of movement provides a theoretical justification for a uniform or constant running pattern. According to Newton's first law of motion, which states that a body continues in its state of uniform motion

\textsuperscript{31}Doherty, \textit{op. cit.}, p. 110.

\textsuperscript{32}\textit{The Times} (New York), January 28, 1962, p. 4S.
in a straight line except as it is compelled by forces to change, it is apparent that changing speed while running requires more energy than maintaining a uniform one.

Bunn, in discussing the proper application of mechanical principles to running, stated that a runner should quickly attain the fastest pace he can maintain for a particular race and hold that pace throughout the race. By this means the runner can increase the efficiency of running considerably and obtain the best results for the energy expended.

When considering the physiological factors of aerobic and anaerobic work in relation to running, evidence tends to support the constant or even pace as the most efficient in terms of energy cost. Exercise physiologists agree that the efficiency of physical movement is higher when muscular activity primarily depends on aerobic work rather than on anaerobic work and a large oxygen debt.

---


Studies dealing with efficiency in terms of energy cost during aerobic and anaerobic work have produced consistent results. Henry and DeMoor, in conducting a study of nine experienced cyclist riding two different work loads, found that the efficiency of the anaerobic mechanism to be lower than the aerobic mechanism. Asmussen reported findings that placed the efficiency of anaerobic work with subsequent aerobic recovery very low—only 40 to 70 percent of the efficiency of aerobic work.

In discussing the rate of buildup of oxygen debt as related to the severity of exercise, Mathews stated that the oxygen requirements for running increase as the square or cube of the speed. Thus; if the speed is doubled, the oxygen requirement is multiplied from four to eight.

Commenting on the practical conclusion an athlete may draw from these data, Karpovich stated that a runner should avoid unnecessary spurts of speed because whenever speed is increased there is a corresponding increase in the rate at which oxygen debt is incurred. He concluded that a

---


39 Mathews, Stacy, and Hoover, *loc. cit.*
runner should find the needed rate of speed to equal the
time desired for a given distance and maintain this speed
as faithfully as possible.\textsuperscript{40}

\textbf{Statement of the Problem}

The purpose of this study was to compare the oxygen
consumption of strenuous work for three patterns of inten-
sity. More specifically, the study was an attempt to deter-
mine the most efficient pattern of intensity in terms of
oxygen cost.

It is hypothesized in this study that the constant
pattern of intensity will be significantly more efficient
in terms of net oxygen cost than either the heavy-constant-
light or the light-constant-heavy patterns. For this study
the three patterns of intensity were as follows:

1. Constant pattern--subject rides the bicycle
   ergometer at sixty revolutions per minute with
   250 watts* resistance for a total of six minutes.

2. Heavy-constant-light pattern--subject rides the
   bicycle ergometer at sixty revolutions per
   minute with 300 watts for two minutes; 250 watts
   for two minutes; and 200 watts for two minutes.

3. Light-constant-heavy pattern--subject rides the
   bicycle ergometer at sixty revolutions per min-
   ute with 200 watts for two minutes; 250 watts
   for two minutes; and 200 watts for two minutes.

\textsuperscript{40}Karpovich, \textit{op. cit.}, p. 88.

*See Table 2, page 30, for watt conversion factors.
Limitations of the Study

This study was limited in the following respects:

1. Subjects consisted of six conditioned soccer players.

2. Each subject was limited to one practice run using the light-constant-heavy pattern utilized in the study.

3. Each subject was limited to one bout with each of the three patterns of intensity.

4. Each pattern of intensity was performed at sixty revolutions per minute for six minutes.

5. Each subject was limited to a thirty minute recovery period.

Significance of the Study

The practice of athletics is both a science and an art. Although new levels of excellence are being reached in all sports each year, there is an obvious need for physiological evidence based on scientific research that will assist individuals to achieve even better performances in the future.

Among those athletic activities in need of scientific evidence is the sport of track. Teachers and coaches of track, as discussed earlier, have been prolific in writing about the proper pattern of pacing middle-distance or distance events, but little has been done to substantiate their opinions with scientific evidence.

The intent of this study is to provide scientific evidence relative to the physiological aspects of running
patterns. The knowledge secured from this study should be of value to the teacher and coach, as well as to the athlete, in their search for means to improve running records. It is also conceivable that any information relative to a physiologically superior pattern of running would be valuable to physical education and athletic programs in general.

Finally, the problem of oxygen cost of strenuous work has particular significance to the field of exercise physiology. Physiologists recognize that muscular activity under anaerobic conditions is considerably less efficient in terms of oxygen cost than under aerobic conditions. If the results of this study indicate one of the three patterns of intensity to be significantly more efficient in oxygen cost, one may conclude that this pattern is physiologically more effective in controlling the amount of work from the aerobic and anaerobic mechanisms. This means that the contributions of the anaerobic mechanism toward the total energy required for the work is less for the physiologically superior pattern of intensity than for the other experimental patterns.
CHAPTER II

REVIEW OF RELATED LITERATURE

The early attempts to establish scientifically a physiological basis for running patterns were mathematical studies of athletic records. Kennelly, in 1906, made a mathematical study of running records and reached the conclusion that the quickest way to cover any distance is to take at the start of a run that speed which will just produce exhaustion at the end, and keep to that speed throughout the run. He advised that an athlete in training ought to be motor-paced and that the speed of the pacing motor throughout a given event be uniform or constant.¹

Other investigators have studied the mathematical relationship of running distances and times in order to suggest a theoretical means of improving athletic performances. A. V. Hill plotted the average speed of running records from 75 yards to 100 miles on a logarithmic graph

and concluded that the most efficient way in terms of energy output to run a race is to maintain a uniform speed throughout.\(^2\)

Henry, utilizing Sargent's data as a basis for applying mathematical calculations, compared the advantage of an evenly paced pattern of running to the speed-float-gather-spurt pattern in the 440 and 880-yard runs. From these calculations, Henry claimed that insofar as the "physiological limit" is involved in setting records, a steady pace would result in a faster time for the 220 and 440-yard runs, the mile, and two mile runs.\(^3\) The conclusions of this investigator supported the steady or constant running pattern as the most desirable.

Nearly two decades after Kennelly's mathematical study of running records, Hill and Lupton performed physiological experiments that compared the oxygen requirement of running different speeds with oxygen intake. They reported that in running, the oxygen requirement increases continuously as the speed increases, attaining enormous values at the highest speeds. They also noted that the actual oxygen intake will reach a maximum beyond which no


\(^3\)Franklin M. Henry, "Research on Sprint Running," *Athletic Journal*, XXXII (February, 1952), pp. 30-34.
effort can drive it. 4 In a later publication dealing with the dynamics of muscular activity, Hill concluded from the results of his earlier experiments that once the oxygen requirement is greater than the oxygen intake, a steady state is no longer possible and fatigue ensues more or less rapidly.5

Additional experiments conducted by Hill, while on a non-resident lectureship in chemistry at Cornell University, involved ten athletes who ran 200-yards at top speed, being timed every 20-yards along the track. On the basis of the experiments, Hill stated that the best method of running a 200-yard race is not to go at top speed all the way, but to maintain a constant speed. He indicated that running at top speed for any race beyond 100-yards is inadvisable, since it can be shown mathematically that if the energy expended varies as the 2.8th power of the speed, then it is much more economical to run as far as possible at a constant speed.6 This speed should be slightly less that the greatest speed of an unfatigued subject.


5Archibald V. Hill, Muscular Activity (Baltimore: The Williams and Wilkins Co., 1926), pp. 97-98.

Approximately at the same time, Sargent studied athletes in a series of 120-yard runs at different speeds and found that a runner's oxygen requirement for 120-yards increased as the 2.8th power of the speed, while the oxygen requirement per minute increased approximately as the 3.8th power of the speed. From this physiological relationship he also concluded that the most economical way to run a race would be to maintain an even pace throughout.7

In other attempts to provide physiological data on the most economical pattern of running, Christensen and Hogberg studied the efficiency of running 20 km./hour at different lengths of time on a treadmill. The experiments supported strongly the point of view that short spells of very severe work where the muscles have to work under almost anaerobical conditions have an efficiency of 50 per cent or less of that of aerobic work. In applying their findings to athletic performances, they advised that a middle-distance runner ought to keep his average speed as high as possible and avoid rushing since such action may require energy from a more expensive source, mainly anaerobic energy.8


Another study conducted by Christensen and Hogberg analyzed oxygen deficit and oxygen debt for a subject running on a treadmill for ten minutes at different speeds between 8 to 20 km./hour. The investigators found a straight line relationship between oxygen uptake and oxygen debt, while determinations of oxygen deficit and oxygen debt showed that the total energy output did not follow a straight line. At high speeds the energy output showed a steep increase. Judging from these results, it is apparent that at high speeds a significant part of the energy has to be delivered by anaerobic processes involving low efficiency.

These results agreed with the later findings of Knuttgen who studied oxygen uptake and pulse rate on two subjects running with undetermined and determined stride lengths at different speeds. The results indicated a nearly linear relationship between oxygen uptake and velocity while running with predetermined stride lengths.

Henry, in 1952, obtained data from a study comparing twenty-four varsity dash men and thirty inexperienced physical education major students in running a steady and

---


all-out 300-yard run.\textsuperscript{11} Overall, there was a 16 per cent
differential in running times between the two groups, but
relatively speaking there was no difference in oxygen re-
quirements.

In relating oxygen requirement of running to velocity,
using linear co-ordinates, Henry obtained a curve which had
a region of maximum curvature or "knee" between seven yards
per second and nine yards per second. The observation made
by Henry was that at velocities well below or well above the
seven to nine yards per second "knee," a specified change in
velocity does not greatly influence the efficiency of run-
ning. For velocities within the "knee," the oxygen cost of
running slower than some reference speed does not signifi-
cantly lower the cost, but the same amount of velocity
change in the direction of increased speed results in a
disproportionately large increase in oxygen cost. From
these results Henry concluded that a variable pace is less
efficient than a steady pace.\textsuperscript{12}

In studying a group of thirty-nine male high school
freshmen running a 220-yard dash in a steady-pace and vari-
able-pace pattern, Kronsbein found that the 220-yard speed

\textsuperscript{11}Franklin M. Henry, "Time-Velocity Equations and
Oxygen Requirements of 'All-Out' and 'Steady-Pace' Running,"

\textsuperscript{12}\textit{Ibid.}, p. 172.
in the steady-pace pattern was significantly faster, to the extent of .48 seconds, than the variable-pace pattern. The difference in time between the steady and variable pace amounts to two per cent. The important finding of Kronsbein's study is that the physiologically better pattern of the two conditions studied experimentally was the one that resulted in the best 220-yard times. From the observed time difference, Kronsbein claimed that the time advantage would be greater in longer runs such as the quarter and half-mile distances.¹³

In an experiment dealing with oxygen cost of running, Bowers studied seven subjects who ran three different paces on a treadmill for a period of four minutes and forty seconds. Analyzing the oxygen consumption for each type of pace, Bowers found that no statistical difference existed among the three conditions.¹⁴ The failure to obtain any difference was attributed to the low demands which the three paces required of the conditioned subjects in the experiment.

A study by Mathews and his associates compared the efficiency of aerobic and anaerobic work performed on a bicycle ergometer by seven experienced varsity track men


for three different pace conditions. The total work load for each condition amounted to 1200 watts. The results indicated a significant difference beyond the .01 level of confidence for net oxygen consumption in cc/Kg. body weight between the steady and light-heavy paces and the steady and heavy-light paces. The raw score difference between the means of the steady and light-heavy paces was 19.86 cc/Kg, while between the steady and heavy-light paces this difference amounted to 13.95 cc/Kg. In relating these data to running, the investigators maintained that a runner should hold the same pace throughout an entire race.\textsuperscript{15}

In 1956, Robinson and his associates studied the influence of fatigue on the efficiency of men running to exhaustion on a treadmill. The subjects were four college men, 19 to 24 years of age, who were middle-distance runners in moderately good running condition. Three different experiments were conducted to determine the effects of varying the running pace on oxygen requirement of the subjects in exhausting runs. The paces used in the experiment included a run at a constant speed, one with the first part

fast and the finish at a slower speed than the average, and another with the first part slow and the last part fast. 16

The oxygen requirement of subject A. H. running the slow-fast pace was 19.6 liters; running the fast-slow pace, 21.2 liters; and running the steady pace the subject required 19.8 liters. For subject M. F. the oxygen requirements were 24.2 liters for the slow-fast pace, 24.7 liters for the constant pace and 25.9 liters for the fast-slow pace. 17 Results for the other two subjects were not reported.

Robinson, in light of these data, concluded that in order to run a given middle-distance race in minimum time a runner should follow a pace which will delay until near the end of the race the sudden change in the physiological state in which the energy cost of running and the development of fatigue are so greatly accelerated. 18 The recommended pace advocates a runner to pace the first part of his race slower than the average speed and to make a fast finish.

Summation of Related Literature

Various mathematical studies of world and Olympic records have been conducted in an attempt to secure

17 Ibid., p. 199
18 Ibid., p. 200.
physiological data that could assist in a general improvement of running records. On the basis of an analytical approach, Kennelly, Hill and Henry agreed that the most efficient and quickest way to cover any distance is to run with a uniform or constant speed.

The results of physiological studies surveyed tended to favor a steady pace pattern over any other running pattern. Hill, Sargent, Christensen and Hogberg, Henry, Kronsbein, and Mathews concluded from their studies that the process of acceleration and deceleration during a race is costly in terms of oxygen cost and therefore a maximum average speed or steady pattern of running would be the most desirable in terms of the physiological factors of running.

Contrary to the findings of a majority of the studies favoring the steady pattern of running were the results obtained by Robinson and his associates. The findings in this study led these investigators to believe that a pattern of running involving gradual acceleration or a slow-fast pace was the most desirable. It was argued that in the slow-fast pace the anaerobic work will be delayed until near the end of the race.

Although most data relative to energy cost of different running patterns support the constant or steady pace as being the most efficient in terms of oxygen consumption, there is other available evidence that do not substantiate
these data. It is evident from the inconsistent findings of the related literature that additional investigations in the area of energy cost for different patterns of running are needed.
CHAPTER III

METHODS AND PROCEDURES

Subjects

The six subjects selected for this study were members of The Ohio State University varsity soccer team and had been in training for a minimum of three months. They ranged in ages from 19 to 22; in weight from 161 to 186.5 pounds; and in height from 65.25 to 73 inches. The age, height, and weight statistics for each subject are presented in Table 1.

<table>
<thead>
<tr>
<th>Subject</th>
<th>Age</th>
<th>Height</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>E.P.</td>
<td>19</td>
<td>68.25</td>
<td>162.25</td>
</tr>
<tr>
<td>R.K.</td>
<td>19</td>
<td>73.00</td>
<td>166.00</td>
</tr>
<tr>
<td>D.T.</td>
<td>19</td>
<td>71.00</td>
<td>180.00</td>
</tr>
<tr>
<td>W.D.</td>
<td>22</td>
<td>67.50</td>
<td>152.00</td>
</tr>
<tr>
<td>N.S.</td>
<td>21</td>
<td>68.58</td>
<td>186.50</td>
</tr>
<tr>
<td>S.C.</td>
<td>20</td>
<td>65.25</td>
<td>161.00</td>
</tr>
</tbody>
</table>

Apparatus

The three patterns of intensity were performed on the bicycle ergometer specifically known as a Jacquet
Universal Ergostat. The Jacquet model permitted a range of work load from a low of five watts at thirty revolutions per minute to a high of 450 watts at ninety revolutions per minute.

The speed maintained by the subjects for each pattern of intensity performed on the bicycle ergometer was sixty revolutions per minute. The rate of revolutions was controlled by the subject observing an electrical synchronized speedometer unit stationed in front of the bicycle ergometer and attached to the sprocket wheel.

A Collins Chain-Compensated spirometer with a 120 liter capacity and an attached electric kymograph drum was used to collect five minute samples of exhaled air during rest and post-recovery. Six 200-liter Douglas bags were used to collect the total volume of exhaled air at two minute intervals during exercise and as needed during the recovery.

Gas analyses of samples of exhaled air were made with the Beckman Oxygen Analyzer, Model E-2. The samples of exhaled air used in each gas analysis were collected from the Douglas bags in a football-type bladder.

A breast plate supporting a two-way mouthpiece was strapped to the subject's chest. The experiment was conducted on an open circuit arrangement with the exhaled air being collected in Douglas bags.
A telemetering system was used for each experimental condition for the purpose of obtaining the subject's heart rate. The telemetering system used in this study consisted of the following: (a) a wireless transistorized transmitter, (b) an A.M. and F.M. receiver, and (c) a Sanborn Viso Cardiette.

**Orientation**

The subjects used in the experiment were given a trial run of the light-constant-heavy pattern of intensity for the purpose of familiarizing each of them with the procedures of the experiment and equipment involved, and to determine their ability to complete successfully the established work load for the trial run. Twelve subjects were given an opportunity to perform the practice run. Only six were able to complete successfully the trial run. These six subjects were invited to continue in the experiment and each consented to do so.

**Procedures**

The subject reported to the research laboratory in the experimental uniform which consisted of low-cut sneakers, shorts, and T-shirt. Electrodes for telemetering purposes were attached to the subject while in a sitting position. Following the attachment of the telemetering equipment, the subject was placed in a supine position on a training table for ten minutes in order to obtain a constant heart rate.
In order to keep unnecessary movement by the subject at a minimum, the training table was positioned adjacent to the bicycle.

Upon completion of the ten-minute rest period, the subject was assisted to a chair directly behind the bicycle ergometer and seated; then the breast plate was strapped to the subject, the mouth piece inserted, and a nose clip fastened in place. The subject then began to wash out the 120-liter spirometer in preparation for the five minute resting collection period.

The spirometer's dead space was washed out four times before commencing with the resting collection period to insure against any contamination. At the conclusion of the washing period, the resting volume of exhaled air was collected in the spirometer and recorded on a spirogram for five minutes. Immediately after the conclusion of the resting collection period, a gas sample was taken and analyzed. The time consumed for the rest period in a sitting position totaled fifteen minutes.

After the termination of the resting collection period, the subject was permitted to remove the mouthpiece and nose clip for the purpose of clearing his throat and nose. Following these adjustments, the subject assumed a riding position on the bicycle. The calibration of the bicycle ergometer to the proper work load and the adjustment of the seat to the subject's height were completed at this time.
The subject remained in the riding position for two minutes while the air hoses were cleared with the subject's exhaled air. Upon the completion of the clearing procedure, the subject then began the exercise period which amounted to a total of six minutes.

At termination of the exercise period, the subject dismounted immediately from the bicycle and was seated while continuing to exhale into a Douglas bag. The recovery period lasted a total of thirty minutes. A post-recovery five minute sample of air was collected in the same manner as that employed in the five-minute resting collection period. The collection of resting and post-recovery air samples was made for the purpose of comparing ventilation rates and VO$_2$.

The research design for the experiment was in the form of the Latin square. This arrangement permitted randomization of the sequence of experiments and the weighting of any effect which might have been caused by environmental conditions and by the order in which the patterns of intensity were performed. The three experimental runs for each subject were performed at approximately the same time of the day.

The exercise periods lasted a total of six minutes on a bicycle ergometer at the rate of sixty revolutions per minute. The three patterns of intensity consisted of the following: (1) constant pattern—250 watts for six minutes; (2) heavy-constant-light pattern—300 watts for two minutes,
250 watts for two minutes, and 200 watts for two minutes; and, (3) light-constant-heavy pattern—200 watts for two minutes, 250 watts for two minutes, and 300 watts for two minutes. The value of the watt as a unit of measure of power is listed in Table 2.

TABLE 2

WORK OUTPUT PER MINUTE

<table>
<thead>
<tr>
<th>Watts</th>
<th>Horsepower</th>
<th>KgM/Sec.</th>
</tr>
</thead>
<tbody>
<tr>
<td>200</td>
<td>.268</td>
<td>20.394</td>
</tr>
<tr>
<td>250</td>
<td>.385</td>
<td>25.982</td>
</tr>
<tr>
<td>300</td>
<td>.402</td>
<td>30.588</td>
</tr>
</tbody>
</table>

Heart Rates

Resting, exercise, and recovery heart rates were determined by means of a telemetry system. The pattern of recording heart rates was in the following manner:

1. Prior to and every five minutes of the supine resting position.
2. Every five minutes of the sitting position of the rest period.
3. At one minute intervals during exercise and the first five minutes of the recovery.
4. At five minute intervals during the last twenty-five minutes of the recovery.

The heart rates were recorded for the purpose of determining the strenuousity of the work load and as a means of determining the extent of the recovery.
Samples of exhaled air collected for five minute interval during rest and post-recovery were taken from the 120-liter spirometer in a football-type bladder and analyzed on the Beckman Oxygen Analyzer, Model E-2, for the purpose of comparing resting and post-recovery ventilation rates and $\dot{V}O_2$.

In addition, samples of air from three Douglas bags, each containing the exhaled air for a two minute interval of the exercise period, and from the Douglas bags containing the recovery air, were removed and analyzed. The air collected was removed from the Douglas bags by means of suction into a 300-liter spirometer. A change in the level of the meter stick attached to the spirometer provided the means to measure the volume of gas in each Douglas bag.

A table with the net oxygen consumption for each of the three conditions in ML. is presented in Appendix A. The work sheet for net $O_2$ consumption in ML/Kg. body weight is contained in Appendix B.
CHAPTER IV

ANALYSIS OF DATA

Description of Data

The primary purpose of this study was to determine and compare the net oxygen cost of strenuous work for three patterns of intensity. Six conditioned soccer players, following an orientation period, individually performed one experiment for each pattern of intensity. The net oxygen cost was computed in milliliters per kilogram of body weight. The results are contained in Table 3. The results of net oxygen cost in milliliters for each subject appear in Appendix A.

TABLE 3

NET OXYGEN COST FOR EACH OF THE THREE PATTERNS OF INTENSITY IN ML./Kg. BODY WEIGHT

<table>
<thead>
<tr>
<th>Subject</th>
<th>Constant</th>
<th>Heavy-Constant-Light</th>
<th>Light-Constant-Heavy</th>
</tr>
</thead>
<tbody>
<tr>
<td>E.P.</td>
<td>274.05</td>
<td>259.65</td>
<td>257.59</td>
</tr>
<tr>
<td>R.K.</td>
<td>262.09</td>
<td>275.23</td>
<td>262.72</td>
</tr>
<tr>
<td>D.T.</td>
<td>255.13</td>
<td>256.62</td>
<td>261.22</td>
</tr>
<tr>
<td>W.D.</td>
<td>273.56</td>
<td>287.71</td>
<td>279.03</td>
</tr>
<tr>
<td>N.S.</td>
<td>237.63</td>
<td>259.00</td>
<td>243.12</td>
</tr>
<tr>
<td>S.C.</td>
<td>288.96</td>
<td>292.71</td>
<td>295.12</td>
</tr>
<tr>
<td>Total</td>
<td>1591.42</td>
<td>1630.92</td>
<td>1598.80</td>
</tr>
<tr>
<td>Mean</td>
<td>265.23</td>
<td>271.82</td>
<td>266.46</td>
</tr>
</tbody>
</table>
To determine whether a significant difference among the three patterns of intensity existed, the analysis of variance for several matched groups, as described by Edwards, was applied to the findings.

**Analysis of variance.** The results of the analysis of variance for net oxygen consumption appear in Table 4. For the rows an $F$ of 15.494 was obtained which is significant beyond the .01 level of confidence. This indicates that statistically the subjects, in relation to one another, varied in their performances of each pattern.

<table>
<thead>
<tr>
<th>TABLE 4</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ANALYSIS OF VARIANCE</strong></td>
</tr>
<tr>
<td>Source of Variation</td>
</tr>
<tr>
<td>------</td>
</tr>
<tr>
<td>Rows</td>
</tr>
<tr>
<td>Columns</td>
</tr>
<tr>
<td>Error</td>
</tr>
<tr>
<td>Total</td>
</tr>
</tbody>
</table>

*Significant at .01 level.

The primary concern of this study was to ascertain the variance of the net oxygen consumption among the three patterns of intensity. According to the Analysis of Variance Table, an $F$ of 1.438 was obtained. In order to be

significant at the .05 level of confidence, an $F$ of 4.10 would have had to be obtained.

Discussion

Although no significant difference among the three patterns of intensity could be statistically determined, the results of this study tend to indicate that the most efficient pattern of intensity in terms of oxygen consumption was the constant pattern.

In reviewing the net oxygen cost of the six subjects for each pattern of intensity in ML./Kg. body weight, it can be observed that five of the six subjects favored the constant pattern as being the more efficient in terms of oxygen consumption than the light-constant-heavy or heavy-constant-light patterns. The same trend in support of the constant pattern can be noted when the mean net oxygen cost for the three patterns of intensity are compared.

Comments of the subjects after each had completed the three patterns of intensity revealed that all six felt the constant pattern was the least difficult of the three patterns. All indicated that the light-constant-heavy pattern seemed to be the most demanding. In spite of their reactions to this pattern, the subjects' performances did not confirm their opinions relative to the degree of strenuousness. One subject required less net oxygen consumption for the light-constant-heavy pattern than for the other two
patterns, while the results of three other subjects found the same pattern the second most demanding in energy cost.

**Mean heart rates.** In order to establish the degree of strenuosity of each pattern of intensity, heart rates were recorded by means of a telemetering system. The mean heart rates for the start and end of the rest period, each minute of exercise and the first five minutes of recovery, and every five minute interval during the remainder of the recovery appear in Figure 1.

The results of mean heart rates show that the light-constant-heavy pattern produced the highest mean heart rate of 193 during the sixth minute of exercise. The constant and light-constant-heavy patterns showed a continual increase in mean heart rates throughout the exercise period while the heavy-constant-light pattern displayed an increase through the first four minutes and then a slight decrease in the remaining two minutes. The change in the heart rate pattern of the heavy-constant-light condition can be attributed to the fact that the subjects started their recovery during the last two minutes of the exercise period when the work load was reduced to 200 watts.

The heart rates for all three patterns of intensity averaged twenty beats higher at the end of the recovery period than the resting heart rate. The heavy-constant-light pattern showed the lowest decline to 93 beats per minute, while the remaining patterns returned to a rate of 97.
Fig. 1: MEAN HEART RATES PLOTTED FOR 5 MINUTES OF REST, 6 MINUTES EXERCISE, AND 30 MINUTES OF RECOVERY
Mean net oxygen consumption for two-minute intervals during exercise. In order to observe the relationship between oxygen consumption and the change in intensity during each work pattern, the exhaled air of each subject was collected in two-minute intervals during the exercise period. The results of mean net oxygen consumption for two-minute intervals during exercise and the 30-minute recovery appear in Figure 2.

Upon inspection of the bar graph of the three patterns, one can observe a relationship between mean net oxygen consumption and the intensity of work during each work pattern. During the exercise period of the constant and light-constant-heavy patterns, an increase in mean net oxygen consumption occurred in each two-minute interval.

The heavy-constant-light pattern showed an increase in mean net oxygen consumption during the first and second two-minute intervals of exercise, but a noticeable decrease was obtained for the last two-minute interval.

In view of the reasonably high mean net VO₂ recorded for the three two-minute intervals during exercise and the mean heart rates obtained during the work pattern, it is apparent that the three patterns of intensity can be considered strenuous for the subjects used in this study.

\( \dot{V}O_2 \) and \( \dot{V} \) as recovery indicators. The resting and post-recovery \( \dot{V}O_2 \) and \( \dot{V} \) in milliliters per kilogram body weight were recorded for the purpose of indicating the
Figure 2

Mean net VO₂ in ml for two minute intervals during exercise and 30 minute recovery
degree of recovery following exercise. The data on the recovery indicators appear in Tables 5 and 6 and are graphically illustrated in Figure 3.

**TABLE 5**

*\( \text{VO}_2 \text{ in mL/kg body weight for rest and post recovery} \)

<table>
<thead>
<tr>
<th>Subject</th>
<th>Constant Rest</th>
<th>P. Rec.</th>
<th>Heavy-Constant-Light Rest</th>
<th>P. Rec.</th>
<th>Light-Constant-Heavy Rest</th>
<th>P. Rec.</th>
</tr>
</thead>
<tbody>
<tr>
<td>E.P.</td>
<td>4.09</td>
<td>3.47</td>
<td>4.17</td>
<td>4.39</td>
<td>4.70</td>
<td>3.76</td>
</tr>
<tr>
<td>R.K.</td>
<td>4.38</td>
<td>4.05</td>
<td>3.89</td>
<td>4.15</td>
<td>4.82</td>
<td>4.33</td>
</tr>
<tr>
<td>D.T.</td>
<td>4.66</td>
<td>4.80</td>
<td>4.25</td>
<td>4.17</td>
<td>4.15</td>
<td>4.05</td>
</tr>
<tr>
<td>N.S.</td>
<td>3.87</td>
<td>3.93</td>
<td>3.59</td>
<td>4.21</td>
<td>3.68</td>
<td>3.92</td>
</tr>
<tr>
<td>S.C.</td>
<td>3.91</td>
<td>3.87</td>
<td>4.05</td>
<td>3.87</td>
<td>4.02</td>
<td>4.19</td>
</tr>
<tr>
<td>Total</td>
<td>24.39</td>
<td>23.71</td>
<td>24.13</td>
<td>25.04</td>
<td>25.61</td>
<td>24.57</td>
</tr>
<tr>
<td>Mean</td>
<td>4.07</td>
<td>3.95</td>
<td>4.02</td>
<td>4.17</td>
<td>4.27</td>
<td>4.10</td>
</tr>
</tbody>
</table>

The results showed that for the constant and the light-constant-heavy pattern, the post-recovery mean \( \text{VO}_2 \) in milliliters per kilogram body weight fell below the resting level, while the heavy-constant-light pattern remained above resting level. The difference found under the heavy-constant-light pattern can be attributed to the subjects acquiring a larger oxygen debt. It should be noted that although differences were obtained between the resting and post-recovery
COMPARISON OF PRE-EXERCISE AND POST RECOVERY VO2 IN ML/KG BODY WEIGHT

Figure 3
mean \( \dot{V}O_2 \), no significant difference was found when these
data were statistically analyzed.

**TABLE 6**

<table>
<thead>
<tr>
<th>Subject</th>
<th>Constant</th>
<th>Rest</th>
<th>P. Rec.</th>
<th>Constant-Light</th>
<th>Rest</th>
<th>P. Rec.</th>
<th>Light-Constant-Heavy</th>
<th>Rest</th>
<th>P. Rec.</th>
</tr>
</thead>
<tbody>
<tr>
<td>E.P.</td>
<td>82.10</td>
<td>77.49</td>
<td></td>
<td>94.50</td>
<td>84.99</td>
<td></td>
<td>95.55</td>
<td>90.18</td>
<td></td>
</tr>
<tr>
<td>R.K.</td>
<td>106.00</td>
<td>81.04</td>
<td></td>
<td>114.87</td>
<td>115.17</td>
<td></td>
<td>117.22</td>
<td>105.88</td>
<td></td>
</tr>
<tr>
<td>D.T.</td>
<td>105.88</td>
<td>102.18</td>
<td></td>
<td>99.19</td>
<td>91.70</td>
<td></td>
<td>98.03</td>
<td>108.83</td>
<td></td>
</tr>
<tr>
<td>W.D.</td>
<td>107.30</td>
<td>99.69</td>
<td></td>
<td>86.71</td>
<td>95.96</td>
<td></td>
<td>103.06</td>
<td>114.26</td>
<td></td>
</tr>
<tr>
<td>N.S.</td>
<td>76.94</td>
<td>75.31</td>
<td></td>
<td>73.88</td>
<td>73.88</td>
<td></td>
<td>77.74</td>
<td>73.85</td>
<td></td>
</tr>
<tr>
<td>S.C.</td>
<td>102.63</td>
<td>92.58</td>
<td></td>
<td>96.04</td>
<td>93.90</td>
<td></td>
<td>96.92</td>
<td>96.48</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>580.85</td>
<td>528.29</td>
<td></td>
<td>565.19</td>
<td>555.60</td>
<td></td>
<td>588.52</td>
<td>589.48</td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>96.81</td>
<td>88.05</td>
<td></td>
<td>94.20</td>
<td>92.60</td>
<td></td>
<td>98.09</td>
<td>98.25</td>
<td></td>
</tr>
</tbody>
</table>

As can be observed from Figure 3, differences be-
tween mean \( \dot{V} \) in milliliters per kilogram body weight from
resting to post-recovery were obtained. When comparing the
resting and post-recovery mean ventilation rates under each
pattern of intensity, no significant difference was found.
CHAPTER V

SUMMARY AND CONCLUSIONS

Summary

The oxygen consumption during strenuous work for three patterns of intensity was determined with six subjects. Each pattern of intensity consisted of a six-minute ride on the bicycle ergometer at sixty revolutions a minute. The first pattern of intensity involved a constant work load of 250 watts a minute. The second condition consisted of a heavy-constant-light pattern in which the subject worked at 300 watts for the first two minutes, 250 watts for the next two minutes, and 200 watts for the last two minutes. The third pattern of intensity of light-constant-heavy was performed in reverse of the second condition. All subjects in this study were given a practice ride on the bicycle ergometer which duplicated the procedure in an actual experiment.

The open circuit method was utilized in which the subjects inhaled room air and exhaled into a 120-liter spirometer during rest and post-recovery, and six 200-liter Douglas bags during exercise and recovery. The total volumes of exhaled air were recorded on an electric kymograph drum when using the spirometer and a meter stick when evacuating the Douglas bags into a 300-liter spirometer. For purposes
of gas analysis a Beckman Oxygen Analyzer, Model E-2, was used. Samples of exhaled air were collected in a football-type bladder for each gas analysis.

The design of the study required eight separate gas analyses for each experiment. The analyses included one during rest, three each during exercise and recovery, and one during the five-minute post-recovery. After a sample of gas from each Douglas bag used during the exercise and recovery periods was analyzed, the total volume of exhaled in each Douglas bag was measured.

The gross oxygen consumption was calculated by adding the total volume in each Douglas bag used to collect gas during exercise and recovery. The net oxygen cost for each pattern intensity was determined by subtracting the volume of oxygen required for rest from the gross oxygen consumption. All volumes were corrected to STPD. The average time required of each subject to complete each pattern of intensity was one hour and forty minutes.

A telemetry system was used to record heart rates during the rest, exercise, and recovery periods for each experiment. Heart rates were obtained for the purpose of indicating the degree of strenuousness of the three patterns of intensity on each subject and the extent of the subject's recovery following exercise.
An analysis of variance was administered to ascertain any significant difference in the oxygen consumption among the three patterns of intensity. The $F$ of 1.438 obtained in the analysis was not statistically significant.

**Conclusions**

The findings of this study permit the following conclusions:

1. The oxygen consumption for the constant, heavy-constant-light, and light-constant-heavy patterns of intensity does not differ significantly from each other.

2. A comparison of resting and post-recovery mean ventilation rate and $V_{O_2}$ did not reveal a significant difference for the three patterns of intensity.

**Recommendations**

To quantitatively assess the factors which limit the physiological performance of a runner is not an easy task. The results of this study indicate that there is no significant difference among the three patterns of intensity as investigated in this experiment. In view of the fact that a trend favoring the constant pattern of intensity was observed in the findings, it is recommended that further research be conducted in this area in order to statistically substantiate this trend.

It is further recommended that the time for each pattern of intensity be lowered to more closely resemble the present running time for distance events. In addition, the
possibility of performing the degrees of intensity for each pattern at time intervals similar to actual running conditions should be investigated.

Finally, it is recommended that additional treadmill experiments be conducted to determine the efficiency of running patterns. In such studies, the subjects could run to exhaustion within five minutes at different treadmill speeds between 10-15 miles per hour and thus more nearly simulate racing conditions.


APPENDIX A

NET OXYGEN CONSUMPTION FOR EACH OF THE THREE PATTERNS OF INTENSITY IN ML.

<table>
<thead>
<tr>
<th>Subject</th>
<th>Constant</th>
<th>Heavy-Constant-Light</th>
<th>Light-Constant-Heavy</th>
<th>Sum</th>
</tr>
</thead>
<tbody>
<tr>
<td>E.P.</td>
<td>20,167.67</td>
<td>19,107.95</td>
<td>18,956.11</td>
<td>58,231.73</td>
</tr>
<tr>
<td>R.K.</td>
<td>19,732.94</td>
<td>20,722.26</td>
<td>19,780.19</td>
<td>60,235.39</td>
</tr>
<tr>
<td>D.T.</td>
<td>20,828.90</td>
<td>20,951.13</td>
<td>21,326.41</td>
<td>63,006.44</td>
</tr>
<tr>
<td>W.D.</td>
<td>18,859.87</td>
<td>19,834.95</td>
<td>19,236.78</td>
<td>57,931.60</td>
</tr>
<tr>
<td>N.S.</td>
<td>20,101.38</td>
<td>21,908.82</td>
<td>20,565.78</td>
<td>62,575.98</td>
</tr>
<tr>
<td>S.C.</td>
<td>21,099.93</td>
<td>21,374.16</td>
<td>21,550.05</td>
<td>64,024.14</td>
</tr>
<tr>
<td>Total</td>
<td>120,790.69</td>
<td>123,899.27</td>
<td>121,415.32</td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>20,131.78</td>
<td>20,649.87</td>
<td>20,235.88</td>
<td></td>
</tr>
</tbody>
</table>
APPENDIX B

WORK SHEET

NET OXYGEN COST FOR EACH OF THE THREE PATTERNS OF INTENSITY IN ML./Kg. BODY WEIGHT

<table>
<thead>
<tr>
<th>Subject</th>
<th>Constant</th>
<th>Heavy-Constant-Light</th>
<th>Light-Constant-Heavy</th>
<th>Sum</th>
</tr>
</thead>
<tbody>
<tr>
<td>E.P.</td>
<td>274.05</td>
<td>259.65</td>
<td>257.59</td>
<td>791.29</td>
</tr>
<tr>
<td>R.K.</td>
<td>262.09</td>
<td>275.23</td>
<td>262.72</td>
<td>800.04</td>
</tr>
<tr>
<td>D.T.</td>
<td>255.13</td>
<td>256.62</td>
<td>261.22</td>
<td>772.97</td>
</tr>
<tr>
<td>W.D.</td>
<td>273.56</td>
<td>287.71</td>
<td>279.03</td>
<td>840.30</td>
</tr>
<tr>
<td>N.S.</td>
<td>237.63</td>
<td>259.00</td>
<td>243.12</td>
<td>739.75</td>
</tr>
<tr>
<td>S.C.</td>
<td>288.96</td>
<td>292.71</td>
<td>295.12</td>
<td>876.79</td>
</tr>
<tr>
<td>Total</td>
<td>1591.42</td>
<td>1630.92</td>
<td>1598.80</td>
<td>4821.14</td>
</tr>
<tr>
<td>Mean</td>
<td>265.23</td>
<td>271.82</td>
<td>266.46</td>
<td>803.52</td>
</tr>
</tbody>
</table>


APPENDIX C

SUM OF SQUARES COMPUTATIONS FOR NET OXYGEN CONSUMPTION ML./KG. BODY WEIGHT

Correction

\[ C = \frac{(\text{sum } x)^2}{N} = \frac{23,243,390.90}{18} = 1,291,299.49 \]

Total Sum of Squares

\[ (274.05)^2 + (262.09)^2 \cdots (243.12)^2 + (295.12)^2 \]
\[ = 1,295,918.73 \]
\[ = 1,295,918.73 - 1,291,299.49 = 4,619.24 \]

Row Sum of Squares

\[ (791.29)^2 + (800.04)^2 + (876.79)^2 \]
\[ = 3,885,781.34 \]
\[ = \frac{3,885,781.34}{3} = 1,295,260.44 - 1,291,299.49 = 3,960.95 \]

Column Sum of Squares

\[ (1591.42)^2 + (1630.92)^2 + (1593.80)^2 \]
\[ = 7,743,679.10 \]
\[ = \frac{7,743,679.10}{6} = 1,291,446.51 \]
\[ = 1,291,446.51 - 1,291,299.49 = 147.02 \]
Error Sum of Squares

\[ 3,960.95 + 147.02 = 4107.97 \]
\[ 4,619.24 - 4107.97 = 511.27 \]
BIBLIOGRAPHY

BOOKS


Murphy, Michael C. Athletic Training. New York: Charles Scribner's Sons, 1925.


PERIODICALS


UNPUBLISHED MATERIAL